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Advances in Materials Technology: MONITOR

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MATERIALS FOR CUTTING TOOLS

Dear Reader,

This is number 12 of UNIDO's state-of-the-art series in the field of materials entitled Advances in Materials Technology: Monitor, which is devoted to materials for cutting tools. Two professors from Warwick University in Coventry, United Kingdom, have written the main article for this issue.

In each issue of this series, a selected material or group of materials is featured and an expert assessment made on the technological trends in those fields. In addition, other relevant information of interest to developing countries is provided. In this manner, over a cycle of several issues, materials relevant to developing countries could be covered and a state-of-the-art assessment made.

We invite our readers also to share with us their experiences related to any aspect of production and utilization of materials. Due to paucity of space and other reasons, we reserve the right to abridge the presentation or not publish them at all. We also would be happy to publish your forthcoming meetings (please see section "Past events and future meetings").

We would also be grateful to receive your opinion on possible subjects for our forthcoming issues. In this way we expect to have a dialogue with our readership to establish the feedback which will allow us to effectively monitor the developments in the field and better serve our readers, especially in the developing countries.

For the interest of those of our readers who may be unaware UNIDO also publishes two other Monitors: Microelectronics Monitor and Genetic Engineering and Biotechnology Monitor. For those who would like to receive them please write to the Editor, Microelectronics Monitor and Editor, Genetic Engineering and Biotechnology Monitor.

Department of Industrial Promotion,
Consultations and Technology

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1. REVIEW OF THE MANUFACTURE AND PROPERTIES OF CERAMIC CUTTING TOOLS BY E. O. EZUGWU AND J. WALLBANK

Synopsis

The last 15 years have seen major advances in the development of ceramic tool materials achieving high cutting speeds with long tool lives. These developments require rigid machine tools with higher power motors and a change in the way the tool tips are used. The major areas of application of these new tool materials is in the aerospace industries and probably somewhat less in the cast iron field. There is now an ever-increasing number of grades (and trade names) available and this paper explains the background and development of the materials.

Briefly, the materials may be classified as alumina- or silicon nitride-based and these base compositions then give rise to families of materials with alloying additions. The manufacturing routes are discussed as these have influence on both grain size and porosity of the finished material both of which influence the behaviour of the materials in use. Finally, the wear of these tools is examined against the resulting understanding of the microstructures.

1. Introduction

In metal cutting a chip is formed by plastic deformation and fracture of the workpiece material. It has been shown by simple continuum mechanics [1] that deformation in the region of 200-400 per cent is required to form a continuous chip. With cutting speeds of 100 m/min deformation rates of about 10^4 sec^{-1} are often observed in this process leading to high temperatures and requiring high forces for this to occur. The stresses on the tool when machining even soft materials such as 70/30 brass may be as high as 1,800 MN/m^2, consequently tool materials need to withstand extremely high stress at temperatures up to 1,000°C for high-speed machining.

Ceramics were introduced in commercial quantities during the Second World War because of the scarcity of tungsten, the basic raw material for cemented carbide tools. The history of ceramics dates as far back as the upper paleolithic times when ceramic tools were used in the first simple machines. [2] There was no record of the development of ceramic tools after their early use until the early part of this century.

Ceramic tool materials exhibit very high hardness and wear resistance, high resistance to plastic deformation, chemical stability, etc. They presently constitute about 4-5 per cent of the total estimated indexable insert market for metal cutting [3] and are used in the automotive industry predominantly for high-speed machining of grey cast iron for producing brake drums, brake discs and flywheels. Ceramic tools are also used for high-speed machining of superalloys, hard chill cast iron and high-strength steels. In each step of the advances from carbon steel tools to HSS, to cemented carbides, to ceramics, each produced new machining capabilities and spurred machine tool manufacturers to develop new, faster and more powerful machines. This development however has necessitated much more rigidity in the machine tool structure to ensure cutting progresses smoothly with little or no accidental impact to these more brittle tools. Higher cutting speeds now available also demand higher power motors and consequently the adoption of new materials in this market has always relied on manufacturers re-equipping the factory.

1.2. Manufacturing route

That ceramic tooling has only recently been adopted by the metal-cutting industry can be attributed to the failure of the early ceramic tools by brittle fracture. Also these early tools failed to find wide acceptance because they had many failures as a result of improper application, unsuitable equipment or both. The low fracture strength was directly related to the presence of porosity in the pressed composite as a result of the conventional sintering techniques used. The tools produced with these early process routes also had large grain sizes, and hence were inherently weak in tension, impact and dynamic loading. These deficiencies restricted the application of the early ceramics to the continuous cutting of soft materials and cast irons at moderate speeds and feeds in sufficiently rigid machines. Development work [2-4] resulted in higher strength, more uniform and better quality tools through an understanding of the importance of microstructure in controlling the mechanical properties, coupled with improved processing techniques. There are three major categories of ceramic tool materials available today: pure oxide, mixed oxide and nitride ceramics. Alumina (Al_2O_3) is predominant in the pure oxide and mixed oxide ceramics, while silicon is predominant in the nitride ceramics. It is therefore useful to classify ceramic tools into alumina- and silicon nitride-based materials.

Alumina-based materials

These include Al_2O_3, $Al_2O_3 + ZrO_2$, $Al_2O_3 + TiC$, $Al_2O_3 + TiC + TiN + ZrO_2$, $Al_2O_3 + TiN$ and the recently developed Al_2O_3 reinforced with SiC whiskers [5]. Pure oxide (Al_2O_3) ceramic was first considered for machining operations in Federal Republic of Germany as early as 1905, 25 years before cemented carbides were introduced. This was a relatively high purity tool in which pure alumina was densified in the presence of grain growth inhibitors (such as MgO, TiO etc.). Mixed ceramics were introduced in the 1950s as one of a range of different materials based on consolidate alumina in order to meet the stringent mechanical property requirements of metal cutting. They may be classified into metal bonded and alloy tools. [6] In metal-bonded ceramics, alumina is bonded by one or more of the transition metals while in alloyed tools, various alloying components either result in secondary phases or remain in solid solution. The main alloying additions are Zirconia (ZrO_2), TiC and TiN.

Silicon nitride-based materials

These were developed in the late 1970s. There are two forms, the α and β': α-Si_3N_4 is harder than the β'-Si_3N_4 and both forms are hexagonal, but with slightly different lattice dimensions. The maximum theoretical density of Si_3N_4 cannot be achieved by conventional sintering techniques; instead two shaping methods, known as "reaction bonding" and "hot pressing", are used.
The β'-Si_3N_4 is formed during the nitriding of silicon at temperatures up to 1,300°C (reaction bonding). It has a smaller yttria (Y_2O_3) content and a higher aluminium content.

The β'-Si_3N_4 is a covalent solid, which contains a negligible amount of oxygen and is a well-formed particulate crystal in contrast to the whiskers sometimes observed in the α-Si_3N_4. [7]

Methods used for producing ceramic tools

The early ceramics were produced by sintering almost pure alumina which was then cut to size and shape and subsequently polished. Sintering aids are still used to achieve high-quality microstructures (i.e. to retain small grain size while achieving high densities). The sintering aids can be divided into three categories: those which promote grain growth, those which have no effect on grain growth, and those which retard grain growth (table 1). Some sintering aids produce double functions during sintering: [8] those which promote grain growth (such as Ti, Nb) also promote sintering, while those which retard grain growth also retard sintering. Grain growth inhibitors must therefore be selected with care to prevent recrystallization and yet ensure full density. The properties of a sintered tool also depend strongly on the time and temperature of sintering. A high pore density and fine grain powders (0.5-1 micron) are required to produce a good sintered ceramic tool. Tools made from very fine powders usually produce a coarser final grain size than those made from coarser starting materials. [2] The high temperatures in sintering progressively coarsen the grain structure, with deleterious effect on the mechanical properties of the tool material. [9] The grain boundaries tend to migrate towards their centre of curvature resulting in further increases of the large grains at the expense of the smaller ones which shrink. This process also traps most of the residual porosity within the grains, leaving only a small amount on the boundaries, and making further densification extremely slow.

These early problems resulted in the development of hot pressing, hot isostatic pressing, cold pressing, and reaction bonding as alternative methods of manufacturing ceramic tools. These processes achieved densification with reduced grain growth.

The hot pressing technique was developed by Deeley and others in 1961 to overcome the problems of solid state sintering to full density of solids with covalent bonding. [10] Ceramics have low self-diffusivity at temperatures below that at which thermal decomposition is dominant. In this process sintering aids such as magnesia (MgO) are used. The major difference betwsen sintering and hot pressing is the application of pressure during the consolidation process. Hot pressing ensures rapid densification and generally results in higher density and transverse rupture strength (475-700 $MN\ m^{-2}$) for alumina ceramics than are obtainable by conventional sintering (190-350 $MN\ m^{-2}$). Hot pressing produces specimens with fine grain sizes because the temperature and time required are lower than in conventional sintering. Structural changes during plastic deformation can result in residual stress in the hot-pressed ceramic tool. In hot pressing, powder compacts undergo a succession of processes: repacking, plastic flow, grain rearrangement, stress enhanced diffusion and a final stage of stress enhanced diffusion related to a creep model of deformation. An oversized die made from mould graphite is used to allow for shrinkage during sintering. The rate of pressing should be controlled - too fast a rate will not allow trapped air to escape, and the preform will disintegrate during stripping. An organic binder is added to the powder to provide internal lubrication between the powder particles during pressing, and to make the pressed compact easier to strip from the die. The furnace atmosphere during hot pressing is necessarily reducing because of the presence of graphite in the die, unlike conventional sintering.

Hot isostatic pressing (hipping) was originally developed for the fabrication of nuclear fuel components and materials not readily produced by conventional routes. The process makes use of inert gas pressure at elevated temperatures for the solid state diffusion bonding and joining of components of various metals and ceramics. The process involves an isostatic pressurizing medium where uniform pressure can be applied over the whole surface of the compact using hot pressurized gas channelled through an expendable impervious container. This leads to the deformation of individual particles and the promotion of interparticle bonding. Lower pressure is required to consolidate most structural materials by hipping than with conventional hot pressing. High pressure is used in hot pressing since the material is pressed in one direction and pressure is often lost due to friction with the container sidewalls unlike in hipping. The advantages of hipping have been summarized elsewhere, [12] the main drawback is that it can be a much more costly production process than sintering.

Reaction bonding was first used in the 1950s on a small scale for producing Si_3N_4. The process consists of two steps: diffusion of the nitrogen-containing gas through a previously pressed porous compact of silicon particles, and subsequent chemical reaction between the gas and the particles to form Si_3N_4 in situ. Components produced by the reaction bonding process have a lower modulus of rupture and impact strength than similar hot pressed components, largely because higher densities achievable by hot pressing. The reaction bonding process was however used owing to the difficulty of forming components by sintering Si_3N_4 compacts at atmospheric pressure, since densification will not occur below the material's decomposition temperature.

Production of alumina-based ceramics

High purity alumina ceramic tools are manufactured by two different methods: a conventional cold pressing operation similar to conventional powder metallurgy, or a hot pressing operation which is very effective for sintering alumina to high density.

The alumina powder used is produced by chemical or thermal decomposition of an aluminium salt to produce pure alumina, which is then milled to a fine powder. The milled slurry is dried, and mixed with a waxy, temporary binder (e.g. resin, glue) which also serves as a lubricant during the pressing operation and makes it easier to strip the pressed compact from the die. Very fine alumina powders with an average grain size of 0.5 μm and a purity of 99.9 per cent must be used in the initial mixture to ensure the production of fine grained components. Before hot pressing, the compacted powder is presintered at temperatures of 1,500°C to 1,700°C for one hour, followed by the cooling of the sintered body to room temperature. Prior to hot pressing, the compacted powder is presintered at temperatures of 1,300-1,520°C for about 30 minutes in a vacuum of 1.3 Pa. Hot pressing itself is carried out at a pressure of about 20 MPa and temperatures ranging from 1,500 to 1,700°C for one hour, after which the sintered body is cooled to room temperature. If hipping is used rather than hot pressing, the compact is placed in an argon atmosphere at a temperature of about 1,450°C and a pressure of 160 MPa for about one hour. Particles of sintered alumina produced by hot pressing tend to be arranged preferentially because the material is pressed in one direction, and this results in different mechanical and physical properties in planes parallel and perpendicular to the pressing direction. [2]

Mixed alumina ceramic (e.g. Al_2O_3 + TiC) tools are produced by mixing fine-grained (0.5μm-1μm) and pure alumina with 20-30 per cent of TiC powder and pressing at temperatures in the range 1500°C-1800°C and pressure of between 10 and 40 MPa. The carbon content in the TiC should be between 12.5 to 20.05 per cent, with a free carbon content of less than 1 per cent. The powder size of both the alumina and TiC must be small in order to minimize particle growth during sintering. [13]

The average grain size of the TiC should be less than 3μm, with a size distribution range of 0.2-0.5μm in order to avoid particle growth during sintering.

Production of silicon nitride-based ceramics

This type of ceramic can be produced only by hot pressing or reaction bonding. The Si_3N_4-based ceramics were initially produced by hot pressing about 4-12 per cent yttrium (Y_2O_3) and 96-88 per cent Si_3N_4 powders at a pressure between 7.6 and 17.8 MPa and at a temperature in the range 1,650-1,775°C, until a density of at least 3.25 x 10^3 kg mY^{-3} is obtained. [14] The hot-pressed compact will consist mostly of β'-Si_3N_4. Without the yttria addition it would have a low bend strength at high temperatures; the yttria also produces a more compact sinter and a uniform structure. This and other additives (such as Cr_2O_3 TiO, or MgO) accelerate or aid densification without significantly impairing the high-temperature creep resistance of the final ceramic material. Hot pressing of Si_3N_4 results in a reduction of porosity to less than 0.1 per cent, which leads to an increase in strength of the compact. (A detailed description of the hot pressing equipment is given elsewhere. [15] It has been recommended [15] that α-Si_3N_4 powder be used as a starting material in order to achieve complete densification of the end-product.

The starting material for reaction bonding is silicon which then forms a mixture of α- and β'-Si_3N_4. [7] The conversion of silicon to Si_3N_4 is accompanied by a volume increase of approximately 22 per cent, but this increase does not change the overall dimension of the compact as it is accommodated in the pore space of the original compact. The microstructure of the compact therefore undergoes a considerable change as nitriding proceeds with attendant decrease in permeability. The green density of a compact needs to be reduced as its size increases in order to maintain sufficient permeability to allow the reaction to proceed at the centre of the compact. If the density of the compact is not reduced, then a central core of unreacted silicon may occur. A recent development in the manufacture of Si_3N_4-based ceramic tools is to coat the inserts with at least one hard, adherent coating (about 1-10μm thick) of refractory metal nitride to improve their mechanical and chemical properties. These metal nitride coatings, applied by chemical or physical vapour deposition include the nitrides of Ti, V, Cr, Zr, Nb, Mo, Hf, Ta and W. Carbonitrides of these materials can also be used as coating materials. [16]

Some problems with hot pressed or reaction-bonded Si_3N_4 led many workers to carry out further examination of the structure of Si_3N_4. The stronger materials could only be obtained by hot pressing, which is very expensive, time-consuming and limits the end-product to fairly simple shapes. The reaction-bonded materials were easy to make but are porous and not strong enough for many applications. Sialon ceramics are the result of a discovery made independently by Oyama and Kamigaito [17] and Jack and Wilson [18] that oxygen (O^{2-}) may be substituted by nitrogen (N^3) in the β'-Si_3N_4 crystal provided that aluminium (Al^3) is simultaneously substituted for silicon (Si^4) to maintain charge neutrality. Sialon ceramics have the same crystal structure and similar physical properties to the β'-Si_3N_4 but better chemical properties because of this chemical substitution. [19] Si_3N_4, AlN, Al_2O_3 and Y_2O_3 powders are the starting materials for producing sialon tools. [20] They are milled together, dried, pressed to shape and sintered at a temperature of about 1,800°C before being allowed to cool gradually. Y_2O_3 reacts with Si_3N_4 to form a silicate which is liquid at the sintering temperature. The liquid solidifies after sintering to a glassy phase bonding together the fine grained (about 1μm) hexagonal β'-Si_3N_4 crystals.

Properties of ceramic cutting tools

A tool material for accurate and efficient machining must be strong and have high wear resistance. It should also, amongst other requirements, [21] be able to resist brittle and plastic failure. Shaw [22] considers that the best tool material may not necessarily be the one which gives the longest life or is the cheapest, but rather that which performs a given task to the required accuracy and efficiency at minimum cost. Ceramic cutting tool materials exhibit the following properties: high compressive strength, high resistance to plastic deformation, high hardness and wear resistance, and chemical stability. These properties enable them to be used for high-speed machining, in which high temperatures are generated. Ceramic tools exhibit a compressive strength which varies little with temperature, unlike cemented carbides which show a rapid drop in the compressive strength at elevated temperatures [23] (figure 1). Ceramic tools must have negative rake angles, or rounded or chamfered edges to compensate for their low tensile and shear strengths and to take advantage of their high compressive strength and wear resistance. Negative geometries are recommended because positively raked inserts cannot withstand the mechanical and thermal shock of entry and exit from the workpiece. A negative geometry places the ceramic tool tip under compressive loading and suppresses tensile crack formation. It has been reported recently that these negative geometries can lead to favourable residual compressive stress and long fatigue lives of components machined by ceramic materials. [24]

Ceramic tools have a higher hardness than cemented carbides and are much harder than tool steels at both room and elevated temperatures (table 2). Their hardness explains why they resist abrasive wear more than carbides and tool steels, and can machine materials like castings with a long tool life provided fracture can be suppressed.

Additives/alloying elements in ceramics and their effect on the properties of the tool materials

Alumina-based materials

The bonding in alumina is ionic rather than metallic, and consequently is an electrical insulator with poor thermal conductivity. The low toughness and tensile strength of alumina ceramic tools make them less able to withstand rapid fluctuation of temperature and stress during cutting. The addition of additives such as chromium, titanium, or nickel oxides or refractory metal oxides to pure alumina leads to a significant improvement in mechanical properties. [3]

Conventional alumina ceramics are usually highly susceptible to fracture when used for machining superalloys. This tendency is reduced by adding zirconia which helps to retard crack propagation by transforming from a metastable state to a stable state when a crack is initiated, thereby increasing the toughness of the cutting tool. During cooling the zirconia would normally undergo phase transformation. However, the alumina causes constraint on the zirconia particles which inhibits its transformation. This introduces compressive forces into the structure. [25] When a crack forms in a tool in use, the metastable tetragonal zirconia transforms to the stable monoclinic form, with an associated volume change causing compressive stress at the crack tip and preventing propagation. [26] These stresses effectively increase the fracture toughness of the material by about 20-25 per cent. The microstructure and crystal structure of pure oxide (Al_2O_3 + 1 per cent ZrO_2) ceramic tools are shown in figure 2a and 2b respectively. The zirconia phase can be seen as the dark triangular phase at the grain boundaries (figure 2B). The addition of zirconia also enables the tool to withstand high cutting temperatures helping to prevent plastic deformation or oxidation wear. The improved fracture toughness makes a pure alumina ceramic tool suitable for some interrupted cuts and other difficult machining applications it could not perform without the zirconia addition. Rapid temperature changes at the start or finish of a cut or brought about by use of coolants, can cause fracture by inhomogeneous thermal expansion at the cutting edge (thermal shock).

The thermal shock resistance of ceramic tools can be improved by introducing a metallic phase; TiN and TiC are added to provide adequate edge strength and high resistance to thermal shock. It is shown in figure 3 that the thermal conductivity of TiN is about twice that of TiC at temperatures of 1,000°-1,200°C, typical of ceramic chip/tool interfaces. The high thermal shock resistance of mixed ceramics enables them to be used for effective machining with or without coolants. The microstructure and crystal structure of a mixed oxide (Al_2O_3 + 30 wt per cent TiC) ceramic tool are shown in figures 4a and 4b, respectively. The addition of TiC also results in a significant increase in the hardness of mixed oxide ceramics. The addition of SiC whiskers in the recently developed Al_2O_3 + SiC ceramic results in higher strength and an improvement in the fracture toughness of the brittle alumina matrix. [5] The properties of the pure alumina (Al_2O_3 + ZrO_2), mixed oxide (Al_2O_3 + TiC) and the nitride (Sialon) ceramics are given in table 3.

<u>Silicon nitride-based materials</u>

These tool materials have many good characteristics at high temperatures (1,200°-1,400°C) such as good oxidation resistance, good mechanical strength, chemical inertness and high hardness in comparison to alumina-based ceramics. The high thermal shock resistance of Si_3N_4-based ceramics is a result of their good thermal conductivity and low coefficient of thermal expansion (table 3). These two factors reduce the stress set up between the hotter and cooler parts of the insert. The Si_3N_4-based ceramics have very good edge strength because of this. However, the chemical stability and wear resistance of Si_3N_4-based ceramic tools are somewhat lower than alumina-based ceramics. Of the ceramics available Si_3N_4 is one of the toughest. The high fracture toughness makes it less prone to catastrophic failure and makes it possible to machine at higher feed rates that can be done with alumina-based ceramics. Reaction-bonded Si_3N_4 has lower strength because of the higher pore space in the compact. Hot-pressed Si_3N_4 components are theoretically fully dense; this improves their properties considerably. However, the pressing operation at high temperature limits them to fairly simple shapes. The advantages of sialon materials over conventional Si_3N_4 are improved resistance to oxidation, creep, and abrasion [19, 27] and a pressureless sintering technique. The microstructure and crystal structure of a silicon nitride-(sialon) based ceramic tool are shown in Figures 5a and 5b. The crystal structure consists of the β' Si_3N_4 cemented by a glassy phase. The interlocking nature of elongated β' Si_3N_4/sialon grains contributes to the toughness of nitride ceramics. However the fracture toughness of Si_3N_4/sialon materials does not approach that of cemented carbides.

<u>"Whisker reinforced ceramic/ceramic composites (30 wt% SiC + 70 wt% Al_2O_3</u>

Ceramic materials are inherently brittle and thus difficult to use in manufacture. Allied to the inherent brittleness is a tendency towards porosity and thus any particular piece of ceramic has a greater likelihood of a flaw and hence properties are often given with a Wiebull modulus. A higher figure for this modulus indicates a more predictable material. A low figure of about 10 is more commonly seen with ceramics.

Whisker reinforcement is the product of a recent development in ceramic tools in an attempt to improve the toughness, particularly of alumina-(Al_2O_3) based ceramics by mechanical rather than chemical means. Increased toughness has been achieved through the reinforcement of the brittle alumina matrix with extremely strong, stiff silicon carbide (SiC) single crystals commonly called "whiskers" (or fibres). These "whiskers" are grown under carefully controlled conditions and due to their high purity and lack of grain boundaries approach the theoretical maximum strength obtainable (about 7,000 MNm^{-2}). [28] The rod-like SiC whiskars are less than 0.5μm in diameter. The matrix consists of pure alumina of a fine grain size. The SiC whiskers when dispersed in the alumina matrix function in much the same way as fibres in fibreglass. The resulting materials after reinforcing the brittle matrix with SiC whiskers have a fracture toughness (K_{IC}) of 8$MPam^{-1/2}$ well above hot-pressed alumina composites (about 4 $MPam^{-1/2}$) and and silicon nitride (6.8$MPam^{-1/2}$ for Sialon) based ceramics. This improvement is possible because the SiC whiskers act as microcrack deflectors.

The reinforcement of alumina ceramics with SiC whiskers leads to a 40 per cent increase in the thermal conductivity of the composite. This reduces thermal gradients during machining and improves the ability of the tool material to withstand thermal shock. The improved resistance to thermal shock enables the use of coolants when cutting and also permits the use of the ceramic composites for interrupted cutting without fear of catastrophic failure from thermal cracking.

Other important physical properties of the SiC reinforced alumina ceramics include high hardness, strength and a two-to threefold increase in the Wiebull modulus in comparison to hot pressed composites and sialon ceramics. [28] The increased edge strength means that whisker ceramics can be offered as standard inserts without honed edges and with a positive rake thereby allowing their use in finishing operations on aerospace alloys. The absence of edge honing on ceramic inserts tends to eliminate the "smearing" problems common when machining with ceramic materials.

SiC-reinforced alumina ceramic tools are mainly used for machining a range of difficult to cut exotic materials such as nickel-based alloys (including Inconel 718, Waspalloy, Inconel 903, Rene 41 and 95, Hastelloy X and Paralloy D2), hardened steels, chilled irons, and tool steels at high metal removal rates. The cost of "whisker" reinforced alumina ceramic insert is high when compared to previous ceramic and carbide inserts used for machining similar aerospace materials. This high cost will, however, be compensated with the overall improvement in productivity envisaged by using the whiskered ceramics.

Wear characteristics

Ceramic tools fail mainly by wear on the flank face caused by the movement of the newly cut surface of the workpiece against the cutting tool. The rapid flank wear is often caused by the individual particles being dislodged from the matrix of the tool by localized stress concentration during the machining operation. The high temperatures generated during machining may also encourage the development of an uneven stress region in the tool which lowers the cohesive strength of the ceramic bond. The severe wear on the flank face of the cutting tool can lead to the elimination of the clearance angle, and the flank face thus becomes a heat source increasing the temperature and compressive stress at the nose, resulting in the fracture or catastrophic failure of the tool. Flank wear is also a result of the inherent brittleness of ceramic tool materials which encourages chipping/plucking of tool particles at the cutting edge (i.e. attrition wear). Chipping can occur if there are hard spots or inclusions in the workpiece. Plucking of tool particles may also occur if the temperatures generated at the cutting edge are high enough to weaken the interparticle bonds or when sufficiently high stresses result from the cutting action. The chipped or plucked tool particles may travel down the flank face (or less likely over the rake face) causing increased flank wear. [29]

Rake face wear (cratering) occurs but it does not limit the tool life of ceramic materials. Cratering is caused by chips flowing over the tool surface. The chemical stability/inertness of ceramic tools at high temperatures ensures that there is only a slight weakening of the interparticle bonds and minimal diffusion, resulting in the small amount of cratering. Alumina ceramics show less crater wear than the mixed oxide (Al_2O_3 + TiC) ceramics when used to machine steel or materials with high iron content. [30]. This is probably because the mixed oxide ceramics contains TiC which has relatively more affinity for iron than the Al_2O_3.

Ceramic inserts can also fail by plastic deformation, fracture and notching. Notching at the tool nose and the end of depth of cut may be caused either by chemical reaction at the periphery of the tool/chip interface where sliding conditions are dominant, or by work hardening of the workpiece material as a result of the high pressures at the tool/workpiece interface. [29, 31] Notching is a very critical wear process when machining heat resistant steels, nickel and titanium alloys with ceramic tools since these work materials generate segmented chips whose edge makes an intermittent contact with the tool, and also generate segmented chips whose edge makes intermittent contact of the tool, and also generates fluctuating stresses. [32] This condition leads to rapid intermittent seizure of the chips and tool (some several thousand times a second). The release of the chip after the momentary seizure may lead to small fragments of the tool material being pulled out.

Premature failure or fracture of ceramic tools occurs mainly during cutting at lower speeds, as a result of poor toughness and transverse rupture strength. This failure mode can also occur when cutting at high speeds, following reduction of the chip/tool contact length and the uneven stresses acting at the edge. This is disadvantageous since a relatively small area will be heated up during the machining operation leading to the weakening of the tool and resulting in its premature failure. Extensive research work has been carried out on the failure modes and wear mechanisms of sialon materials when cutting various work materials. [32, 33, 34]. Notching and flank wear are the major failure modes when cutting various materials (e.g. nickel and titanium alloys, steel and cast iron). The tendency to notch, mainly when cutting superalloys, can be minimized by using sialon tools with the appropriate geometry and adopting careful machining practices: an approach angle of 45° and a clearance angle sufficient to prevent the tool from rubbing the workpiece and dwelling in the cut. Wear mechanisms in which the sialon material with the atmosphere, particularly nitrogen, have been proposed to explain the occurrence of notching when machined high-nickel alloys. The diffusion of tool and workpiece materials to form spinels, which are easily mechanically removed, has been proposed to explain flank wear. Plastic deformation of sialon tool materials can result from the high compressive stresses occurring during machining and this can lead to cracks because of the tensile stresses around the cutting edge. These cracks have a tendency to open up very quickly as cutting proceeds resulting in the catastrophic failure of the tool edge. Sialon materials however are not subject to the same catastrophic failure modes often seen with alumina-based materials and can be utilized with coolants. These materials have found application in machining nickel-based superalloys and cast irons but have not had success with machining steel. This may be because iron dissolves in the glassy phase of the ceramic, lowering its glass transition temperature and thus altering the mechanical properties.

Summary

The development of ceramic cutting tool materials based on aluminium oxide and silicon nitride is rapidly expanding, with microstructural and property improvements and developments in manufacturing methods proceeding concomitantly. Research indicates that while the toughness of these materials is still lower than that of the conventional materials, successful application is being found. This can be enchanced by reinvestment in modern metal-cutting facilities. The metallurgist entering this field therefore needs a broad appreciation of the problems and potentials associated with all sides of these developments.

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Table 1: Different types of impurities added to alumina during sintering and their effect on grain growth

Table 2: Room and elevated temperature properties of ceramic and carbide (P10) tools [23]

Table 3: Properties of Ceramic Cutting Tool Materials

Figure 1. Difference between the compressive strengths of ceramic and carbide (P10) tools at room and elevated temperatures [23]

Figure 2A: Microstructure of a Pure Alumina Ceramic (less than 1 Wt per cent ZrO_2)

Figure 2B: Crystal Structure of a Pure Alumina Ceramic Tool (less than 1 Wt per cent ZrO_2) (X 10,000)

Figure 3: Illustration of the relative low thermal conductivity of Al_2O_3 compared to other materials

Figure 4A: Microstructure of a mixed oxide ceramic tool (Al_2O_3 + 30 Wt per cent TiC)

Figure 4B: Crystal structure of a mixed oxide ceramic tool (X 8,800) (Al_2O_3 + 30 Wt per cent TiC)

Figure 5A: Microstructure of a silicon nitride-based ceramic tool (Sialon) Showing Si_3N_4 and Y_2O_3 glass

Figure 5B: Crystal structure of silicon nitride-based ceramics (Sialon) (X 50,000) showing Si_3N_4 and Y_2O_3 containing glass phase

Table 1

Increased growth	No effect	Retarded growth		
Ti	Gu	F	Sr	V
Nb	Y	Cl	Ba	Mg
Mn	P	Br	La	
Cu	Fe	I	Cr	
Ge	Th	Sb	Si	
	Ce	K	Su	
	Zr	Na	Ca	

Table 2

Material Properties		Hardmetals P10	Ceramic Al_2O_3
	20°C	1400	2200
Hardness (HV) -	1000	600	1500
Tensile B Mp_a	20	800	200
Strength	1000	600	200
Coeff of μ	20	0.6	0.15
Friction -	1000	-	-
Oxidation - -	20	no	no
	1000	severe	no

Table 3

Grade	Pure Oxide	Mixed Oxide	Nitride
Nominal Composition (vol %)	Al_2O_3 / 99	Al_2O_3 = 70	Sialon
	$ZrO_2 < 1$	TiC = 30	
Density (g/cm^3	3.99	4.29	3.26
Harndess: VHN-1Kg (Kg/mm^2)	1800	2230	1870
Hot Hardness (1000°C)			
VHN-18Kg load	800	900	1230
Toughness, K_{1c} MPa · m 3/2	4.3	4.5	6.5
Young's Modulus, E(GPa)	390	416	304
Thermal Conductivity (cals/cm s°K)			
Room temperature	0.0708	0.0517	0.1284
1000°C	0.0181	0.0236	0.0203
Thermal Expansion Coefficient			
(10^{-6}/°C) Room Temperature - 1000°C			
	8.2	8.6	3.1
Bend Strength (MPa)	700	910	750

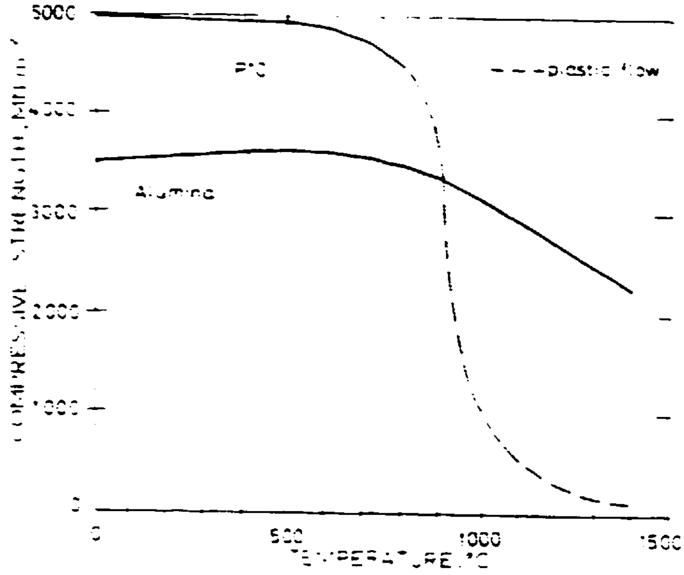

Figure 1.

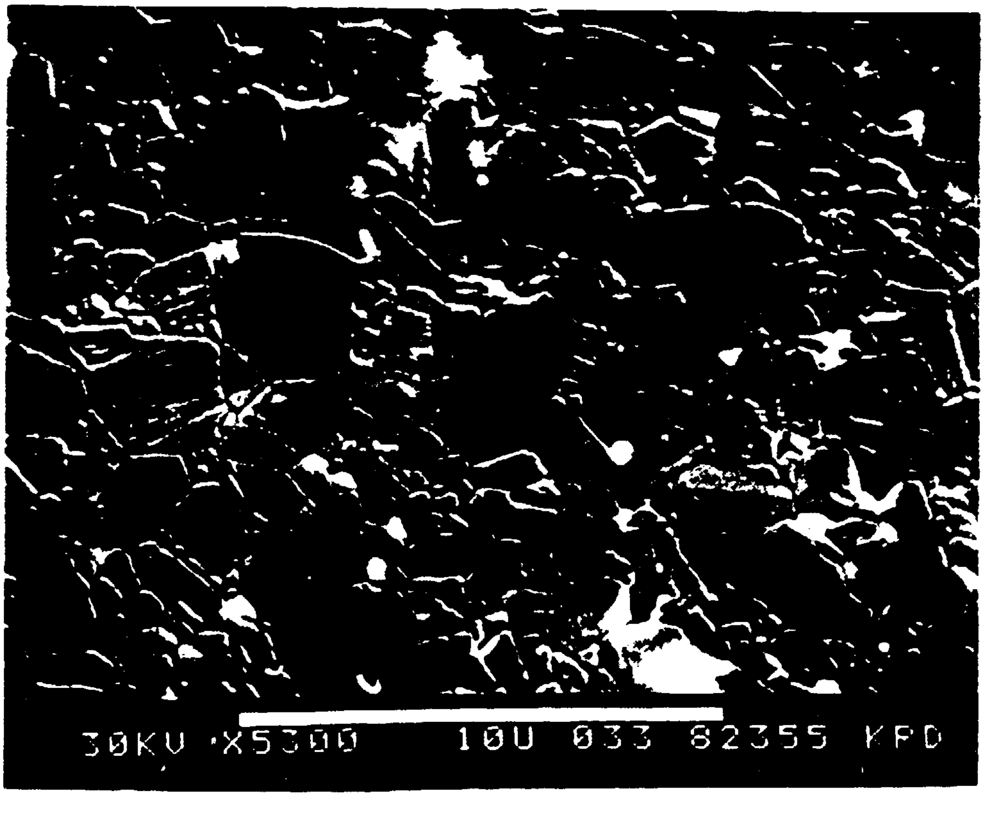

Figure 2a.

Figure 3c.

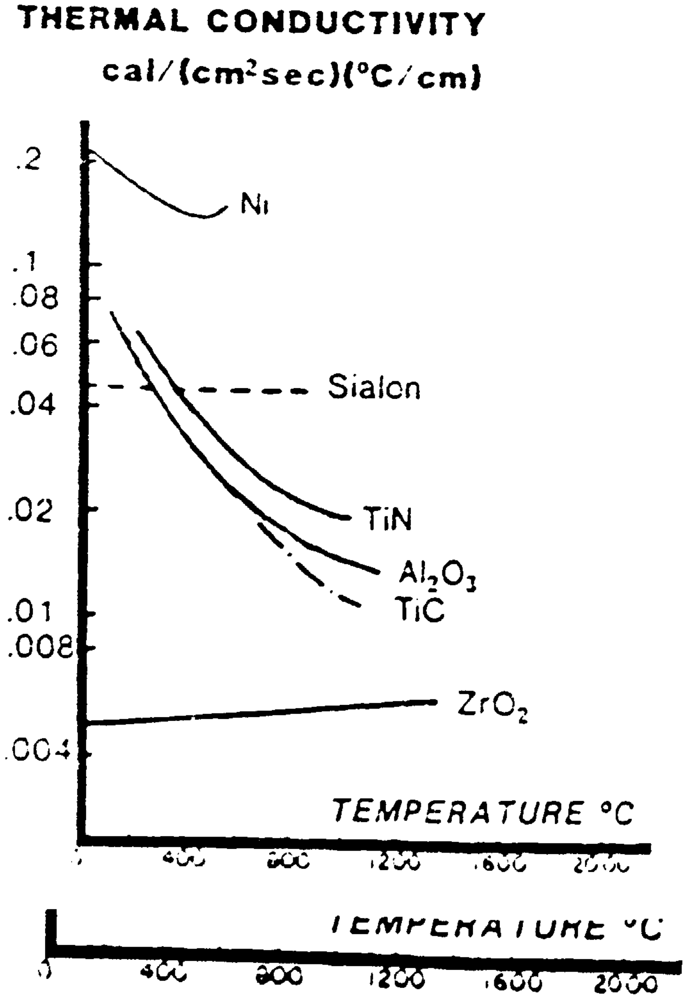

Figure 4.

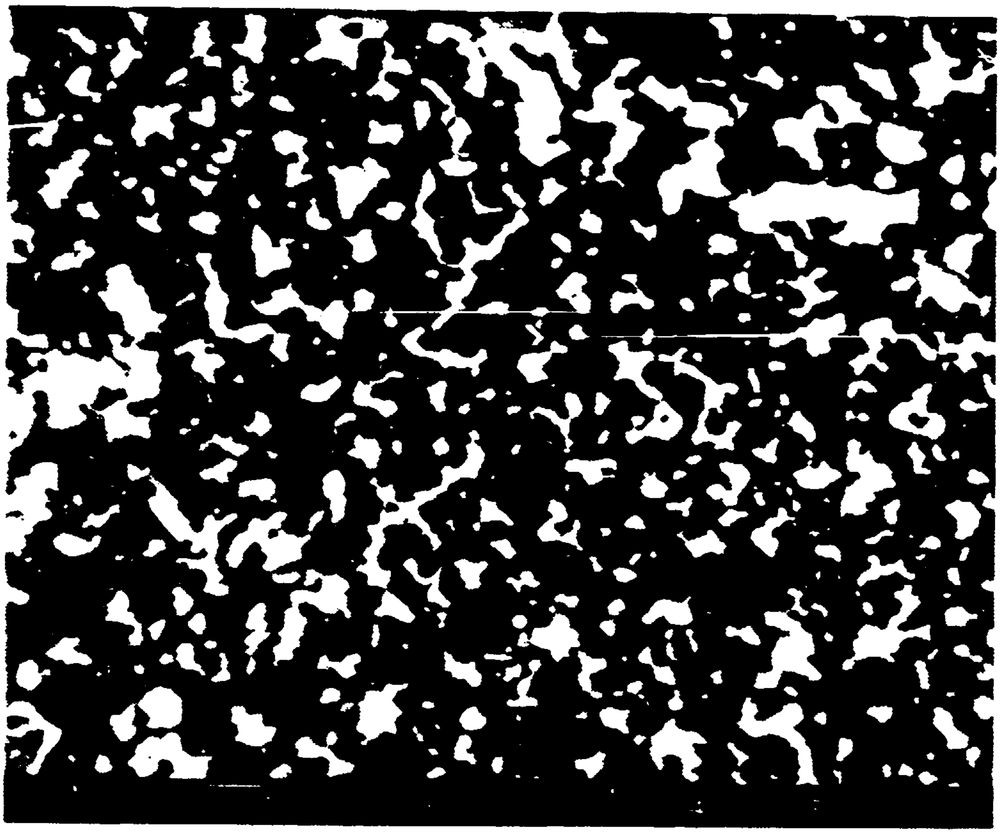

Figure 4a.

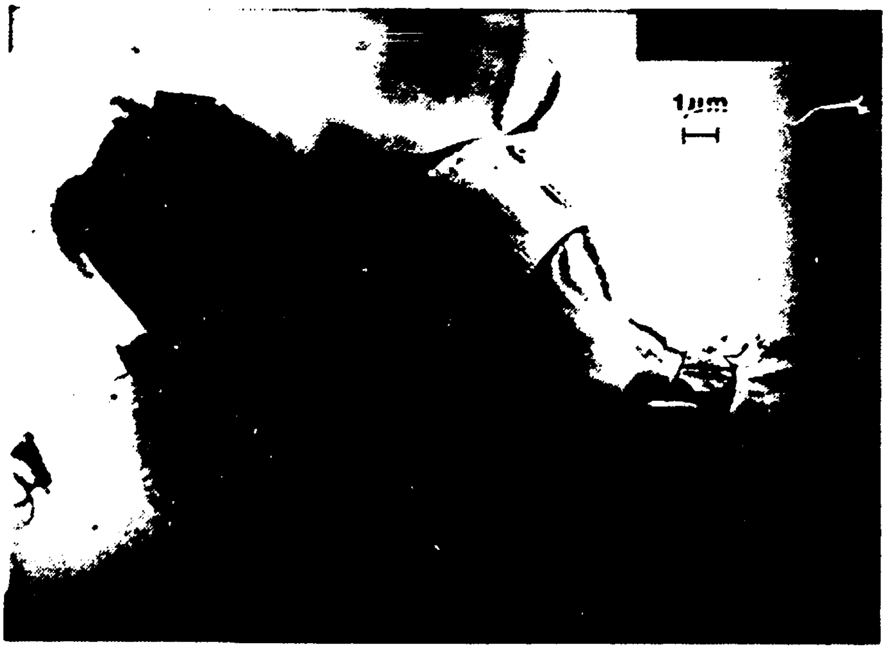

Figure 4b.

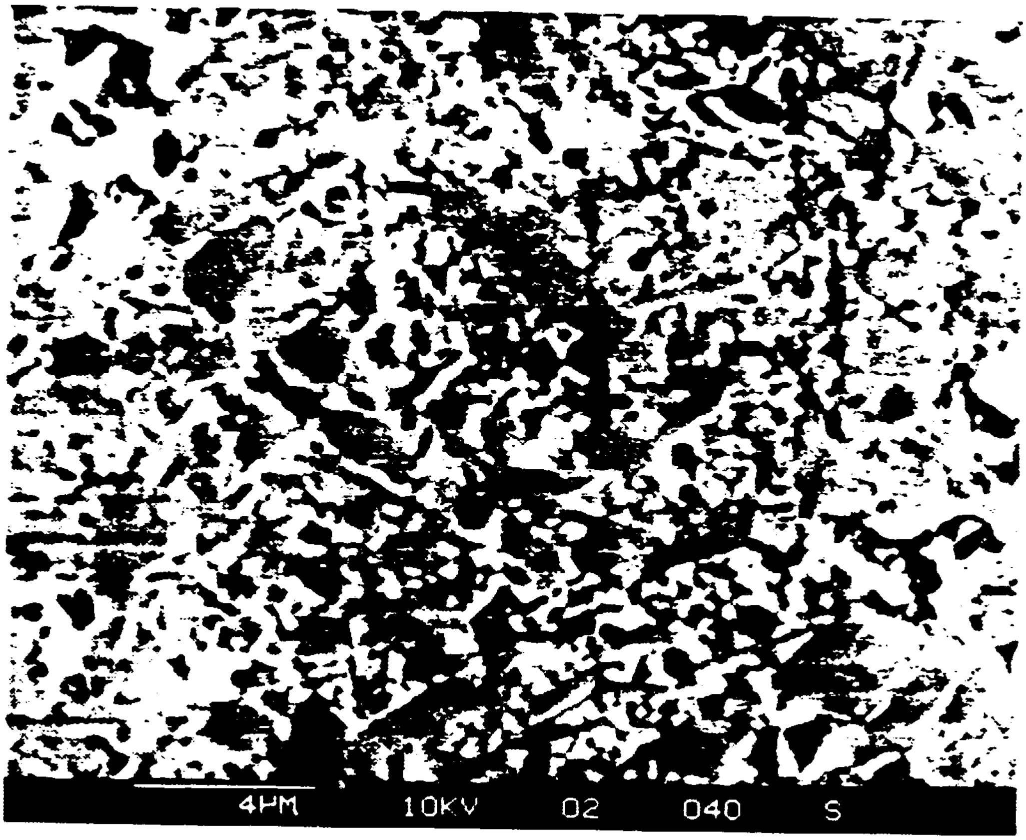

Figure 5a.

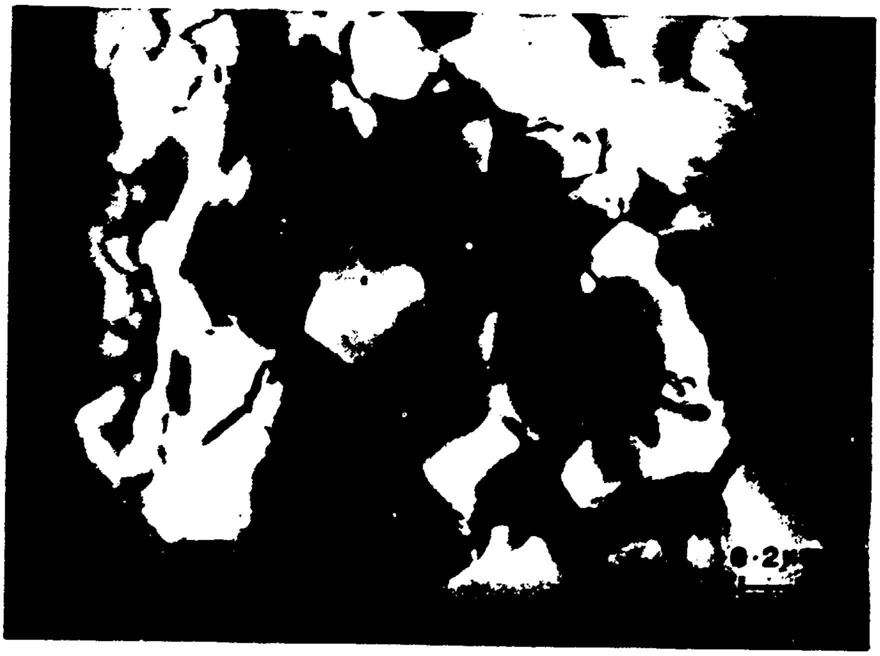

Figure 5b.

2. HARD-PART MACHINING WITH CERAMIC INSERTS

Hard-part machining (HPM), the machining of extremely hard workpieces using ceramic inserts, permits metal-working plants to cut costs and improve product quality at a modest startup cost. It can be done successfully by any skilled turning-machine operator, whether in a machine-shop environment involving small or prototype runs or in a high-volume production operation. HPM can be performed on relatively inexpensive machine tools as long as the machine is sufficiently rigid, and high-quality, uniform ceramic inserts are used.

Machining hardened parts involves materials registering 55 to 65 on the Rockwell "c" scale (R_c) and tensile strengths to 2,400 MPa (350,000 psi). Before ceramic inserts were developed, vitrified-bond alumina grinding media were used to obtain the desired surface finish. Next, a process for machining hardened rolls using ceramic and other composite materials was developed. It was determined that a maximum speed of 3.8 m/s (750 sfm) was required for dressing or semi-finishing cuts. Limiting factors included the machine tool and tool-holder system used for the evaluation.

With this process, the machining steps involved turning, plunging to open the roll, and finish-contour turning the outside form (Figure 1). The cutting parameters were 3.8 m/s (750 sfm) with a 0.036 cm per revolution (0.014 ipr) feed rate and maximum 0.038 cm (0.015 in.) depth of cut. The finished-part specification was to maintain an opening-radii tolerance of ±0.003 cm (±0.001 in.), at a nominal 0.889 cm (0.350 in.) radius. The final edge preparation of the ceramic insert relative to the chamfer, chamfer angle, and the circular or radial grind played a major role in the general grind quality and the success of the HPM process. The primary chamfer angle should be 0.025 cm (0.010 in.) greater than the anticipated crater width. A secondary-chamfer angle showed no appreciable increase in performance or failure of the insert. The strength of the ceramic also affected grinding quality and determined what edge preparation should be used.

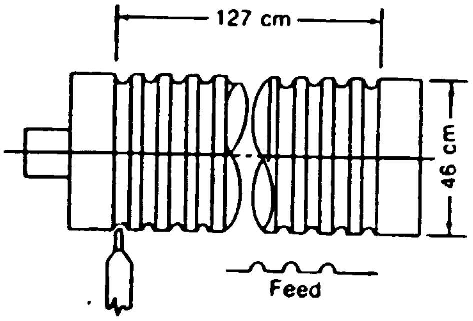

Figure 1. In a machining test of hardened rolls using ceramic inserts, the part was turned, then plunged to open the roll, and finally finish-contour turned on the outside form to complete the shape.

Machining the entire hardness range, 70 to 75 Shore or maximum 55 R_c, had no effect on the ceramic-tool-life performance. Conversely, both the surface hardness and microstructure of the rolls were uniform after machining. To develop this process to its full potential, appropriate equipment and tooling systems had to be designed. Such systems are now being used to rough machine iron rolls hardened to 75 Shore or 55 R_c, with depths of cut from 1.3 to 5.1 cm (0.5 to 2.0 in.) at 0.7 to 2.0 m/s (150 to 400 sfm), and 0.064- to 0.13 cm per revolution (0.025 to 0.05 ipr) feed rates. Semifinishing cuts are being performed at 1.0 to 3.0 m/s (200 to 600 sfm) at the same depths of cut and feed rates.

Hard-part machining was then developed for the automobile industry. The first high-volume application involved back-facing a transmission side gear and then finish turning the hub diameter. Hot-pressed alumina inserts were used for this application. Since then, other tool materials have been developed, resulting in overall acceptance of the HPM process.

Cutting forces: a critical factor

With HPM, two major controlling factors must be considered: selection of the proper speed and proper edge preparation of the ceramic insert. The speed depends on the hardness of the material; in general, as the hardness increases, the speed decreases (figure 2). Edge preparation depends on a variety of parameters: part hardness, the machine tool selected, the part finish and tolerance required, and the part material.

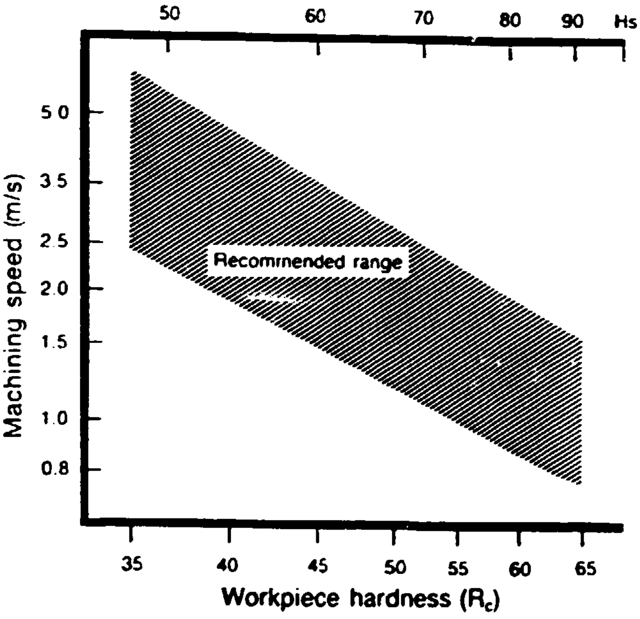

Figure 2. Workpiece hardness determines the recommended speed.

In addition to these parameters, it is important to consider the cutting forces. There are three forces generated in every metal-removal process: tangential force, generated by the part rotation; radial force, generated by the resistance of the workpiece material to depth of cut; and, lastly, longitudinal force, generated by the feed rate applied. These forces are 30 per cent to 80 per cent greater than in "soft" machining processes (figure 3). For example, when comparing preheat-treated to heat-treated steel with a hardness of 62 R_c, the longitudinal force increases from 30 per cent to 50 per cent relative to the edge-preparation width (figure 4). The tangential force increases 30 per cent to 40 per cent, and the radial force increases from 70 per cent to 100 per cent. Therefore, the machine tool must be able to handle the increased cutting forces, especially in the radial direction. However, these increases are small enough to have little effect on small- to medium-volume operations and will require purchase of no new equipment.

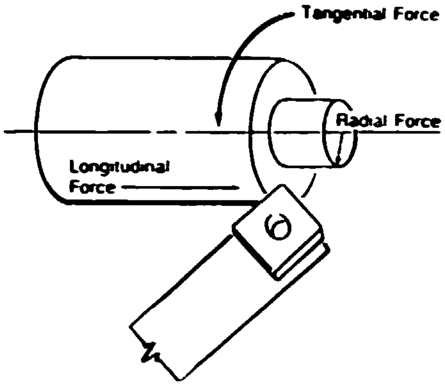

Figure 3. There are three forces generated in every metal-removal process, as shown, that become much greater in HPM than in conventional machining.

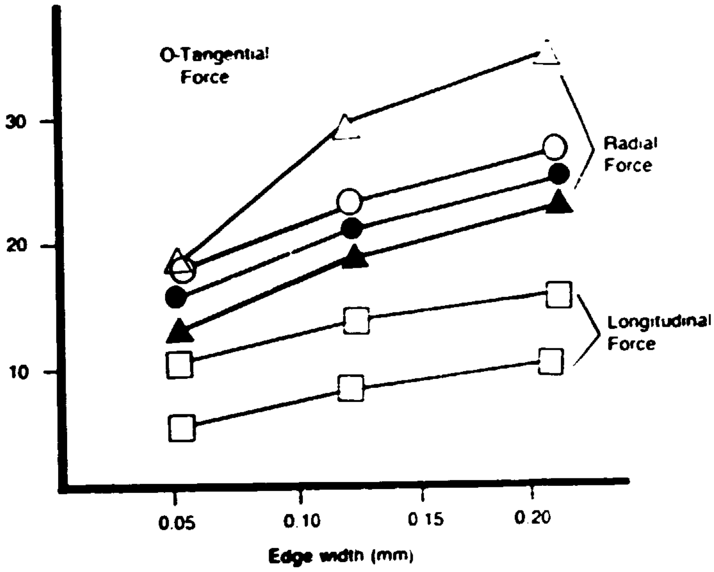

Figure 4. Comparison of cutting forces for D-2 preheat-treated steel (black symbols) and D-2 steel heat treated to 62 R_c (white symbols).

All forces must be considered to adjust the ceramic-edge integrity to maximize insert strength. Because the greatest increase is in the radial force, the major mode of failure of the ceramic is laminate fracture. If an upsharp insert is considered, negative or positive, the chance of laminate fracture increases. With a hone, the chip-removal direction is changed, and the radial force is distributed over a large area tangentially to the hone radius. This allows more aggressive stock removal and affects the surface integrity. Both a land and hone may be required for heavier stock removal, interrupted cuts, inadequate machinery, or dimensional requirements on the machined part. The ideal selection would be to minimize all forces, thereby requiring an upsharp or minimum hone or land to ensure straight-line shear. However, in actual applications, there are many identical parts being hard-part machined on identical machinery that needs different edge preparations.

<u>Advantages over conventional grinding</u>

For grinding cylindrical applications, both the wheel and the workpiece must rotate. Moreover, the wheel rotates rapidly while the workpiece rotates slowly. If the rotating members are imperfectly concentric, the combination of imperfections and rotational-speed differential produces lobing. A geometric out-of-round pattern on the workpiece is produced, which can affect the end-product performance. With HPM, on the other hand, either the workpiece or cutting tool is rotated, not both. Therefore, the machined surface will be as accurate as the machine-tool spindle and the longitudinal direction of the machine tool relative to the centre line of the machine.

Another disadvantage with grinding is the generation of tremendous surface heat at the point of contact between the grinding wheel and the workpiece. Even when flood coolant is properly applied, workpiece surface-stress risers and heat checks can occur, which can lead to premature failure of the ground part in service. With ceramic HPM, less heat is generated, and if properly applied, the heat that is generated will be carried away with the brittle material removed. Thus, the finished parts are produced without stress risers or heat checks. The only disadvantages with HPM involve surface finish and tolerances less than ±0.0008 cm (±0.0003 in.) in high-volume production.

Another major advantage of HPM is that conventional turning machines can be used with workpieces as hard as 65 R_c using commercially available ceramic inserts. Savings occur in two areas, processing and capital investment. In processing, the machining, setup, and tool-changing time are significantly reduced. Grinding-wheel changing, on the other hand, is time-consuming. Guards must be removed, along with the spindle locking nuts, the worn wheel must be changed, and the new wheel balanced and dressed. Wheel changing can take as much as 100 times longer than changing ceramic inserts, which require only simple indexing or replacement in the holder.

Equipment also is less expensive. A turning machine costs significantly less, 90 per cent per spindle, than a production grinder to do comparable work. As already mentioned, setup is easier and quicker. Turning machines also are simpler in construction - there are no reciprocating slides to wear, maintain, or replace - for easier maintenance. However, the strength and rigidity of every component in the machine must be adequate to handle the additional cutting forces.

In addition, HPM usually requires no coolant. Dry cutting eliminates not only coolant costs, but also the expense of related housekeeping. Coolant mist can permeate the plant atmosphere and infiltrate machine controls, and coolant residue can carry grinding-wheel media into material-handling equipment. Spillage and leaks can cause slippery, hazardous areas. Disposal of chips during HPM poses no problem; chips in the machine collection tray have the consistency of dry, brittle steel wool, which disintegrates into very fine powder and can be readily compacted to a small volume for safe, easy disposal.

From small to large operations

A ceramic insert, consisting of alumina and titanium carbide sintered together under pressure, has been developed for HPM. This material has excellent high-temperature hardness, thermal shock, wear, and oxidation resistance. Transverse rupture strength is 862 MPa (125,000 psi) at room temperature and 538 MPa (78,000 psi) at 1,100°C. This cutting tool is applied in both small machine shops and large-production operations. For the latter, the tool is used to machine press-forming components of D-7 steel, a cold-working tool steel containing high carbon and high chrome (2.35 carbon, 12 chrome, 4 vanadium, 1 molybdenum). Though the vanadium content in this steel contributes to its exceptional wear-resistance properties, the vanadium content also makes it more difficult to machine.

Because D-7 steel is so wear resistant and tough, it retains its hardness in impact and friction-heat applications. This makes it suitable for roll-forming and press-forming operations where it retains its hardness, form, and shape for long periods under severe operating conditions. HPM rolls used in such applications have outlived ground rolls by four or five times.

In grinding-production operations, where it took up to 16 h to process a die component, HPM completes the job in <2 h. In machining forming rolls, the time-saving benefits are even greater; the grinding process requires <30 h per roll, whereas HPM takes only ≈2 h. The metal-removal rate accounts for this difference. When machining across holes or other interruptions, running at increased speed dampens the harmonic forces and reduces vibration. The higher speed allows the tool to move through the interruptions under reduced impact conditions, resulting in significantly improved tool life.

The rolls, punches, and dies are hardened to 63 to 65 R_C. A typical application is a punch used in press-forming operations to produce a brake-drum backplate from 0.953 cm (0.375 in.) thick steel for an over-the-road truck. The punch is profiled using the alumina-TiC cutting tool at 2.0 to 2.5 m/s (400 to 500 sfpm) cutting speed with a depth of cut of 0.038 to 0.076 cm (0.015 to 0.03 in.), and a feed rate of 0.015 to 0.020 cm per revolution (0.006 to 0.008 ipr). An engine lathe that can handle large workpieces inside diameters to 25 cm (10 in.) has been successful for this application, but it has been replaced with a more efficient computer-numerical- control machine.

One machine shop using HPM produces a variety of demanding parts. For example, a D-7 steel-forming roll is finish machined to three different diameters using an engine lathe. Despite the roll's hardness (62 to 65 R_C), the ceramic insert machines run smoothly at cutting speeds of 3.0 to 4.0 m/s (600 to 800 sfpm), completing contouring in ≈2 h. Depth of cut is 0.025 to 0.076 cm (0.010 to 0.03 in.), and feed rate is 0.015 to 0.020 cm per revolution (0.006 to 0.008 ipr). Other applications include bearing components, forming rolls for aluminium siding used on prefabricated homes, and recreational parts.

In another high-volume automotive application, proper edge preparation and reprocessing the sequence of operations were the keys in getting HPM accepted. The component is a gear shaft, with hardness ranging from 60 to 62 R_C. The gear is back-faced, and the shaft's diameter is undercut, followed by spacing ±0.003 cm (±0.001 in.) shaft grooves 0.08 cm (0.03 in.) wide with chamfers. The speed has been increased from 3.0 m/s (600 sfm) to 4.6 m/s (900 sfm), with a feed rate of 0.015 cm per revolution (0.006 ipr). With proper edge preparation of ceramic inserts, a manual-transmission shifter ring of 60 to 62 R_C hardness was also successfully machined at a 1.8 m/s (350 sfm) cutting speed, 0.25 cm (0.10 in.) depth of cut, and 0.015 to 0.020 cm per revolution (0.006 to 0.008 ipr) feed rate. The bottom tool is used to separately face, undercut, and finish the ring diameter by ±0.010 cm (±0.004 in.), and the top tool is used to face and undercut the top face of the yoke opening.

Productivity gains for other automotive applications

Hard-part machining can improve productivity for other components. For machining the outside diameter of a hypoidring gear, HPM is faster than grinding: 84 versus 54 pieces per hour per spindle at 70 per cent efficiency (table 1). Although actual machining times are similar, the vertical-boring machine actually doubles the production rate to 168 pieces per hour or 3628 pieces per day at 70 per cent efficiency. In practice, vertical-boring-machine efficiency is 80 per cent. Therefore, output per spindle is increased to 96 pieces, so the machines can work at much less than full capacity for this job. Moderate tool savings result from eliminating coolant and filters.

Table I. A Case History: Hypoid Ring Gear

Parameters	Grinder (one spindle)	HPM vertical boring machine (two spindles)
Output per spindle (pieces/h gross)	78	120
Output per spindle (pieces/h 70% efficiency)	54	84
Output per machine (pieces/h 70% efficiency)	54	168
Output required (daily, pieces/21.6 h)	7 000	7 000
Output per machine (daily)	1 166	3 628
Machines required	6	2
Operators required per shift	3	1
Capital investment ($)	2 812 500	600 000
Consumable tooling costs (annual) ($)	5 900	6 000
Coolant and filter costs (annual) ($)	1 700	none
Floor space required (m^2)	118	10

In another example, production rate per spindle increased only 7.5 per cent over grinding, when turning a differential side gear. But overall savings are more significant: grinding produces 42,000 pieces per day at 60 per cent efficiency, with eight operations per shift, whereas HPM produces the same with only four operations per shift. Using 80 per cent efficiency, output increases to 185 pieces per spindle, or 370 pieces per machine, 800 pieces per day. In other words, just six hard-part machines and three operators per shift can do the job, thereby reducing capital investment by more than $500,000. Secondary operations required with grinding, such as honing and coating, are no longer needed.

A second-speed transmission gear normally requires several grinders. The first grinder machines the bore and then indexes the workpiece and lightly grinds the face - a difficult operation. The workpiece transfers to another machine, where it locates on the front face for grinding the back face. The last grinder is required to grind the outside diameter of the synchronizer. With HPM, on the other hand, all operations are done simultaneously on one machine. The part is chucked on the gear teeth and located on the back face. Because there is no transfer, inaccuracies resulting from workpiece movement from one machine to another are eliminated. Three sqaure and one round inserts are used to perform the four operations simultaneously (figure 5).

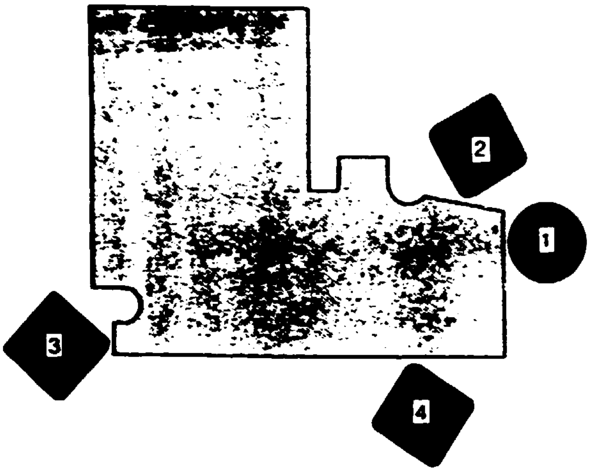

Fig 5. Second-speed gear for a manual transmission is machined in one hard-turning setup using four ceramic inserts. Bore and rear face are machined with double-tooled boring bar, the front face and tapered outside diameter by individual tooling bocks. Round insert machines front face, and bore is easily maintained concentric to pitch diameter. Front and rear faces are automatically parallel and square with bore, and tapered outside diameter (synchronizer cone) is automatically concentric to bore

A drive sprocket with a bearing race pressed onto a recessed hub is distorted during pressing. Until recently, the outside diameter of the race required grinding to bring it back into specification. Because it is difficult to get a grinding wheel into the recess to grind the outside diameter, deviations were allowed to achieve production. HPM can machine the outside diameter to close tolerances with a good surface finish by using a cutting speed of 1.4 m/s (270 sfm) and a depth of cut from 0.020 to 0.025 cm (0.008 to 0.010 in.)

In grinding an axle-shaft-bearing diameter, conventional machining failed to achieve satisfactory roundness. Lobing patterns were impossible to remove by honing or other fine-finishing methods. Needle bearings mounted on the machined surface generated noise that could not be tolerated and also caused severe problems. Hard-part turning on a two-spindle machine solves the roundness problem. Machining is now done with a round insert at 14 m/s (270 sfm), 0.038 cm (0.015 in.) depth of cut, 0.0292 cm per revolution (0.0115 ipr) for roughing and semifinishing, and 0.015 cm per revolution (0.006 ipr) for the finish pass.

HPM represents an opportunity for cutting costs and improving product quality for many applications. These productivity improvements made possible with ceramic inserts. However, edge preparation of the insert requires careful design to withstand the increase in cutting forces. (Reprinted by permission of the American Ceramics Society, Ceramic Bulletin, Vol. 67, No. 6, 1988 ((c) ACerS). Article written by David Bordui, NTK Cutting Tool Division, Farmington Hills, MI 48331. Article is based on a paper presented at the Society of Manufacturing Engineers' clinic on "Ceramic Cutting Tools and Applications," Southfield, MI, 15-16 March 1988.)

3. MACHINING WITH AL_2O_3-SiC-WHISKER CUTTING TOOLS

Significant increases in manufacturing productivity can be achieved by increasing metal-removal rates. In several applications, ceramic metal-cutting tool materials have been economically employed to machine ferrous and non-ferrous metals at rates significantly higher than those possible with carbides or ceramic-coated carbides. This is accomplished by Al_2O_3, Al_2O_3-ZrO_2, and Al_2O_3-TiC cutting-tool materials by virtue of their high wear resistance, thermal-deformation resistance, and chemical inertness. However, they suffer from relatively low fracture resistance. [1]

Sialon cutting-tool materials possess high fracture resistance and thermal-deformation resistance, resulting in their use in machining superalloys and gray cast iron at relatively high metal-removal rates. [2, 3] Recently introduced SiC-whisker-reinforced Al_2O_3 cutting tools exhibit a superior combination of wear resistance and fracture resistance. [4] The effect of SiC-whisker reinforcement of Al_2O_3 on some key material properties and performance of these composites in machining ferrous and non-ferrous metals have been determined.

Properties and performance

Commercial Al_2O_3-SiC-whisker (Al_2O_3-SiC_w) cutting-tool materials contain 30 to 40 vol % SiC_w, with the rest consisting of fine, equiaxed Al_2O_3 and some densification aids such as MgO or Y_2O_3. [4] Table I illustrates that the room-temperature microhardness, fracture

Table I. Properties of Cutting-Tool Materials

Property	Al_2O_3	Al_2O_3-SiC_w
Vickers microhardness at 18.5-kg load (GPa)	17.2	19.7
Fracture toughness ($MPa \cdot m^{1/2}$)	4.5	6.0
Thermal-shock resistance* (%)	54	100
Standard free energy of formation (kJ/cm^3 at 1600 K)	−49.8	−34.3'

*Figure of merit determined by (fracture toughness × thermal conductivity/(Young's modulus × thermal-expansion coefficient) 'Calculated by volume averaging; −5.4 kJ/cm^3 for SiC toughness, and a figure-of-merit for thermal-shock resistance [5] are improved by incorporating SiC_w in an equiaxed Al_2O_3 matrix. However, the high chemical inertness of Al_2O_3, as measured by a low free energy of formation, deteriorates as a result of the addition of SiC_w. [6]

$Al_2O_3-SiC_w$ cutting tool materials have substantially increased metal-removal rates in machining Ni-based superalloys. Figure 1 illustrates suitable cutting conditions for machining a typical superalloy 1/ by various cutting-tool materials. Figure 2 compares tool lives in machining the superalloy 1/ under relatively severe conditions using Al_2O_3-TiC, sialon, and $Al_2O_3-SiC_w$ cutting-tool materials. A desirable feature of the $Al_2O_3-SiC_w$ composition is that the tool-failure mode is gradual wear 2/ even under these severe conditions, compared to catastrophic fracture for the Al_2O_3-TiC material.

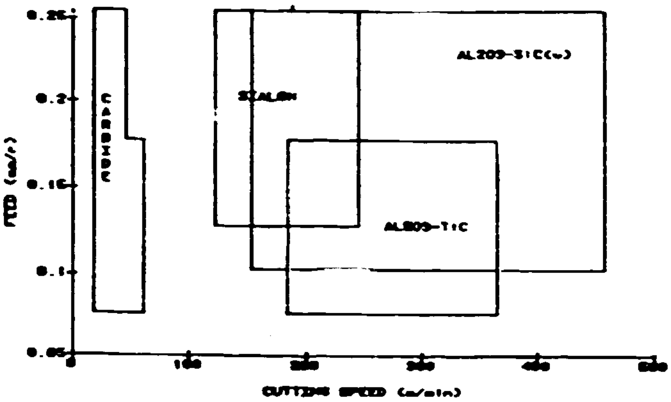

Figure 1. Suitable cutting conditions and cutting-tool materials for machining Ni-based supperalloy. 1/

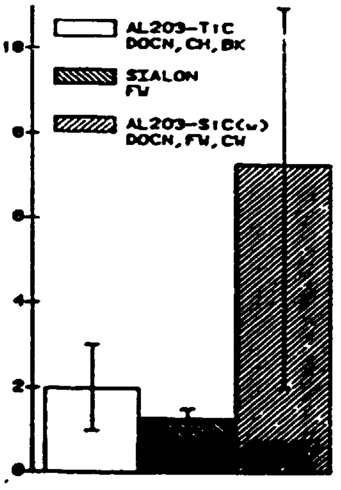

Figure 2. Tool lives in machining Ni-based superalloy 1/ with Al_2O_3-TiC, sialon, and $Al_2O_3-SiC_w$ compositions at a speed of 5.1m/s, feed rate of 0.25mm per revolution, the depth of cut of 2.54 mm. Failure modes: DOCN=depth-of-cut notch, CH=chipping, BK=breakage, FW=flank wear, CW=creater wear.

Double the tool life

Further metal-cutting tests were performed with sialon and $Al_2O_3-SiC_w$ tool materials to analyse their performances at different cutting speeds. At moderately high speeds of 1.7 to 4.2 m/s (330 to 820 sfm), $Al_2O_3-SiC_w$ and sialon tool materials have similar tool lives (figure 3(A)). However, at high speeds of 4.2 to 7.0 m/s (820 to 1380 sfm), $Al_2O_3-SiC_w$ materials have more than double the tool life of the sialon cutting-tool material (Fig. 3(B)). Since the tool-failure mode is an important consideration in selecting cutting-tool materials for machining the superalloy, 1/ feed rates and cutting speeds were analysed in terms of the tool-failure mode (figure 4). Under all cutting conditions, both tool materials reach the end of life by wear, except at conditions of high speeds and high feeds, where the $Al_2O_3-SiC_w$ toll material fails by chipping or breakage, indicating its inferior fracture resistance relative to the sialon material.

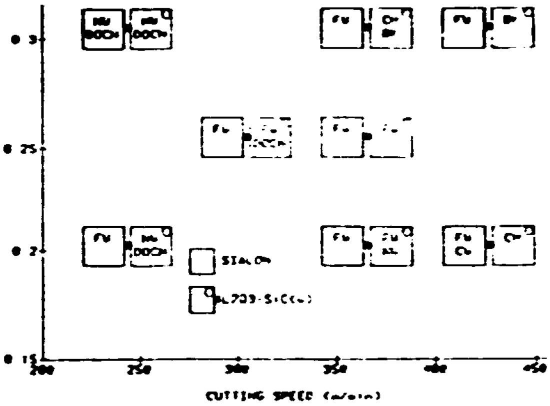

Figure 4. Effect of machining conditions on tool-failure mode of sialon and $Al_2O_3-SiC_w$ tool materials. Machining conditions: Ni-based superalloy 3/ workpiece: 2.54-mm depth of cut; SNG-644 insert style.

Another important Ni-based superalloy, 3/ with a higher Co level and greater tensile strength, [7] was field tested with sialon and $Al_2O_3-SiC_w$ tool materials (figure 5). While sialon tools showed significantly higher flank wear than the $Al_2O_3-SiC_w$ tools, the former never failed by breakage, whereas 50 per cent of the latter tools fractured. Since chipping was the reason for indexing, it was found that the sialon tools could yield a superior performance relative to the $Al_2O_3-SiC_w$ materials (table II).

Tool lives of sialon and $Al_2O_3-SiC_w$ cutting-tool materials in machining yet another superalloy 4/ in a field test are shown in figure 6. In this case, sialon cutting tools outperformed $Al_2O_3-SiC_w$ tools.

1/ Inconel 718, Inco Alloys International, Inc., Huntington, WV.

2/ Tool life ceased when flank wear was 0.38 mm (≥0.015 in.), crater wear was ≥0.1 mm (≥0.004 in.), depth-of-cut notch or nose wear was 0.76 mm (≥0.03 in.), chips were ≥ 0.76 mm (≥0.03 in.), or when the tool broke.

3/ Waspaloy, Precision Rings, Inc. of Indianapolis, Indianapolis, IN.

4/ Incology 901, Inco Alloys International, Inc., Hungtington, WV.

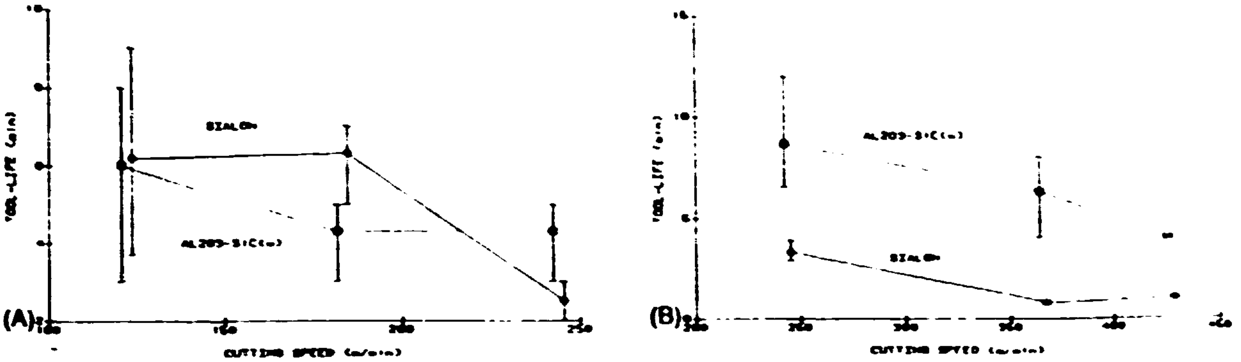

Fig. 3 Tool lives of sialon and Al_2O_3–SiC_w cutting-tool materials in machining Ni-based superalloy* at (*A*) 1 7 to 4 2 m/s with RNG–45 inserts and (*B*) at 3 3 to 7.5 m/s with SNG–644 inserts For both, feed rate and depth of cut were 0.20 mm per revolution (0 008 ipr) and 2 54 mm (0.1 in.), respectively

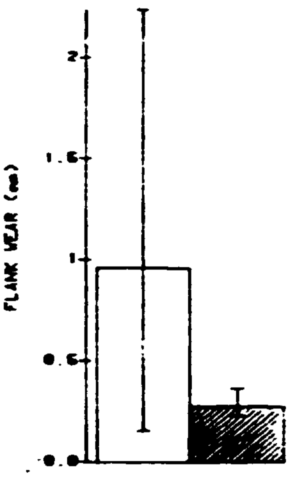

Fig. 5. Flank wear in sialon and Al_2O_3-SiC_w materials machining superalloy 1/ in a field test. Unshaded area represents sialon with a 0 per cent rate of breakage: shaded area represents Al_2O_3-SiC_w with a 50 per cent rate of breakage. Machining conditions: plunge-profile operation; speed of 3.5 m/s; f ed rate of 0.13 mm per revolution; depth of cut of 1.27 to 2.54 mm.

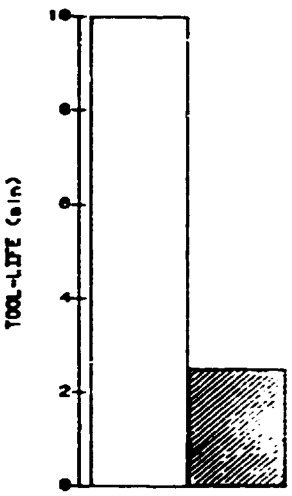

Figure 6. Tool lives in machining superalloys 2/ with sialon and Al_2O_3-SiC_w tool materials in a field test. Unshaded areas represents sialon; sharded areas represent Al_2O_3-SiC_w. Machining conditions: speeds of 6.0m/s; feed rate of 0.12 mm per revolution; depth of cut of 2.5 mm.

Table II. Field Test* of Cutting-Tool Materials

Parameter	Al_2O_3	Al_2O_3-SiC_w
Insert style	RNG–45	RNG–45
Workpiece diameter (mm)	152 4	152 4
Depth of cut by length of cut (mm)	2 5 by 135 9	2 5 by 135 9
Feed rate (mm per revolution)	0 18	0.13
Cutting speed (m/s)	4.6	4 8
Cutting time per piece	0.66	0 75
Pieces per edge	1	3
Tool life per edge (min)	0 66	2.25
Reason for indexing	Chipping	Chipping
Total cost per piece (insert plus machine) ($)	4 99	1 34
Estimated saving (%)		73

*Material Waspaloy (as-forged, 43 Rc) Precision Rings, Inc of Indianapolis, Indianapolis, IN Operation rough turn outside diameter Machine tool Mazak Slant Turn 30, Mazak Corp., Florence, KY

1/ Waspaloy, Precision Rings, Inc. of Indianapolis, Indianapolis, IN.

2/ Incology 901, Inco Alloys International, Inc., Hungtington, WV.

Ferrous alloys: a machining headache

Gray cast iron and 1045 and 4340 steels were the three ferrous alloys selected for machining with Al_2O_3-SiC_w cutting tools in another study.

Competitive tool materials were included for comparison, and results are shown in figure 7. These data suggest that Al_2O_3-SiC_w tool material is unsuitable for machining these ferrous alloys.

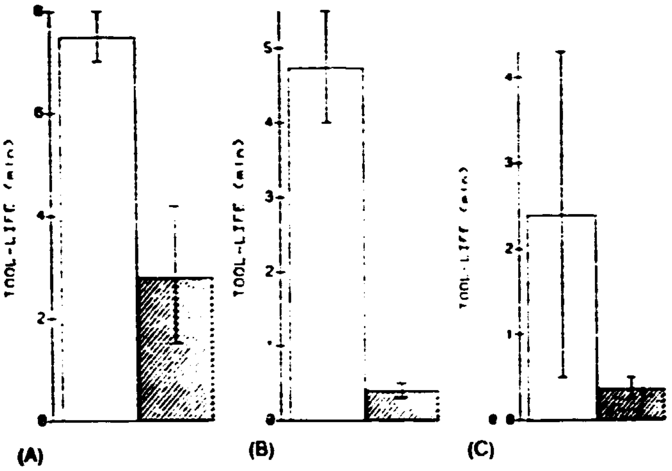

Fig 7. Comparison of tool life (*A*) Sialon (unshaded), flank-wear-failure mode, versus Al_2O_3–SiC_w (shaded), flank wear and chipping. Machining conditions: workpiece of cast iron, speed of 10.2 m/s, feed rate of 0.23 mm per revolution, depth of cut of 2.54 mm. (*B*) Cermet (unshaded), crater wear and breakage, versus Al_2O_3–SiC_w (shaded), crater wear and breakage. Machining conditions: workpiece of 1045 steel, speed of 5.1 m/s, feed rate of 0.64 mm per revolution, depth of cut of 2.54 mm. (*C*) Al_2O_3–TiC (unshaded), chipping, versus Al_2O_3–SiC_w (shaded), breakage and chipping. Machining conditions: workpiece of 4340 steel, speed of 5.1 m/s, feed rate of 0.64 mm/revolution, depth of cut of 2.54 mm

Conclusions

Reinforcement of Al_2O_3 with SiC whiskers improves certain basic properties, except chemical inertness. Cutting-tool performance is thus improved for certain machining applications. Productivity increased in machining some Ni-based superalloys; however, this advantage was unobserved with other superalloys. Further material developments are needed before Al_2O_3-SiC_w tool materials can be competitively used to machine ferrous alloys.

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(Extracted by permission of the American Ceramic Society, Ceramic Bulletin, Vol. 67, No. 6, 1988 ((c) ACerS). Article written by Elizabeth R. Billman, Pankaj K. Mehrotra, Albert F. Shuster, and Craig W. Beeghly, Kennametal Inc., Latrobe, PA 15650)

4. HIGH-PURITY POLYCRYSTALLINE DIAMOND TECHNOLOGY

In recent years, the spread of polycrystalline diamond tools has been remarkable, but now we are entering a new situation with respect to dealing with cost reductions, new uses, and new materials. Toshiba Tungaloy Co., Ltd., has developed (on commission from the RDCJ (Research Development Corporation of Japan)) a new technology in order to meet the market trend. This new technology is used to manufacture at one time a large number of high-purity polycrystalline diamonds which can be used to work cut-resistant materials with high efficiency. This manuscript describes the outline of this development work and resulting product.

1. Preface

Polycrystalline diamond tools are better than single crystal diamond tools in toughness, wear resistance, form freedom, quality stability, etc. They have spread as cutting tools, wire drawing dies, civil and mining tools, dresser, since they were commercialized by GE Corporation in the United States for the first time in 1973. They have been used in the field of hard metal tools as well as having replaced grinding and single crystal diamond tools as cutting utensils. Polycrystalline diamond tools cost more than hard metal tools initially, but are superior to these hard metal tools in longevity and quality of machined surfaces. Recently, a drill with a very small diameter has been developed. A polycrystalline diamond tip is incorporated in this drill.

In accordance with the development of the above use, expectations are increasing in the market that cut-resistant materials, such as high silicon aluminium alloy, FRM (fibre reinforced metal), new ceramics, etc., can be worked with high efficiency. In addition, the reduction in cost of polycrystalline diamond tools has been increasingly required. In order to meet the market trend, Toshiba Tungaloy Co., Ltd. has promoted the "Development of Technology for Manufacturing High-Purity Polycrystalline Diamond" on commission from the RDCJ based on research results obtained by the NIRIM (National Institute for Research in Inorganic Materials) of the STA (Science and Technology Agency), and has successfully completed the development work.

In this development work, the company aimed at developing a technology for manufacturing at one time a large number of large-diameter polycrystalline diamonds in order to reduce costs, as well as high-purity polycrystalline diamond which could be used to cut 20 per cent-Si-Al alloy, etc., with high efficiency. The purity of conventional products is 85 to 95 vol per cent, and about two sheets of sintered bodies with a diameter of about 12 millimeters can be manufactured by using conventional technologies of the company. Thanks to the success of the above development work, several sheets of polycrystalline diamonds with a purity of about 97 per cent and a diameter of 18 millimeters can be manufactured at one time. (Polycrystalline diamond used as a cutting tool is formed as a composite material in which a sintered diamond layer with a thickness of 0.5 to 1 millimeter is laminated on a trapezoid of a hard metal, because the polycrystalline diamond must be brazed, etc.)

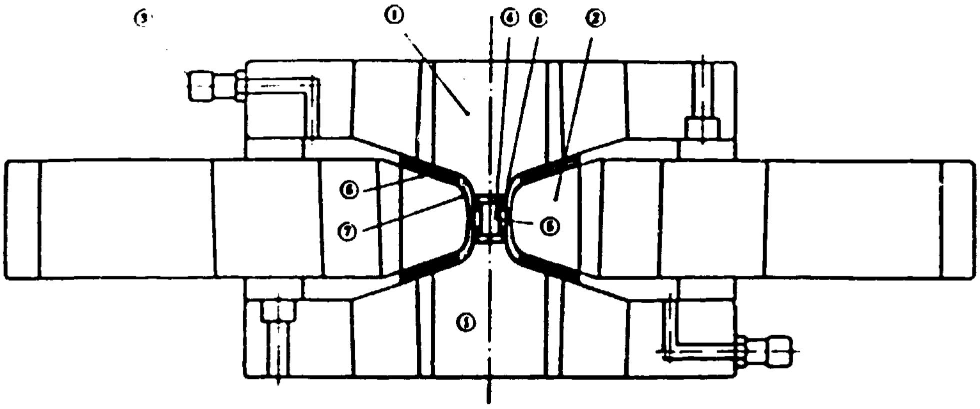
The following is the outline of the above development work and developed products.

2. Development of ultrahigh pressure sintering unit

Diamond sintering production needs a unit which can stably generate a pressure of more than 60,000 normal atmosphere (60 tons per square centimeter) and a temperature of more than 1,500°C. A flat belt type ultrahigh pressure unit developed by the NIRIM was adopted as this unit to sinter diamond. This unit is one of the further developed versions of the belt type ultrahigh pressure unit made by GE Corporation, and possesses the following features: (i) it can stably generate ultrahigh pressure and temperature with little danger of blow-out (sealed pressure leaks explosively), (ii) the volume of a large test piece room can be taken, because the compression stroke of a piston is large, (iii) in particular, it is possible to carry out multilayer sintering work. Also, the following items are devised: (i) shape of cylinder and piston of a truncated cone, usually called an "Anvil", (ii) gasket (pressure sealing member), (iii) high pressure vessel.

Figure 1 shows a typical drawing of the flat belt ultrahigh pressure unit. The principle is the same as that of the belt type ultrahigh pressure unit. That is, a carbon heater and a test piece are incorporated into a high pressure vessel consisting of solid pressure media, the high pressure vessel is mounted on a disklike cylinder together with a compressible gasket and an electrode plate, ultrahigh pressure is generated by pressurizing the high pressure vessel through the hydraulic press and a piston of the upper and lower truncated cones, and the high pressure vessel is heated by electrifying a heater through the piston. The piston and cylinder core are made of hard metal, and are reinforced by being press-fitted onto multilayer steel rings. Generally, the cylinder core is made of hard metal, but it is possible to use high speed steel, which is less expensive than hard metal, in the cylinder core. This can be cited as one of the features of the flat belt type ultrahigh pressure unit. The press-fitting operation is an important technology which affects the life of the unit, and it requires the accumulation of considerable technology. The company has long experience in press-fitting of ultrahigh pressure units, but has gained a great deal of knowledge based on theoretical analyses from the NIRIM. The conical angle is slightly smaller than that of the belt type ultrahigh pressure unit. The outside of the gasket consists of laminated paper, and the inside of pyrophyllite ($Al_2O_3.4SiO_2.H_2O$) powder compact. The most important feature of the flat belt type ultrahigh pressure unit is that the gasket is double-structured using laminated paper. The high pressure vessel consists of a salt-zirconia mixing power compact and a steel ring. Pyrophillite and salt are used as a gasket material and as a pressure medium well known in the field of ultrahigh pressure technology. Pyrophillite has the proper fluidity and high pressure sealing capacity. It is also used as a pressure medium. Usually, natural rock mined in South Africa is used as a gasket material, but the company has succeeded in using domestically produced and formed powder. Salt is used as a pressure medium, because it is soft, has excellent hydrostatic pressure and insulation properties, and the amount of volume reduction caused by decomposition or phase transformation under the ultrahigh pressure and temperature is small. Zirconia is added to salt to increase the heat insulating properties. These parts are throwaway goods, but the number needed is large and they require accuracy, and the radio accounted for by them in terms of cost is large. Therefore, the problem is how to reduce the cost in the future.

Before introducing this unit into the company, it has made some improvements in the unit considering basic specifications stipulated by the NIRIM so that the unit can be used smoothly to manufacture products. Important improvements are as follows: (i) a balance between horizontal retaining of a cylinder and longitudinal pressuring to the



Key: 1. Hard metal anvil
2. Hard metal die
3. Inlet and outlet of cooling water
4. Reaction room
5. Graphite heater
6. Laminated paper gasket
7. Pyrophyllite gasket
8. Electrical ring

cylinder has been attained by developing an automatic mechanism for the operation of the unit and by adopting a link type cylinder retaining mechanism developed independently by the company, (ii) devices and experience gained by the company as a powder metallurgical manufacturer have been used to granulate powder, increase the fluidity of the powder, select the binder and parting agent, and design the mold and molding machine, because parts must be molded with high density and accuracy, (iii) a press has been modified for use. The press has long been used by the company for the purpose of synthesizing diamond powder.

The unit developed by the company can stably generate a pressure of 70,000 normal atmospheres and a temperature of 1,600°C. The pressure at normal temperatures is measured with a pressure sensor (the crystalline structure is changed by pressure, and the electrical resistance changes discontinuously), such as bismuth, thallium, barium, etc., and that at high temperatures is checked by synthesizing diamond, etc. The temperature is measured directly by inserting a thermocouple into the unit. But when the unit is operated normally, it will be controlled with hydraulic pressure and electric power due to the correlation between pressure and temperature, the pressure generation and temperature change depending on the composition of parts or test pieces. The pressure generation efficiency is in tens of per cent, with the remaining pressure being used to compress the gasket and high-pressure vessel and works to deal the ultrahigh pressure generated in the test piece section. The pressure generation efficiency is decided with consideration given to the stress distribution of the entire unit.

3. Development of sintering technology

3.1 Principle of sintering of diamond

From the thermodynamic standpoint, diamond exists unstably under a pressure of less than about 16,000 normal atmospheres, even at normal temperatures. Actually, it seems that diamond exists stably, because it exists metastably, but when the temperature rises, the diamond will be transformed into graphite which exists stably by nature. (The transformation of diamond into graphite will start at a temperature of about 1,500°C in a vacuum, 1/ and will start at about 600 or 700°C in an oxidizing atmosphere 2/ in the presence of ferrous metal, 3/ etc. Diamond will burn at a temperature of more than 650°C in the atmosphere. But in the case of diamond powder, the combustion temperature depends on particle size.) For these reasons, it is necessary to sinter diamond within an area in which it is not transformed into graphite. It is difficult to cause the diffusion of atoms and the plastic fluidity in diamond, because diamond has high hardness, and is a covalent bond crystal with a high melting point. It is said that, for example, a pressure of 85,000 normal atmospheres and a temperature of about 2 200°C are required to sinter diamond without any use of a sintering assistant. 4/ These conditions are not economical at the present technical level, because they take a great deal of money. Accordingly, a ferrous metal (alloy) solvent is used as a sintering assistant in the same manner as in the synthesis of diamond according to a solvent-catalyst method. When diamond is synthesized, graphite will melt into solvent metal at ultra high pressure and high temperature, and will be crystallized as a diamond. When diamond is sintered, the surface of diamond particles or a part of these particles will be melted into solvent metal, and will be crystallized as a diamond. At this time, diamond particles will combine with each other. It is said that the driving force of reactions caused by synthesizing diamond can be expressed as a solubility difference based on the difference between the chemical potential of graphite and that of diamond. It is considered that the driving force of reactions caused by sintering diamond can be expressed as a solubility difference based on the difference of the curvature radius of the surface among diamond particles. It is possible to sinter diamond to which graphite has been added, but it is very difficult to obtain useful polycrystalline diamond by simultaneously synthesizing only graphite. The diamond synthesizable area is a section between a graphite-diamond equilibrium line and a solvent (nickel)-graphite eutectic line. According to this figure, the lower limit conditions of synthesis are a pressure of about 52,000 normal atmospheres and a temperature of 1,400°C. The case of cobalt being used as a solvent is almost the same as that above. Conditions in the sintering case are slightly more severe than those in the synthesizing case. The sinterable area is slightly smaller than the synthesizable one. The appropriate sinterable area is further narrower than the sinterable one. When cobalt is used as a solvent, a pressure of about 60,000 normal atmospheres and a temperature of more than 1,500°C are required as lower limit conditions of synthesis.

Diamond sintering is very similar to that of hard metals (WC-Co) in that it involves liquid phase sintering according to melting and crystallization. The difference between it and that of hard metal is that the strength is increased by combining diamond particles with each other. In the case of hard metal, the wettability between WC and Co is good. Co satisfactorily circulates around WC and functions as a binder, and the strength increases. But in the case of diamond, diamond particles are combined with each other because the wettability with Co is bad. After sintering Co, it remains in the shape of a pool in a part of the grain boundary of the diamond particles. This is not a binder, but an inclusion phase. [Note: It seems that the diamond sintered compact in which diamond particles are combined with each other is internationally called "PCD (polycrystalline diamond)", and is distinguished from the sintered diamond in which diamond particles are combined with each other. In addition, this sintered diamond is combined with metal, cermet, ceramics, etc. Natural polycrystalline diamond exists in the world, but its output is very small. Single crystal diamond has the cleavage along the octahedral plane (111 plane), but polycrystalline diamond has no cleavage and is resistant to impact, because it has random crystal direction. Also, it has no directional properties in hardness and wear resistance.] Co is indispensable during sintering, but afterward it will remain in a part of the grain boundary, will lower the heat resistance of sintered compacts due to the difference of the thermal coefficient of expansion between diamond and it, and will reversely promote the transformation of diamond into graphite as well as reducing the area in which diamond particles are combined with each other, and will prevent the strength from increasing. In addition, it will cause a decrease in wear resistance due to reactions with materials to be machined. Therefore, in order to cut the high silicon aluminium alloy, new ceramics, etc., it is necessary to minimize the amount of this residual Co.

3.2 Sintering technology

The development of ultrahigh pressure units is the most important factor because, generally speaking, the completion degree of ultrahigh pressure technologies is not high. But even if there is a unit which can be used to obtain necessary pressure and temperature, of course,

polycrystalline diamond will not be obtained only by using this unit. The basic method of manufacturing polycrystalline diamond is to pack the diamond powder, solvent metal, hard metal trapezoid metal, etc., in metallic capsules with high melting point and to sinter these capsules in the test piece room of the high pressure vessel. (The hard trapezoid metal is integratedly sintered in order to simplify the brazing work during tool manufacturing.) Also, there are factors in the method of using solvent, method of packing such materials, consideration to residual gas, etc. The technology developed independently by this company has been used as its basic sintering technology. The heater and test piece room are deformed under ultrahigh pressure and high temperatures. In addition, cracks may get mixed with sintered compacts, because the ultrahigh pressure and high temperature rapidly return to normal pressure and temperature. Therefore, it is necessary to take measures against these problems. In order to do so, generally speaking, it is important to solve the following problems involving hydrostatic pressure. The problems are
(i) structure of the high pressure vessel,
(ii) structure of the test piece room, (iii) method of packing materials in the test piece room,
(iv) method of raising the temperature and pressure, and (v) method of lowering the temperature and pressure.

Other problems were caused by expanding the diameter of sintered compacts and multi-layering these sintered compacts. Therefore, these problems had to be solved. First, the previously mentioned unit is unsatisfactory as a productive sintering unit, because it is basically designed to synthesize diamond. Accordingly, it was necessary to make technical improvements in this unit. That is, the structure of the heater and that of the test piece room had to be modified to enhance the soakability in the heater, because conditions for sintering diamond are more demanding that those for synthesizing it. As a result, it has become possible to actually multi-layer and sinter diamond. Also, it was necessary to study a new the methods of selecting heater materials, packing test pieces, increasing and decreasing the temperature and pressure, etc., because the following problems are liable to occur. The problems are (i) electric current trouble caused by damage of the heater, (ii) leakage of pressure medium caused by damage of capsules, (iii) deformation of test pieces, (iv) ingress of cracks in sintered compact.

It has become possible to manufacture a high purity polycrystalline diamond by selecting diamond powder as a raw material and devising sintering conditions, etc., as well as using the above-mentioned sintering technologies.

4. Development of working technology

In order to offer polycrystalline diamond extracted from a sintering unit as a tool manufacturing material to users, the surface of this diamond must be polished, because the diamond is put in a metallic capsule or is deformed. However, the diamond is so hard that its surface cannot be polished with the usual diamond-bonded grinding wheel. The higher the purity of the diamond, the more difficult it is to polish the surface. As a result of studying various matters, it has become possible to efficiently work such diamond by using a special-purpose machine. Also, in order to offer such diamond as a tool manufacturing material to users, the diamond must be broken finely into an optional shape. But it was difficult to (wire cut) the high purity diamond, because such diamond has little electrical conduction. When this diamond is cut with laser beams, areas damaged by the laser beams will be considerable. In order to solve this problem, research on a wire-cut using technology was conducted. As a result, it has become possible to electric-discharge-machine such diamond. However, there is room for further improvement in working technology. The working technology will become significant in reducing the cost of polycrystalline diamond in the future.

5. High purity polycrystalline diamond and cutting performance

The high purity polycrystalline diamond has a structure in which coarse and fine particles are mixed. The amount of Co remaining in the grain boundary is small. In can be understood that diamond particles are combined. The Knoop hardness is more than 8,000 kilograms per square millimeter, which is close to the hardness of penetrators made of diamond. Therefore, it is difficult to measure precisely such a high Knoop hardness.

The amount of wear is about half that of conventional products. Materials to be machined are attached to the Co phase of the grain boundary of polycrystalline diamond, and the attachment degree of Si is more pronounced than that of Al. It is difficult to grind the high silicon-aluminium alloy, presumably for the following reasons: (i) primary phase Si particles coarsely dispersing in this alloy are hard and abrasive, (ii) the wear is promoted by the pressure-connection, separation, and damage caused by chemical reactions between Si and Co. Therefore, it can be said that the high purity polycrystalline diamond with a small amount of residual Co is advantageous from the above standpoint.

Diamond tools have heavy chemical wear (diffusion wear) against iron-based materials. For this reason, usually sintered compact tools are not used to work such materials. But, depending on conditions, these sintered compact tools are effective for working cast iron, because the amount of carbon contained in cast iron is large and reactions are restrained. High purity polycrystalline diamond is also promising for this use.

Features of this product (high purity polycrystalline diamond) developed by the company are as follows: (i) it has high purity, high hardness, and high wear resistance, (ii) it can be used to work 20 per cent Si-Al alloy, ceramics, etc., with high efficiency and (iii) it can be used in tools with a long cutting edge, because it has a large diameter. (Source: Tokyo KINO ZAIRYO, February 1987, pp. 5-152)

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5. R&D TRENDS IN DIAMOND TOOLS

Demand for diamond tools has recently been increasing very significantly, because productivity and processing accuracy have been pursued in processing technology fields; therefore diamond tools have been finding wider applications. In addition, increasingly active development of new material has required processing of hard-to-cut materials, which has further expanded the application fields of diamond tools.

Major diamond tools are cutting tools and grinding stones, and wider use of these tools has required the development of tooling technology.

Up to the present, attention has been directed primarily toward technological development of processing machines but not much toward tooling technology. This tendency is ascribed to the fact that the ratio of tool cost to overall processing cost is small and a traditional opinion that conventional tools are good enough for cutting jobs.

On the other hand, more efficient and accurate processing has recently been sought and widespread use of hard-to-cut materials such as fine ceramics has been significant. Consequently tooling technology has come to attract general attention.

Iron and steel materials for sliding components of processing machines are not accepted until differences in characteristics of carbon steel, hardening steel, cast steel, and others have been fully identified. Many kinds of diamonds are used in diamond tools, and although there are appreciable differences in their characteristics, there has been a tendency to use them without a full understanding of those differences.

Becoming fully familiar with the characteristics of diamond tools is essential for the development of tools.

More than 90 per cent of the diamonds used for diamond tools are synthesized with the static high pressure method using solvent; their characteristics differ widely depending on synthesizing conditions. This means that diamonds that have desirable characteristics for tools can be manufactured.

In addition, diamond synthesis based on vapor-phase growth and under low pressure has recently been made possible; tools using this type of diamond have been announced, indicating the application of those tools to machine processing is nearing. In the following, diamond tools will be described while the manufacturing method and characteristics of diamonds will be briefly mentioned.

Diamond cutting tools

Cutting tools consist of single-crystal tools for ultra-precision and sintered tools for long wear.

Mirror cutting using a single-crystal cutting tool, which has long been used for processing watch parts, has recently advanced significantly enough to set up a new field, the ultra-precision cutting process. This ultra-precision cutting process is targeted at a size accuracy of 0.2 micron meter/150 millimeter and surface coarseness of 0.02 micron meter. Although size accuracy mainly depends on processing machines, surface coarseness relies on tools and is greatly affected by the performance of single-crystal cutting tools.

Single-crystal diamonds are used for ultra-precision cutting tools, because they have characteristics such as: the blade edges can be processed into sharp shapes because of high atom density of diamond and high rigidity; long wear is possible because extreme hardness produces little wear; ability to etch the blade edge shaped marks into a workpiece because hardness and high rigidity permit minute cutting-in; little chance of producing a constitutional blade edge because of chemical stability. They recently have been used for processing magnetic disk and laser reflection mirrors, contributing to high-precision processing of parts.

For these processing purposes, cutting tools with slightly arced scooping area (or part) and flat-surfaced sliding area are used.

The current grinding technology can provide only a limited reduction in edge tip radius. Our experience in the manufacture of conic diamond indicates a minimum possible tip radius is 0.9 micrometer for a conic angle of 80° and 0.7 micrometer for 120°degree conic angle.

Wear on diamond depends greatly on the quality of rough diamond stone and angles and dimensions formed in process of crystallization. Rough stone is formed with hexahedron, octahedron, or dodecahedron, or a combination of them; nitrogen is the main impurity, and has defects and distortion.

Rough stone of dodecahedron crystal dimensions which requires less cutting allowance is mostly used for cutting tools for economic reasons, but hexahedron and octahedron versions are not usually used. Therefore, a crystal surface on a cutting tool is automatically selected, and there is not much chance that a crystal surface with good wear resistance will serve as a sliding or scooping surface. In addition, crystallized angle is not yet considered as an acceptable means of selection.

Wear on a single-crystal diamond cutting tool generally is heaviest on a front sliding surface, smaller on a side sliding surface, and smallest on a scooping surface. It is necessary to study which crystal surface is to be used for which tool surface.

Expansion of application range of sintered diamond expected wear resistance improved

There is a considerable variation in the quality of rough diamond to be used for a cutting tool. Our wear experiment with diamond shows different coarse diamonds present different amounts of wear. In general, the more nitrogen contained in the diamond, the less wear resistance it has, and its wear resistance also depends on the presence of defects and distortion.

Recently, a new technology has been established whereby a seed crystal diamond is allowed to grow to synthesize a single-crystal of 1 carat using solvent metal at high temperature and under high pressure. Although the wear resistance of this crystal is similar to that of natural diamond that contains much nitrogen, it has a good homogeneity. Therefore a good cutting tool can be made if a wear-resisting crystal surface is formed on the cutting tool.

It has been more than 10 years since a sintered diamond-based cutting tool was manufactured. At present it is used for high-performance and high-precision processing of non-iron metal such as aluminium alloy and copper alloy, and FRM, FRP, and carbon supported by such non-iron metals. Its application is expected to expand in the near future. The reason is that sintered diamond is a sintered polycrystal, has no anisotropy generally found in single-crystal diamond, is difficult to cleave, and has larger thermal diffusivity than ultra-hard metal providing an ability to decrease cutting heat.

Sintered diamond is made of sintering diamond powder and solvent material sintered at the same degree of high temperature and high pressure as for diamond synthesizing, this type of sintering being different from solid-phase sintering performed in conventional powder metallurgy. The current technology cannot completely remove this solvent material after sintering, and reduction level of the solvent material remaining in diamond grain greatly affects the performance of a sintered diamond cutting tool.

Generally, the less solvent matter a cutting tool contains, the sharper blade edge and better wear resistance it has. With the method of processing the surface of the sintered diamond, a vapour-phase growth method to cover solvent material with diamond, indicating that the entire surace is covered with diamond, with a cutting tool of polycrystal diamond without solvent matter on its surface can be made.

Nevertheless, since even sintered diamond has not enough wear resistance to withstand non-iron metal material processing, it finds its application merely in the processing of comparatively soft temporarily-baked ceramics and ceramic-group bricks. However, the wear resistance can be improved significantly if the cutting tool shape is improved.

The observation of chip generating mechanism shows that a cutting tool with a minus scooping angle is good for cutting, and cutting of an aluminium sinter substance was attempted with that cutting tool. The application field of sintered diamond cutting tools will expand in future.

Ceramic plating on diamond grains, CVD method

A good diamond grinding stone is such that cohesion between the diamond grain and the bond should be strong, but the cohesion is not generally strong. Strengthening this cohesion is a secret of manufacturing a good diamond grinding stone; therefore, an Ni-P metal coating is used. This coating technique, diverted from a non-electrolytic wet type plating used for plastics, has been in practice for some 20 years. Another technique was that ceramic plating was applied to a diamond grain with the CVD method, and the suitability of this grinding particle for a diamond grinding stone was ascertained.

Diamond grindstones are classified, according to bond used, as resinoid bond, sintered metal bond, vitrified bond, and electrodeposition metal bond grind-stone. A resinoid bond grinding stone mainly uses thermosetting phenol resin, and is moulded with a 170°C hot press after a packing agent has been added. This grinding stone is excellent in cutting ability but poor in wear resistance.

A metal bond grinding stone uses mainly copper-tin family metal powder, to which a packing agent is added, and is formed with hot pressing of about 700°C. Metal powder rich in tin is used for the grinding stone for the processing of hard-to-cut materials. A heavy-duty grinding stone uses metal powder of iron, cast iron, tungsten, and is excellent in wear resistance but poor in cutting ability.

A vitrified bond grinding stone uses vitreous bond; a filler is added to the bond, then is molded under pressure, and is heated in an inert gas environment. Hot pressing may be used for the molding.

The former grinding stone has pores, but the latter has none. Although various vitreous substances are available for the bonding purpose, those with low melting points and high intensity are used to prevent heat deterioration as a result of the oxidation and graphitization of diamond during heating. This type of grinding stone is, in cutting ability and wear resistance, between a resinoid bond and metal bond grinding stones, but superior to them in rigidity.

Vapour-phase synthesized diamond for near future tools

Diamond can be synthesized at high temperature and under high pressure, because the presence of solvent substance deposits diamond out of carbon solution. In the same manner, diamond can be deposited out of vapour such as hydrocarbon. Research on this method has recently been very popular.

Three methods are available for synthesizing diamond as vapour phase methods: Chemical vapour phase growth method, wherein vapour such as hydrocarbon is heated and pyrolyzed on the base surface to deposit diamond. Plasma chemical vapour phase growth method, wherein high energy is given to electrons with microwave or high-frequency wave and positive ions are generated from hydrocarbon gas to deposit diamond. Ion beam evaporation method, wherein high-energy electrons in plasma are forced to impact against hydrocarbon in a high vacuum to generate hydrocarbon ions which are collided with each other in a low electric field. In addition, a method has been proposed for depositing diamond by adding various energies.

The selection of a substrate material that permits diamond to be deposited out of vapour is important; ultra-hard alloy and tungsten alloy are being studied in a tool application. An experiment was conducted to grow diamond on a sintered diamond surface. Vapour-phase methods can produce granulated diamonds of good shape.

Before diamond made by vapour-phase method can be used for tools, many problems must be solved such as suitability of substrate for diamond tools and finishing method of a diamond film surface. Nevertheless, this type of synthesizing method provides a comparatively simple synthesizing using a low-cost device. Therefore, it will be used for tools before long, depending on future research/development.

Diamonds will play a large role in the development of a processing technology. However, while high-precision and high-efficient processing machines for material processing have been drastically developed, diamond tools have been improved at a slower pace.

One of the reasons is that diamond, although the most high priced among materials, is seldom used effectively. It scarcely wears off with cutting or grinding processing, but in most cases is consumed through crushing, breaking, or during repair.

It is hoped that the diamond tooling technology will be developed while the mechanical and chemical properties of diamond are fully identified.
(Source: Tokyo NIKKAN KOGYO SHIMBUN,
5 February 1987, pp. 22 23)

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6. CARBIDES, CERAMICS AND LOTS MORE

Review of the International Machine Tool and Manufacturing Technology Exhibition, 13-21 April 1988, Birmingham, UK, organized by the Machine Tool Association, 62 Bayswater Rd., London W2 3PH.

Titanium nitride has many applications, including wear-resistant coatings on punching, forming and precision tools, diecast and injection moulds, and machine parts subject to heavy wear. Multi-Arc is one company offering the physical vapour deposition (PVD) of titanium nitride (TiN), and says the process can cater for most metals, including non-ferrous. The thickness of the coating is normally three to five microns.

In the case of Balzers' Baltride TiN coating, deposition takes place below 500°C making the process, which is also based on PVD, suitable for high-speed steels, hot-work tool steels and certain cold-work tool steels.

TiN is, of course, finding increasing favour with drill and cutter manufacturers such as Presto, which will introduce at MACH 88 TiN-coated M42 cobalt high-speed steel SM200 drills in standard and long series dimensions. And jobbers in M2 high speed steel are an addition to the company's portfolio of TiN-coated products. But Presto will also unveil a new carbide tool range which includes two-flute drills from five to 16 mm diameter (26 sizes) and three-flute drills from three to 16 mm diameter (35 sizes). This range is produced to BS 328/DIN 1897 with tangs to DIN 1809.

SKF & Dormer Tools will extend the size range of its exclusive ADX drill which, because of its unusual lip geometry, enables the TiN-coated high speed drill "to compete favourably with carbide drills on both penetration and cost". And to prove the point, SKF & Dormer Tools will demonstrate the ADX drill, now available in sizes up to 20 mm diameter, on a machining centre, along with TiN-coated fluteless taps and DHD drills.

But for all its advantages, a titanium coating will not make a bad design good. And that is the premise on which International Twist Drill has refined the basic design of its XT series before introducing the XT36 titanium-coated version with a 135° notch-thinned point. This drill is said to give excellent results in stainless steels, and acid- and heat-resisting austenitic steels, and to have limited suitability for special alloys such as Inconel, Hastelloy and Nimonic.

TiN has also been adopted by Arthur Klink of the Federal Republic of Germany (UK agent Umak) for its broaches, resulting in up to eight times the life of conventional broaches. Klink claims to be the only European broach manufacturer with its own titanium nitriding plant, which is capable of handling broaches three metres long.

Clarkson, too, has adopted TiN coating as a standard option on most of its new cutting tools, but the company also claims that its Crest-Kut end mills have been re-writing the speed and feed tables for HSS tools. According to Clarkson, these end mills have even competed successfully with carbide tools on tough metals such as titanium, providing the equivalent metal removal capability at a much lower cost. And to complement Crest-Kut, particularly for heat-resistant metals, Clarkson has developed its Super HSS end mill range. Made from ASP 30 and with a 40° helix angle, the cutters are said to be capable of producing a high quality finish. For really hard and abrasive materials Clarkson does, however, offer a comprehensive range of solid carbide cutters in two, three- and four-flute forms and with ballnosed versions as standard.

Although the British hard metals industry does not contain a single company of world rating, Nuloy has established itself as a leading UK manufacturer of tungsten carbide "specials". Production divides broadly into three areas: standard and special inserts, toolholders and milling cutters; rod and strip for toolmakers; and hard metal wear parts. And the latest investment has been in a £1/4 million grinding cell comprising a Wendt WAM 300/35 CNC three-axis peripheral grinder, the latest Blanchard top and bottom grinder, and special machines for primary land and edge conditioning. Following this installation, Nuloy reckons it can fulfill virtually any order for special carbide inserts, to BS 5750 quality standards, within three weeks.

Over 20 separate and distinct geometries and styles of Fetoga solid carbide cutters are now available from Fenn Tool & Gauge in the size range from 0.2 to 25 mm diameter. And the company will use MACH to promote a specially-developed grade of micro-gain carbide which gives a transverse rupture strength 75 per cent better than "traditional" carbides. Fenn will also show the Kestag range of heavy-duty cobalt steel milling cutters for use on exotic materials such as titanium-nimonic and Inconel. The cutters can be supplied ex-stock in diameters from 50 to 200 mm and in two geometries.

Plansee Tooling specializes in cemented carbide tooling, with a comprehensive selection covering most applications. New for MACH will be the uncoated S40T, an ultra-heavy duty grade intended for applications involving interrupted and varying depths of cut, forged and cast workpieces with skin or inclusion problems and impacting entry cuts. This will be joined by the multi-layer Sr.127, a multi-application steel cutting grade covering the P10-P40 and K10-K30 application areas. Three sub-micron grades (TSM) will also be launched - aimed at applications on, for example, super alloys and abrasive materials.

A revolutionary design of end mill which effectively doubles stock removal rates in materials ranging from mild steel to titanium and aluminium alloys, will be the major attraction on the stand of Ingersoll GmbH. Called the Multi-Effective end mill, the cutter will be available in a range of sizes and is being promoted as "one of the most significant tooling developments since inserted carbide cutters were invented".

Four new products for parting-off and grooving applications will be offered by Mircona, with practical demonstrations on 316 grade stainless steel taking place on a Traub CNC mill-turning centre. Among the new offerings is a line of toolholders and carbide inserts for face grooving down to a diameter of 14 mm. This eliminates the need to use HSS or brazed products for "small diameter" external or internal radial grooving.

Mitsubishi's SG20 milling cutters and SR turning tools feature carbide or carbon-nitride circular inserts with unusually high rake angles. UK agent Kingston Cutting Tools says the SG20 milling cutters are offered in six sizes, with diameters from 101 to 271 mm and from four to 12 inserts rigidly located by novel clamping wedges. Of .0 mm diameter and 4.76 mm thick, the flat-faced inserts have 30° clearance angles and 24° effective cutting rake. Stocked grades are HTi10, HTi20T, UTi20T and NX55, the latter being a high performance, carbon-nitride cermet with super alloy binder. Made in variants for side and end cutting, the SR turning tool takes inserts similar to those used in the SG20 mill but with rigid centre hold clamping and moulded-in chip-breakers. Typical cutting speeds are 105 m/min for stainless steel, 50 m/min for titanium alloy and 15 m/min for hardened steel.

Cermets also figure on the stand of Sumitomo Electric Hardmetal, with two new nitrogen-enriched cermet (solid TiC) grades - T110A and T130A. Demonstrations planned include intermittent cutting of hardened steels with the toughest yet Sumiboron CBN cutting grade BN300; drilling with the new Multi-Drill series (MG for grey and nodular/SG cast iron and aluminium, and ME for hardened steels above 40 R_c, titanium alloys, Inconel and stainless steels); and milling with new types of solid carbide end mills.

An alternative cutting material for hard materials in Feldmuehle's new Wurbon (WBN), which consists of a special hexagonal crystal structure of boron nitride made by explosive forming. Particularly good results are said to have been obtained in cutting off hardened rim zones and in turning hard materials with interrupted cuts. Feldmuehle also has a new nitride ceramic grade SL200, intended for rough turning and round milling of grey cast iron.

In addition to a wide range of tooling for machining centres, CNC lathes and sequence-controlled automatic lathes, PCM Tooling will show the Zurn EG400 pre-setting unit which has a basic capacity of 200 mm on diameter and 320 mm on length. Stretched versions are available and, being of moduler construction, it is possible to match non-standard requirements such as gang type tooling.

A more sophisticated offering is DeVlieg's Microset EGW 3050 horizontal pre-setter equipped with a new, state-of-the-art DPC control. This will interface with a wide range of peripherals such as tape punches, DNC links and microchip tool ID tags. Tool data are stored under identification numbers with up to 20 digits of which five can include pre-defined alpha characters.

The complex geometry incorporated in modern tooling tools must be maintained if optimum performance is to result. And that is where the latest optical measuring unit manufactured by Strasmann (UK agent Euro-Tools) has its place. Basically, it allows the measurement of cutting and clearance angles on various types of tooling, including milling cutters, reamers, countersinks and taps. It can also measure spiral and start angles, tapers, thread pitch, concentricity and the curvature on ballnosed or radiused cutters.

In a bid, it says, to increase machine tool utilization (and reduce inventories) Sandvik will display its TOMAS computerized tool control system. This is designed to run on IBM 43XX hardware and System 36, and caters for all aspects of tool management including issues and returns, item level control, bits and assemblies, and management information. And the Swedish company has also come up with TRIM - a pocket-sized computer which allows the busy production engineer to access information such as cutting tool choice for turning, milling and drilling along with support data such as feed and speed for each tool use. TRIM (Tool Rationalization in Manufacturing) has separate programs for each operation type, and a specially-developed program for the user to establish actual tool costs, economical tool order points and optimal stock levels. There is also an economy program to provide details such as machining cost per component and tool pay-off time calculations.

Modular tooling systems, which aim to make the best use of today's wide choice of standard and insert-type tooling, will be well represented at MACH 88. A new name is a British company called Contract Toolholders, which has come up with a solution to the familiar centre drill, drill, tap, chamfer sequence. The company's Easychange allows tool changes to be executed by hand without key or spanner. Easily fitted to the existing drawbar, Easychange can be left in place and used for most milling and drilling tasks.

Another example is Kennametal, Erickson's new KM modular machining centre tooling line, which comprises rotating tool adaptors in various standard and proprietary configurations. These have been designed with a compact, rigid, quick-change joint to accommodate rotating toolholders and boring tools. KM modular tooling (which can also be used on any lathe equipped with the KM tooling system) is locked/unlocked with a T-wrench, with the patented Ball Track clamping mechanism contributing to a repeatability of ±0.0025 mm in both radial and axial directions.

A third example is Valenite's system which features a "floating wedge" design to permit fast and easy assembly of a wide range of tool lengths plus reducers, adapters, rough and finishing boring heads, drills, milling cutters and many other types of tooling.

Modular tooling is being promoted by Krupp as part of its "total tooling technology" concept. This is based on Widax "conventional" tooling and Widaflex, a modular tooling system for both turning and prismatic applications. Widaflex is said to combine the best features of the existing Multiflex (turning) and Rotaflex (milling/drilling) modular systems, making it widely applicable to concepts such as FMS or CIM. The major innovation is in the design of the new tool head coupling in which a 5° 43' taper is combined with face contact on the holder and a mechanically-actuated ball bearing locking system. The resultant cutting edge positional repeatability is said to be within 2.5 microns.

Completing the tool management chain is Widatronic ICS, a tool-mounted read/write identification system that can be integrated into any piece of tooling. Typically, a read/write facility is situated on or adjacent to a tool presetter, allowing the tool-set information to be written into memory. A read/write head on the machine tool then scans the chip for identification and offset information upon installation in the turret or tool magazine. This is passed to the machine control via a converter unit and the Widatronic ICS data manager. If the insert wears during machining and an offset adjustment has to be made, then the chip information is rewritten after the tool has completed the cycle.

Keeping track of expensive tooling is also the function of a range of read/write and read-only tool identification systems available from Multiswitch. On show at MACH 88 will be the entire range - from miniature, read-only code tags able to carry 16 bits of information for simple tool identification applications, to a two kbyte read/write tag for more complex installations, such as the storage of instructions for the machining of a part on a pallet.

Euchner also offers an inductive read/write coding system for the detection of tools, toolholders or pallets without physical contact. The system comprises three component parts: a miniature data carrier set in a stainless steel waterproof housing, with oxide-ceramic protection of the sensing face to guard against hot chips; a read/write head with transmitter and receiver coil for inductive transmission of energy and data; and a processor unit for communication between the data carrier, read/write head and master control. Data transmission to the master control is by means of a 20 mA current loop or serial interface.

On the toolholding front, Dicksons will unveil its Auto Indexing Carousel, the first of a proposed range of CNC dedicated tool posts, while Eppinger's (UK agent DMC Machine Tools) new VDI holders from 20 to 60 mm diameter will include a range of power driven tooling that is intended as an "off-the-shelf" package for all the major NC lathe producers.

Block-type tooling made by the Davis Tool Company of the US will be shown by its UK agent Forth Tool & Valve on a stand shared with Giddings & Lewis. The company will also launch its new CH-8 contouring head for use on four, five or six indispindle horizontal boring machines and machining centres. With a maximum bore/face diameter of 381 mm, the contouring head has a slide length of 200 mm, head length of 303 mm, spindle travel of 76 mm and a maximum speed of 800 rev/min.

Also on show

VDI tooling from the PCM and Zurn ranges will be fitted to many of the CNC lathes in action at MACH 88, as well as being featured on the PCM Tooling stand. Specialized spindle tooling includes the Zurn Mickro-Klick and Flexi-Compact ranges of quick-change and modular systems for standard and CNC milling applications, while the Unidorn modular system made by Dornag is a more sophisticated alternative for use in manufacturing cells and automatic tool management systems.

The Swedish Machine Group will show for the first time in the UK the automatic block tool changer (BTS) on a Swedturn 6 CNC lathe equipped with automatic parts changer. The BTS system is mounted on the back of the automatic handling system, eliminating the expense of additional robot and control equipment.

Sandvik has extended its range of long edge milling cutters with the type R215.45, which is available in sizes from 32 to 40 mm diameter. The range now extends from 32 to 88 mm diameter in four styles - including Varilock, Weldon and Morese taper. Also new from Sandvik is the Q series of turning tool insert with three chipbreaking geometries; the T-Max Q-Cut parting-off and grooving tools based on a new form of insert clamping; and the GC425 grade of cemented carbide with application areas from P15 to P35 (light and medium roughing of steel stock and steel castings at high cutting speeds and moderate feeds).

A new low-cost automatic toolchanger for turning machines will be shown for the first time on a Churchill FOUR Series four-axis lathe. Both passive and live tooling, which will be based on the new Kennametal KM system, will be changed automatically. A tool datuming probe mounted on the headstock will provide automatic tool setting on the machine, which will also be fitted with a turret-mounted probe for in-process gauging of the workpiece, and full control of spindle positioning.

The cutting tool division of Hahn & Kolb will display an extended range of precision equipment associated with the machining of bores to close tolerances.

Bristol Tool & Gauge recently received orders worth over £80,000 for the large Veridex 200 and smaller 150 electronic indexers for both fourth and fifth-axis use, including special twin-table fifth-axis units. (Source: Machinery and production engineering, 23 March 1988)

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7. CURRENT AWARENESS

Carbides

Carbide combination tools drill and ream at one pass

Centre drilling, drilling and reaming can be carried out in succession with the new OMI carbide V drill-reamer for producing high-accuracy holes with one-hit machining.

It is stated that holes can be held to H7 accuracy for diameter, 3S standard of surface finish, and to a better straightness accuracy than can be obtained with twist drills.

Accuracies can be maintained for cross-drilled holes, starting a hole on an inclined work surface and for enlarging low-accuracy pre-drilled holes.

Tool geometry includes a 120° point angle, and a 2 to 30 mm long drill portion which produces a hole 30 microns smaller than the required diameter.

The remainder of the flute length is used for reaming with skiving cuts, and includes "button" lands which ensure a good surface finish.

Swarf is evacuated from the drilling area along wide (85°) flutes, and there are smaller flutes to carry coolant to the cutting edges.

OMI drill-reamers are marketed by Berkswell (UK) in standard and long series with diameters from 3 to 13 mm in 0.1 mm increments, and from 13 to 30 mm in 1 mm steps. (Source: Machinery and Production Engineering, 6 May 1988)

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Carbide inserts made in new grades

Indexable cutting inserts are made in aluminium-oxide-coated and cermet grades for rough and finish milling at speeds up to 1,600 sfm. They include grades with multilayer aluminium-oxide coating for high-speed finishing, with thick triphase aluminium-oxide coating for high-speed finishing, with multiphase aluminium-oxide coating for light roughing, as well as cermet materials in several grades. These cutting materials, from Sumitomo Electric Carbide are in an AC Series and a T Series (cermets). (Source: American Machinist, September 1988)

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Slab mill tips at constant helix

Niagara Cutter Inc. (North Tonawanda, N.Y., USA) has introduced a line of carbide-tip slab mills with tips formed to a constant helix angle. The true spiral design of the carbide tips allows the chip load to be distributed over the full length of the cutting edge to help create free-cutting action.

This design can also diminish chatter and reduce the chances of chipping the carbide tips.

Replaceable carbide tips formed to fit the tip pocket can be purchased. The mills are available in a variety of diameter and face widths and can be ordered with the company's special TiN coating for longer life, finer finishes and increased feeds and speeds. (Source: American Machinist, August 1988)

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Ceramics

Cotronics Corp.'s Rescor Series machinable ceramics enable machining of detailed close tolerance components on conventional shop equipment with standard cutting tools, drills, or taps. Available in a variety of rods and plates, the ceramics offer corrosion resistance, thermal shock resistance, and are usable to 1649°C in oxidizing, reducing, or vacuum atmospheres.

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Whisker reinforced ceramic inserts

An aluminium oxide/silicon carbide fibre (whisker) cutting tool material, designated CC670, is offered by Sandvik Coromant Co., Fair Lawn, N.J., USA. Developed for turning and boring nickel-based alloys at high speeds, the material exhibits greater tool life than conventional tungsten carbide inserts.

The idea of silicon carbide fibre reinforcing ceramic cutting tools is a relatively new approach for the metalcutting industry. The distribution of the silicon carbide fibres in the alumina powder is much like fibreglass matting and glass resin; the result is a strong, durable cutting tool material. (Source: Advanced Materials and Processes, July 1987)

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RS-HIP yields heat-resistant ceramics

Rapid solidification (RS) is often used to make metal powders, but Battelle Columbus researchers have found a way to make solidified ceramic powders. When hot isostatically pressed (HIPed), they form ceramics that are tougher and more temperature-resistant than transformation-toughened (usually by zirconia) ceramics.

HIPing is an expensive way to go, but in combination with RS, it provides some real advantages. Foremost, the resulting ceramics resist heat fractures to 1,400°C to 1,500°C. They also withstand rapid thermal cycling. HIP also produces near-net-shape monolithic ceramic parts that need little or no machining, so there is less labour and fewer flaws.

Ceramics made by RS-HIP are naturals to compete with zirconia in diesel, turbine, and internal combustion engines. They could also be used for wear applications, such as bearings and cutting tools. Battelle is now putting together a two-year research programme to commercialize the process. (Source: High-Tech Material Alert, February 1987)

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Silicon nitride powders from Ferro in advanced ceramic applications

Ferro Corp. (Cleveland, Ohio, USA) has introduced a line of silicon nitride powders for advanced ceramic applications.

The materials are said to have good lot-to-lot uniformity and can be shaped by several methods including pressing, casting, extrusion and injection moulding. They can be pressureless sintered, hot pressed, hot isostatic pressed (HIP), or sinter-hot isostatic pressed.

Typical applications for the ASN-series powders include cutting tool inserts, turbocharger rotors, pump seals, valves and extrusion dies. Conditions requiring high-temperature performance, corrosion, wear, or thermal shock-resistance, or superior hardness are particularly suitable. (Source: Manufacturing Chemist, May 1988)

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Ceramic engineering material

A ceramic engineering material, known as AmAlox 68, offers extreme wear resistance and mechanical stability to near 3,000°F (1,649°C). Available from Astro Met Associates Inc., Cincinnati, Ohio, USA, the material also features high resistance to corrosion and oxidation. It has Rockwell A hardness of 91.5 and compressive strength of 450,000 psi (3,103 MPa). In addition, part tolerance can be held to 0.0001 in. (0.00254 mm).

AmAlox 68 is recommended for use in such custom ceramic parts as wear plates for industrial equipment, sandblast nozzles, cutting tool inserts, acid pump seals and bushings, broachable glue nozzles, spray nozzles, critical electrochemical machining fixtures, and extrusion dies. (Source: Advanced Materials and Processes, June 1986)

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Koreans improve silicon nitride cutting tools: Silicon nitride-based cutting tools containing titanium carbide exhibit excellent cutting properties but they do have disadvantages. Chief among them is their relatively poor sinterability owing to formation of nitrogen gas (N_2) during the process. When the gas is released a number of fine pores are apt to form in the material.

Korean researchers have what appears to be a simple solution to these and related problems. They use titanium nitride as an enhancing agent for toughness instead of titanium carbide. Quite simply, they coat fine particles of titanium carbide with a thin titanium nitride film and add the material to silicon nitride. Thus the titanium carbide coated with titanium nitride film acts like titanium nitride during sintering. In essence, this means the titanium carbide can be dispersed into the silicon nitride without the production of N_2 and/or by-products. Results is a silicon nitride tool-bit material that is more easily sintered and which delivers higher performance. (Korea Advanced Institute of Science and Technology, P.O. Box 131, Dong Dae Mun, Korea). (Source: INSIDE R & D, 4 March 1987)

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Many cutting tools and cutting tool material developments are taking place in the US. New developments in materials forming interest include announcements by major cutting tool producers of cutting inserts containing silicon carbide whisker-reinforced ceramic and ceramic composites. While ceramic composite cutting tool materials are claimed to replace coated and uncoated carbides and non-composite ceramics, the materials market is stable.

Technological breakthroughs in cutting tools involve their use as systems. The advent of the machining centre brought with it automatic tool storage and toolchangers requiring that tool holders be able to be held tightly in the spindles, be identified, and be of known size and length. To raise productivity, tool holding systems now simplify the numbers of required tools to lower tooling costs and increase rigidity and accuracy. Tooling sensors and probes are used to replace the need for presetting tools off-machine. Techniques to load and unload tools from spindles, remove workpieces from chucks and change the chuck's jaws are now common. Turning machine technology is becoming more oriented to machining cells and systems. The trend is to include rotary or live tooling in a turret to enable the turning machine to finish secondary operations, especially milling and cross drilling, in the same chucking. (Source: Iron Age, 01/00/87, p. 50)

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Superfine silicon carbide ceramics

Professor Koichi Niihara and his research group in the School of Physics, National Defense Academy, announced that they had succeeded for the first time in developing silicon carbide ceramic which is very strong and heat resistant and has mechanical workability exceeding that of metals, by sintering the ceramics powder and precursor mixture and performing "Nano-control" of its crystal grain boundary structure. The material, named "SF (superfine) silicon carbide", can be cut by a superhard tool without using oil or water, the depth of each cut being 2-3 mm and causing no cracks. This new material exhibits a bending strength of 445 mega pascals at the maximum application temperature of 1,500°C or above, and 400 mega pascals at room temperature when heat treatment is performed in the air. Along with the material's characteristic of being porous, SF silicon carbide could be used not only as a high-strength heat-resistant structural material, but also a functional material.

The technology developed by Professor Niihara has drawn attention both in Japan and overseas because the nano-control of the crystal grain boundary structure which can be applied not only to silicon carbide but also to silicon nitride, other carbide substances, and their compound materials to give such materials high strength, heat resistance and mechanical workability.

The SF silicon carbide developed this time is made by mixing silicon carbide powder 80 per cent with the precursor polysilane stylene and an auxiliary agent and sintering the mixture under normal pressure at approximately 1,600°C. Structurally, the material is made of super fine silicon carbide with nano-level crystal grain boundary and "its chemical bond is different from that of ordinary silicon carbide" (Professor Niihara).

Owing to such characteristics, the material exhibits an excellent mechanical workability for cutting, drilling, and so forth. Conventionally available ceramics with good machinability include crystallized glass (mica), boron nitride hexagonal crystals, and compound material of aluminium nitride and boron nitride, the maximum application temperature of all being on the order of 1,000°C.

SF silicon nitride, on the other hand, has a bending strength of 445 mega pascals at 1,500°C or above. In addition, this new material features (1) spray molding and extrusion molding (difficult for use with silicon carbide) can be employed, making it possible to mass-produce ceramic pieces in complex forms and with good machine workability; (2) the dimension accuracy after sintering is 3/1,000; and (3) a highly porous material containing about 30 per cent 0.1-0.2 m holes is very light in weight. (Source: Tokyo Nikkan Kogyo Shimbun, 17 February 1987

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Riken fibre-reinforced ceramics

Riken developed fibre-reinforced fine ceramics (FRC) by using alumina as the base material and adding to it silicon carbide whisker and zirconia. As a result of the research Riken has been engaged in with Tohoku University, a high standard of destruction toughness value, 8 MPa, and three-point bending strength, 1,600 MPa, were attained. The company is sample-shipping this new fibre aiming application toward superhard tools. Specific business talks are ongoing based on the company policy to make the fibre into products by the end of this year.

At present, tungsten carbide mixed with cobalt is mainly used for superhard tools. But cobalt has been regarded as a problem when used for superalloy cutting tips and tape cutters because of its low melting point and magnetic property; various improvement efforts are being made including one to lower the cobalt content by adding titanium carbide and tantalum carbide. The FRC developed by Riken this time is designed to replace such superhard tools.

FRC is prepared by adding alumina with 10 per cent zirconia (containing 2 per cent yttrium) and 20 per cent silicon carbide whisker, mixing and kneading them by the bowl mill method for about 48 hours, then sintering the material at 1,500°C. The process could achieve a high level of destruction toughness of 8 MPa and a three-point bending strength of 1,600 MPa.

In general, improvements in destruction toughness value is a subject to work on in ceramics. Known mechanisms for the improvement include: (1) crack-shielding; (2) crack deflection; (3) whisker drawing; (4) microcracking; and (5) crack bridge.

For instance, when alumina is changed into FRC using silicon carbide whisker, destruction toughness value improves from 3 to 6 MPa due to the crack deflection effect. Similarly, zirconia can improve the value from 3 to 7 MPa by adding about 3 per cent yttrium, magnesia, calcia, and silica oxide.

The FRC Riken developed this time is a hybrid of alumina/silicon carbide whisker compound and zirconia. The concept is called multitoughening. When this material is actually used for superalloy cutting tips, the tool could cut 150 m per minute while the conventional tips could only cut 80 mm per minute.

In light of the above, Riken has been sample-shipping new ceramics for targeted superhard tools such as tips, tape-cutters, drawing dies, drills, and punches. Currently, specific talks are ongoing based on the condition that the FRC is to be accepted by the purchasing companies, and Riken intends to commercialize the product by the end of this year. (Source: KAGAKA KOGYO NIPPO, 26 February 1987)

Diamonds

Polycrystalline diamonds cut plastics

The abrasive resistance of polycrystalline diamond is said by Lach Diamond (Grand Rapids, Mich., USA) to be 125 times that of Grade K-20 carbide, which is useful in machining highly abrasive plastic compositions. The cutting tools can produce chips in cutting these materials, instead of troublesome dust. Tools made include cutters, drills, and flash-trimmers. (Source: American Machinist and Automated Manufacturing, September 1988)

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The use of diamond abrasives to precision finish ceramic parts is examined by K. Subramanian of Norton's Superabrasives Division (Worcester, MA., USA). Complex form grinding of carbides, thin-film magnetic heads and thread forms in ceramic tools in output methods suggest that ceramics, when successfully finished with diamond abrasives, can meet extreme performance needs. Cost-effective techniques are expected to be unveiled for finish machining of ceramic parts using diamond abrasives, as they come out of their prototype stage to output volume. This will need active interaction between materials scientists, mechanical engineers and production technologists, and an entrepreneurial approach for early commercialization. (Source: Ceramic SB, June 1988)

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Machining with PCD tools

Polycrystalline-diamond cutting tools have been used cost-effectively for 15 years, predominantly by manufacturers working with production volumes of non-ferrous materials.

The primary limitation in the applicability of PCD cutting tools is chemical incompatibility. Many materials react with diamond (carbon) at high temperatures (above 750°C) to form carbides and consume the diamond cutting edge: iron, steel, nickel, cobalt, manganese, tungsten, titanium, tantalum, and zirconium. PCD tool life is so short with such materials that it becomes impractical.

Along with a number of general guidelines, broad machining-parameter starting points for using PCD tools were presented by Raymond L. Kester, of Smith-Megadiamond (Provo, Utah, USA), at the Composites in Manufacturing 7 Conference. His paper, "Polycrystalline diamond tooling", is available from the Society of Manufacturing Engineers (Dearborn, Mich., USA) as Technical Paper MR87-230.

Parameters for using PCD cutting tools

Material	Speed (sfpm)	Feedrate (ipm)	Depth of cut (in)
Aluminium alloys	3000-5000	0.002-0.020	0.005-0.050
Copper alloys	1500-3000	0.001-0.010	0.005-0.050
Glass composites	400-3000	0.001-0.010	0.001-0.070
Carbon composites	500-2000	0.003-0.015	0.007-0.070
Alumina ceramics	1500-3000	0.001-0.004	0.0005-0.005

(Source: American Machinist and Automated Manufacturing, April 1988)

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Prospects for new diamond utilization

The pioneer in the new diamond commercialization was the Asahi Diamond Industry, Ltd. The product was the company's "thin-film cutting tool", which was produced by coating, using electron beam irradiation chemical vapour deposition equipment, a diamond thin film, 5 gmm (1 gmm is a thousandth of 1 mm) thick, on a tungsten substrate (tungsten chip with a cutting edge).

In a dry cutting test using an aluminium alloy, the thin-film cutting tool has been confirmed to withstand a continuous cutting operation of 100 minutes. According to the company, the tool's cutting performance is more than 50 times that of ultrahard cutting tools, a performance that places it in competition with compact tool bits (produced by sintering polycrystalline diamond grains at high temperature and pressure) and that is over 10 times more than the available cutting time of thin film diamond cutting tools unveiled by other makers. Asahi Diamond Industry, Ltd., will soon start sample shipments of the product.

Not limiting itself to the manufacture of cutting tools, Asahi Diamond Industry, Ltd., is planning to make a foray into the market for jigs and abrasion-resistant tools, such as FA sensors and feelers for measuring. It is planning to construct a mass production plant at its Tamagawa plant (Kawasaki City).

Repetition of diamond tools revolution

Diamond tools are used in a broad variety of industries, including electronics, precision machinery, automobiles, construction materials, stones, and civil engineering. Their production has grown for the past 11 years, with 1981 output reaching Y76 billion. Their rate of increase has already surpassed that of special steel tools and of ultrahard tools.

With GE's success in February 1955 in synthesizing artificial diamond for the first time in the world taken as a turning point, the market for diamond tools centered on diamond grinding stones has rapidly expanded. With the commercialization of diamond thin-film technology, which could be called "a second revolution" after the impact produced by GE's synthesis of artificial diamond, the market for tool materials, where technological innovation in the field of high-tech materials is rapidly taking place, will achieve further expansion.

Tools are based on synthetic diamonds

As for industrial diamonds used in such operations as grinding and cutting, synthetic diamonds are coming to be used widely and, at present, more than 95 per cent of these tools are accounted for by artificial diamonds. For reference, Japanese imports of industrial diamonds last year were 37,419,000 carat (1 carat equals 0.2 gram), of which 36,113,000 carats were accounted for by artificial diamond powders and a mere 1,306,000 carats, or 3.5 per cent, were made up of natural diamonds.

Diamond tools have come to be used in various industrial fields, including aerospace, electronics, precision machinery, automobiles, construction materials, stone materials, and civil engineering. The mass production of synthetic diamonds that followed has helped to lower their costs, and particularly in the field of powder (diamond grains smaller than about 0.7 mm in diameter), natural diamond, it may be said, has lost its price competitiveness.

The faster the pace of widespread use of high-tech new materials is, the greater will be the sustained growth of the diamond tool market. Once the diamond thin-film technique has been established, a market will emerge for abrasion-resistant sliding diamond products. These include bearings, drawing dies, magnetic heads/disks, printer heads, measuring jigs and tools, rolls, and machining tools.

Technical problems involved include the establishment of the coating (thin-film vapour deposition), finish working and low-cost production technologies. (Excerpted from Nikkon Kogyo Shiusbun, July 1987)

Table 1. Development of new tool materials

Year	Tool materials developed
1955	Synthetic diamond
1958	Ceramics (Al_2O_3 system) (white ceramics)
1961	Thermet (TiC system)
1968	High-toughness ceramics (Al_2O_3 + TiC System) (black ceramics)
1970	High-toughness thermet (TiN system) Ultra-fine, ultra-hard alloy Coating chip (TiC coating)
1974	Sintered high-speed steel
1977	Multilayer coating chip Cubic boron nitride (CBN) sintered body
1978	Diamond sintered body Coating high-speed steel
1980	Wurtzite-structure boron nitride (WBN) sintered body
1981	Diamond thin film
1983	CBN thin film

Advances in carbon thin-film, ceramic powder reported

Film fabrication by plasma CVD

Research has been conducted by Atsuo Konishi, Tatsuhiko Ozaki, and Takuya Honda, at the Faculty of Science and Engineering, Tokyo Institute of Technology on fabrication of carbon thin film by CVD.

Recently, synthesis of diamond thin films at low pressure has become possible by means of chemical vapour synthesis methods (such as plasma CVD method), and the technology is drawing attention. In the research, fabrication of thin-films was attempted using the simple direct current glow discharge process of various plasma CVD methods. The result revealed that under a condition rich in methane, a transparent and crystalline type of electrically insulating thin-films can be fabricated at or near room temperature.

In the experiment, thin-film fabrication was conducted inside a glass bell jar, and plane parallel plates of stainless, 50 mm in diameter, were used as the electrodes. The power source had the capacity of applying up to 1 KV of direct current voltage. For the substrate, a copper plate, 50 mm in diameter and 0.5 mm thick, was used, which was installed on the negative electrode plate. The main reaction gas was a high-purity methane gas (above 99.9 per cent), to which was added a hydrogen gas (above 99.9 per cent) as needed.

An observation by a scanning-type electron microscope (SEM) revealed that the film grown had a uniform coating. Judging from the height of a peeled surface, the film is considered to have a thickness on the order of submicrons. Judging from the fact that the rupture surface of a piece of peel, in another SEM photo, shows a good directionality, the film is considered to be of a crystalline type. In the current experiment no granules were observed. The film is electronically insulating, and it is an inorganic material because there is no change in its weight after it is immersed in n-heptane for 10 hours from it pre-immersion weight. The coating is transparent and electrically insulating.

Next, another experiment was conducted, in which the total quantity of flow was 25 ml per minute, the discharge (electric) time was 30 minutes, and the ratio of methane-hydrogen flow and the power source voltage were changed. The results revealed that the amount of coating increased as the ratio of methane increased. No film developed when the source voltage was low at 600 V. In still another experiment, in which the quantity of methane was fixed at 11.4 ml per minute and different quantities of mixing hydrogen were added, the higher the source voltage, the larger the amount of coating, it was discovered.

Conclusions

From the foregoing, it was found that good thin films can be fabricated by means of DC glow discharge. It was also learned that the higher the electrode voltage and the larger the content of methane, the larger the amount of coating that is produced. The research results have confirmed that a transparent crystalline type of electrically insulating thin film can be grown on an unpolished copper substrate by DC glow discharge at or near room temperature under a condition rich in methane. (Source: Kagaku Kogyo Nippo, 17 July 1987)

Special steel

Crucible materials (Syracuse, NY, USA) has developed wear-resistant cold-work tool steels, using particle metallurgy with rapid solidification. The CPM 10V cold-work material, which has 10 per cent vanadium and 2.45 per cent carbon, has excellent wear resistance with good strength and toughness. The firm is presently using the same techniques to develop hot-work tool steels. Some alloy tool steels break apart due to alloy segregation in the metallurgical forming process. The particle metallurgy process eliminates this segregation, providing better strength based on most tests. In the rapidly solidified (RS) method, a binder is added to the powders. The material is then cold-compacted in a die or mold, followed by sintering. However, in the particle metallurgy process, no binder is added and the material is hot isostatically pressed (HIPed). With the rapid solification process, pre-alloyed spherical particles are produced by gas atomization. These are then compacted to full density with the HIP compaction. The material can then be used as HIPed or may be hot-worked to billet, bar or rod products. (Source: Metalw News, 4 November 1987, p. 29)

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Firms and products

New cutting tool materials extend tool life

A new family of cutting tool materials based on titanium carbonitride (TiCN) that can take high cutting speeds and heavy feeds has been developed by the Israeli company ISCAR. As described at the recent International Powder Metallurgy Conference in Orlando, Florida, USA, compared with titanium-carbide-based cutting tools, TiCN-based tools have increased tool life at both high and low speeds as a consequence of their improved resistance to adhesive and diffusive wear, and also have increased fracture toughness and resistance to plastic deformation. A lower thermal conductivity than TiC-based tools enables their use at higher cutting speeds (up to 300 m/min) without plastic deformation.

In addition to TiCN, these new cermet cutting tool materials are composed of a nickel and cobalt binder plus the carbides of molybdenum (Mo), tungsten (W), titanium (Ti), tantalum (Ta), niobium (Nb), and vanadium (V). The Mo, Ta, V, and Nb carbides increase the material's fracture toughness; the Ta and Nb carbides raise its melting point, thus improving its resistance to plastic deformation; and the Mo carbide acts to reinforce the Ni-Co binder. By varying the carbide composition and the amount of binder, three different TiCN-based cutting tool materials have been developed that can be used for a wide range of applications at both low and high cutting speeds. The figure below shows the range of applicability of these new TiCN-based cermets relative to other cutting tool materials. One of the compositions, which has tested to be most effective for turning, milling, and grooving operations, is now available commercially as ISCAR IC30N. (Source: Materials and Processing Report, August 1988)

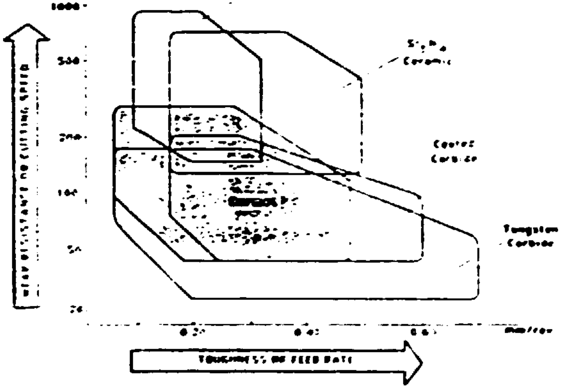

Fig. 3 Wear resistance vs. toughness of ISCAR cermet cutting tools.

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Low-cost cutting tool

Mechanics, tool makers, and metalworkers can use the "Stub Roughing End Mill" in Bridgeport-type milling machines to remove stock without chatter or vibration. This tool is a low-cost replacement for more expensive, standard-length mills, the manufacturer states. It is made from long-lasting M42 cobalt steel in sizes ranging from 1.587 to 5.08 cm. Models are available in flat tooth (truncated) for fine cutting and in knuckle tooth for fast removal. (Source: Commercial News USA, May 1988)

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Computer aids tool, cutting-data choices

The pocket-sized TRIM (Tool Rationalization in Manufacturing) computer from Sandvik Coromant (Fair Lawn, N.J., USA) is designed to help the user make tool and cutting-data choices quickly and easily. It also indicates the possibilities for assortment rationalization based on economic order quantities and for increased production capacity.

Four separate programs are provided: one for each of the machining areas (turning, milling and drilling) and one for economic calculations. Recommendations are a "first choice" based on the latest tooling developments from Sandvik Coromant.

The programs are available in inch and metric English-language versions and in French, German, Italian, Spanish, and Swedish. Users need no computer experience to use them. (Source: American Machinist, September 1988)

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A zirconia cutter blade from Orientation, Inc. exhibits low wear and very low oxidation characteristics, no metal particle contamination or static electricity, a sharp cutting edge, high-temperature capabilities, and is thin, lightweight, and nonmagnetic. Applications for this product include use as textile, plastic film, paper, and special material cutters. The standard dimension for the blades is 0.25 (thick) by 35 by 15 mm; however, blades can be made to widths of 110 mm, lengths of 250 mm, and thicknesses of 0.1-0.2 mm. (Source: Ceramic Bulletin, Vol. 67, No. 9, 1988)

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The UMT-7, a rotary ultrasonic machine tool from Branson Ultrasonics Corp., machines composites, aluminum oxide, ferrite, glass, zirconium, berylium oxide, ruby, sapphire, and other materials by applying axial 20 kHz ultrasonic vibrations to a rotating diamond tool. The ultrasonic activity reduces friction between tool and material which minimizes tool loading and enables drilling and milling with less pressure. The equipment features a swingarm control console for convenient viewing and operation. Setup includes a manual mode for independent control of each function which can be switched to automatic. The head design incorporates a twin stainless steel slide assembly for increased rigidity and accuracy, and a three-axis adaptor for precise alignment with the table and workpiece. Three configurations are available: a floor-standing ultrasonic milling/drilling machine; the ultrasonic head assembly with feed mechanism, control panel, and ultrasonic power supply for mounting on any milling machine or special machinery; and the ultrasonic spindle and power supply only. (Source: Ceramic Bulletin, Vol. 67, No. 9, 1988)

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Precision core drills

Edelschnitt Co., Ltd. has started marketing a series of new precision core drills capable of drilling holes with diameters as small as 0.4 mm into advanced materials such as new ceramics and new glass.

With the development of advanced materials the machining industry must keep pace to work with these new materials. However, ordinary drills are incapable of working with comparatively hard, new materials such as garnet, YAG, GGG, crystal, quartz glass and alumina.

When numerous holes must be drilled, the introduction of an expensive ultrasonic wave drilling machine might be profitable but not when only a few holes have to be drilled. To cope with this, a need has arisen to develop core drills which can be procured at moderate prices for drilling a few holes at a time economically yet accurately and efficiently.

Normally, a hole is drilled at the core part of a core drill by a mechanical process in order to produce the core drill in a hollow state. However, mechanical machining becomes increasingly difficult the smaller the hole and up to now the smallest hole had a diameter of about 0.5 mm when working with an ultrasonic wave drill and only up to a diameter of about 2 mm with an ordinary drill.

The core drill of 0.4 mm accuracy developed by the company uses a special type of pipe (already having a diameter). The drill has been made available at a moderate price by fitting diamonds to the drill bits electrically. The product drills holes with diameters from 0.4 mm to 2.0 mm in 0.1 mm graduations. (Source: JETRO, September 1988)

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More efficient roughing end mills

The roughing end mill has become a more widely used tool in the past decade, and new designs to make it more efficient have been appearing lately to replace the "corn cobs". At Westec in Los Angeles in March, several such new designs were shown.

Valenite (Troy, Mich.), Ingersoll (Rockford, Ill.), and Waukesha (Waukesha, Wis.) showed new indexable-insert carbide end mills. Designs of the first two eliminated the gaps between inserts, typical of indexable-insert mills, so that each flute is fully effective, instead of having two rows of inserts to make one effective flute. Ingersoll says the design was developed to raise productivity in milling titanium.

Valenite says the three-flute-design v-Mills permit 50 per cent increases in feedrate compared with two-effective-flute designs. The triangular inserts overlap within the three high-helix-angle flutes. They are made with modified Weldon shanks in sizes from 1 to 2 in. A single-flute design is used for the 0.62 and 0.75 in. sizes. Valenite has also introduced new single and multiple-insert, indexable-insert ball-nose end mills.

Max-I-Effective end mills from Ingersoll use overlapped squarish side-cutting indexable inserts and a radiused insert on the end to achieve the same doubling of effective flutes. These are built in sizes from 1.25 to 2.5 in. on straight and tapered shanks, with two to five effective flutes. Ingersoll says the feedrate will be twice that of a carbide "half-effective" mill.

Waukesha demonstrated the line of Walter end and face milling cutters that it is starting to market in the US, many of which are designed with fairly high positive rake.

There were also introductions of new HSS and cobalt-steel end mills, but these designs were not as radical. For example, Fette Tool (Brookfield, Wis.) showed a WF three-flute 5 per cent cobalt rougher for aluminium with 22° positive rake, ground 40°-helix flutes, a large heel, and overlapping of the truncated teeth of adjacent flutes.

New three-flute solid-carbide drills were shown by Guhring (Brookfield, Wis.) and VNE Corp. (Janesville, Wis.). The Guhring GS200 can spot, drill, and core-drill. Size range is 1/8 to 3/4 in. A 3/8 in. three-flute drill in low-alloy steels can feed at 0.0055 ipr. The Klenk M-point multifacet three-flute drill, sold by VNE Corp., is said to be another fast production drill in metals.

At the premium end of the insert-material introductions was a CBN insert called SumiBoron BN300, from Sumitomo Electric Carbide (Mount Prospect, Ill.) The company claims that the tips can withstand interrupted cutting of parts with Rc 60-65 hardness. Ceratip Cutting Tools (Mountain Home, NC.) introduced its KF2100 whisker-reinforced ceramic, and Valenite introduced its Quantuum 10 whisker material - suggesting a growing field of competitors providing this new class of advanced tool material.

Sandvik (Fair Lawn, NJ.) introduced a handy pocket computer for the tool engineer and planner called TRIM. It uses four separate program cards for turning, milling, drilling, and machining economics. A program recommends a modern tool, the right grade of carbide, the right geometry, and speeds and feeds. The economic program calculates machining costs per component, pay-back time for tooling investments, and other economic effects of tooling decisions.

Tecnara Tooling Systems (Cerritos, Calif.) demonstrated the Auplex Tool Sensor System from Nippon Pneumatic Manufacturing Co. for prevention of breakage of drills 0.039 to 0.236 in. It works by sensing torque: when it senses a preset torque level at which the drill is about to break, it stops the tool and sends a message to the machining-centre control. The unit can discriminate between signals indicating excessive wear and those indicating clogging. The angle of the coolant-injection system can be adjusted for drills of varying lengths. The toolholders are BT40-, 45-, or 50-taper, and each accept Jacob's taper No. 0, 1, or 2 drill chucks. (Source: American Machinist and Automated Manufacturing, June 1988)

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Recent growth of the specialty ceramics industry and the introduction of new hard glass and advanced ceramic products has spurred research and development of new bonding materials for cutting wheels at the US North Jersey Diamond Wheel. The firm manufactures a comprehensive array of superabrasive wheels using state-of-the-art techniques for all branches of industry, but is pioneering advanced bonding technology, particularly for difficult-to-machine ceramics. Recently, North Jersey Diamond Wheel engineers developed CX11, a new bond that has shown promising results for most the advanced ceramics. The cool free-cutting action of the CX11 bond allows greater downfeeds and faster cutting speeds, while exhibiting wheel life comparable to metal-bonded diamond wheels.

North Jersey Diamond Wheel specializes in manufacturing superabrasive cut-off wheels (1A1Rs), ranging in size from 7.62 to 35.56 cm (3 to 14 in.) in diameter and thickness from 0.51 to 3.18 mm (0.020 to 0.125 in). Tolerances as close as ±0.025 mm (±0.001 in.) can be accurately held with the company's precision manufacturing techniques. (Source: Ceramic Bulletin, Vol. 67, No. 7, 1988)

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Composites industry seeks high-heat tools

High-temperature tooling for advanced aerospace composites was a main topic at the Society of

Manufacturing Engineers' first Tooling for Composites conference, held in Los Angeles. The use of performance thermoplastics, bismaleimides, and polyimides in carbon fibre-reinforced parts for aircraft has pushed processing temperatures into the 430°C range, placing new demands on tooling. Metals are unsuitable above 260 to 315°C, say industry spokesmen, mainly because of their high coefficient of thermal expansion. Carbon composites include monolithic or bulk graphite, ceramics, and carbon fibre-reinforced composite tooling.

"We have been working in the 400°C range for the past four years and above 430°C for the last 1 1/2 years," says the technical director for Programmed Composites Inc. (Brea, CA, USA). He explains that higher-temperature composites are required for such high-performance aircraft as the National Aerospace Plane and the Advanced Tactical Fighter.

Bulk graphite has the advantage of "extreme" dimensional and chemical stability. We have used monolithic graphite tools for forming thermoplastic composites repeatedly at temperatures up to 430°C. With proper care, these tools will probably survive for hundreds of cycles.

"Proper care" is the catch, say critics. They point out that graphite is easily damaged and scratched and is therefore unsuitable for a shop floor environment. Other criticisms: Since graphite tools are machined from a block, they are massive and take a long time to heat and cool; the isostatic molding process for making the graphite limits block size, so pieces have to be bonded together for larger tools; and a vacuum bag cannot be placed directly on the tool because it is not vacuum-tight.

Spokesmen for Great Lakes Carbon Corp. (Niagara Falls, NY, USA) and Stackpole Carbon Co. (St. Mary's, PA, USA) counter that their bonding systems have good integrity and that the material is easy to machine.

Ceramic is stable at high temperatures and has a relatively low CTE, but is brittle and porous. However, Occidental Chemical (Lanham, MD, USA) claims that its CBC (chemically-bonded ceramic) tooling is vacuum-tight. This is achieved mainly using a low-permeability binder, says the manager of CBC tooling technology.

Oxy's material consists of graded metal aggregate in a silica-modified portland cement matrix. Steel fibre is also used to provide greater tensile strength, toughness and resistance to cracking. It has been used at temperatures over 430°C and could be used up to 455°C. The tooling is relatively thin (15 mm) and light-weight.

Relative costs of tooling are not easy to pin down. Monolithic graphite is fairly inexpensive and the tooling is competitive with metal, according to Stackpole. Graphite costs less for simpler tools, but ceramic is competitive for geometrically complex tooling because it can be cast in thin, intricate shapes. High cost is considered the main drawback of the high-temperature composite prepreg for tooling made by Du Pont. But a Du Pont research associate claims that carbon fibre Avimid N polyimide material is expensive only because it is still in small-volume production. He adds that it is a tough material with the potential for long use life, which is significant in determining actual cost. It is also lightweight, has a low CTE, and is easily laid up in contoured shapes by conventional prepreg methods. The material has a glass-transition temperature of 400 to 410°C. (Source: Modern Plastics International, September 1988)

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Abrasive-water-jet cutting shapes metal-matrix and organic-matrix composites

A high proportion of present and future aircraft will be made of composite materials, one example being the mostly composite-structured V-22 Osprey tilt-rotor aircraft. An effective method of shaping such materials is with an abrasive water jet, and Lockheed Aeronautical Systems Co. (Marietta, Ga., USA) is becoming more proficient in applying this technology, which it has been using for several years. Lockheed-Georgia is able to electronically link its CAD system to the NC water-jet machine.

A variety of materials (a few of which are listed in the accompanying table) are cut with an abrasive-jet stream 0.030-0.040 in. diameter and under approximately 45,000 psi of pressure.

Materials are cut cleaner with no ragged edges, no thermal, delamination, or deformation problems. The abrasive jet will cut 1/8-in.-thick graphite epoxy at a rate of 40 ipm; this same job would take nearly four times longer with traditional methods, and then more time would have to be spent sanding the ragged edges."

This technology is cost-effective because it cuts out metallic and composite parts with greater speeds and eliminates many of the materials handling problems.

Currently, the system is used to cut parts from whisker- and fibre-aluminium for the vertical tails of a generic advanced fighter aircraft. The system is expected to be used in future production programmes for both metal-matrix and composite aircraft parts.

Cutting with abrasive water jet

Material	Thickness (in)	Cutting rate (ipm)
Aluminium metal-matrix-composites	1/8	20-30
Graphite epoxy	1/8	40
Graphite thermoplastic	1/8	40
6061-aluminium tooling plate	3/4	3-5 (rough)
4340 stainless steel	1/2	2-3

(Source: American Machinist and Automated Manufacturing, June 1988)

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Abrasive water jet cuts composites

In research partially supported by the BOC Division of General Motors, four investigators at the University of Wisconsin - Milwaukee (USA) found that metal-matrix composites, such as solidification-processed aluminium-silicon-carbide and magnesium-based composites, could be cut with an abrasive water jet of 25,000-45,000 psi at traverse speeds of 0.5-10 in./min. These materials are difficult to cut conventionally, and tools dull quickly.

K.F. Neusen, P.K. Rohatgi, C. Vaidyanathan, and D. Alberts used a five-axis-robot positioning system and varied the cutting speed, water pressure, and abrasive flow rate. They held constant the stand-off distance, 2.54 mm; abrasive material, garnet; abrasive size, 80 mesh; and depth of cut for finish cuts, 12.7 mm. Their results are also published in the Proceedings of the Fourth US Water Jet Conference.

The surface roughness increases with an increase in cutting speed and decreases with an increase in abrasive flow. For a given cutting speed in thick workpieces, there is a maximum depth of cut.

Scanning-electron microscopy reveals that individual garnet particles lodge in the cut surface - at the end of their track, when they have apparently lost sufficient kinetic energy to penetrate further. Interestingly, the silicon-carbide particles in Al 357-15 per cent SiC composite are cut to almost the same depth as the aluminium. This composite was cut at speeds from 1 mm/sec (60-mm depth of cut) to 3 mm/sec (25-mm depth). (Source: American Machinist and Automated Manufacturing, November 1987)

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Cutting ceramics by abrasive water jet

Abrasive water jets can be used to machine various industrial ceramics. To determine the optimal cutting parameters in cutting sintered aluminium oxides by that process, researchers D.C. Hunt, C.D. Burnham, and T.J. Kim, at the University of Rhode Island (Kingston, USA) did a series of experiments using a force sensor to control the process and obtain the desired surface finish.

The force sensor was an aluminium-beam force transducer with four identical strain gauges. Both 60-mesh Al_2O_3 and 80-mesh garnet abrasives were used on workpieces ranging from 6.4 to 20.6 mm thick. All the process variables except the traverse speed were kept constant.

When a 9.5-mm-thick work-piece of AD 99.5 alumina was cut with the garnet abrasive at 0.85 mm/sec, the maximum speed at which this ceramic could be cut with the garnet, it took an average force of 21.5 N. Switching to the harder Al_2O_3 abrasive reduced the force required to 4.1 N. The corresponding quality of the surface finish was markedly improved from 270 in. RMS value for the garnet to 130µ in. for the aluminium oxide. The force level increases linearly as the cutting speed increases with both abrasives; the higher the force the rougher the finish. This means that the efficiency of water-jet machining can be controlled by the level of the force output.

If the same workpiece is cut at the maximum speed for the Al_2O_3 abrasive, the speed rises to 4.8 mm/sec, but then the surface finish becomes slightly worse (300µ in. RMS) than that recorded for the maximum cutting speed for the garnet abrasive. To say it another way, the harder Al_2O_3 abrasive can produce about the same surface quality as the garnet abrasive at four times the speed. (Source: American Machinist and Automated Manufacturing, November 1987)

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Enhanced cutting capability at Macreadys

Rugby-based steel stockholders Macreadys (Glynwed Steels Ltd.) has reported a further improvement in their cutting service with the recent installation of the latest Behringer HBP 530 CNC bandsaw from Kaltenbach. The machine has already considerably speeded up the turnround of multiple orders of larger diameter bar materials, and follows the introduction earlier this year by the company of the first Kaltenbach CNC batch production circular saw to be used by a UK steel stockholder.

The new Behringer HBP 530 band-saw handles a wide variety of carbon and alloy steel materials of up to 530 mm diameter and cuts to a high accuracy (±0.1 mm). Once set for multiple cutting, the machine works automatically (currently 24 h/day) under the supervision of a single operator who oversees five other saws at the same time. The machine also self-reports faults, such as when the squareness tolerance may be exceeded or a blade become damaged, stopping if necessary. (Source: Ironmaking and Steelmaking, Vol. 15, No. 1, 1988)

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Carbide tool drills printed circuit boards

This rotary cutting tool for printed circuit boards is manufactured from the finest micrograin carbide on advanced state-of-the-art computer controlled CNC equipment to tolerances 50 per cent tighter than the industry standard, the company states. Available in configurations for drilling and routing, the durable instrument is designed to offer superior hole quality, to last longer, and to allow greater ease in resharpening. The drill features a thin web to aid penetration, a narrow margin to limit heat generation, and highly polished flutes to provide rapid chip removal. (Source: Commercial Views USA, November-December 1987)

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Triple-coated carbide inserts cover wide machining range

Higher cutting speeds and extended tool life are claimed for the new Spectra SV3 triple-coated inserts available from Valenite-Modco.

During the tool production process, titanium carbide, ceramic and titanium nitride are added in turn to a tungsten carbide base material, to give high wear resistance, thermal protection and lubricity, respectively, says the firm.

Spectra SV3 inserts can be used for performing roughing, semi-finishing and finishing operations on cast iron and carbon, alloy and stainless steels.

Because of high impact strength and shock resistance, the inserts are said to stand up well to milling and other interrupted-cut operations.

Applications are stated to cover 60 to 70 per cent of machining operations in a typical factory. (Source: Machinery and Production Engineering, 5 February 1988)

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Whiskers that grind alloys

Cutting high-temperature alloys is a tough job, but a new silicon carbide whisker-reinforced alumina cutting tool insert, CerMax 490, should speed things up. It promises finished jobs in only 10 per cent of the time taken by conventional carbides, and 67 per cent of the time used by advanced sialon (silicon-aluminium-oxygen-nitrogen) ceramic tools. Alumina is ordinarily too brittle to stand up to vibrations caused by machining. It checks in at 4 on the fracture toughness scale, compared to 16 for cemented carbide tools. CerMax 490, however, rates between 8 and 9. Single-crystal SiC whisker reinforcements, which are extremely strong, improve alumina's fracture toughness by blunting and deflecting cracks. The material is particularly suited for rough and finish turning of Inconel 718, a widely used nickel-crhomium alloy. Tests at several aircraft plants reached cutting speeds of 500 to 1,500 ft^2/min, normal feed rates up to 0.020 in./rev and maximum depth of cut of 0.0500 in. (Source: Aerospace America, November 1986)

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Ultrasonic cutting system for hard-to-machine materials

The Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology has made available an ultrasonic cutting system that cuts high manganese steel and other materials that are highly resistant to machining very well.

The research group had been striving to develop a cutting system that displays excellent cutting efficiency to cope with the increasing use of high manganese steel, ceramics, and other hard-to-machine materials for producing machine and engine parts.

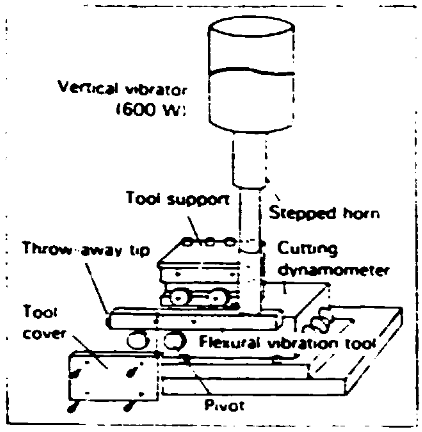
Ultrasonic cutting enables very accurate, efficient cutting by vibrating the cutting tools, and can therefore be used to cut special types of materials. The newly developed ultrasonic cutting system is an application of this cutting technology.

The system essentially consists of cutting tools which are fit into the cutting assembly with their cutting edges fixed in position, an ultrasonic horn with a 600-W vibrator, and a vibration horn, and generates ultrasonic waves of 20 kHz. The tool's cutting edge is vibrated synchronous with the ultrasonic waves, and two fulcrums are provided to change the vibration amplitude flexibly.

Cutting tests with 6-4 brass, hastelloy, and high manganese steel showed that the newly developed cutting system's cutting efficiency and accuracy are improved substantially over systems not using vibrations.

Furthermore, in tests conducted by fixing hard-to-machine materials at the tip of a 15-mm diameter bar, the new cutting system was found to accurately cut materials positioned more than 125 mm away, better than the 100 mm of conventional cutting systems. Therefore, the system is attracting attention as a new method for cutting material that is hard to machine.

(The Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology, 1-2, Namiki Sakuramura, Niihari-gun, Ibaraki Pref.)



Ultrasonic Vibration Cutting System

(Source: JETRO, April 1987)

Ceramics set for rapid growth

The use of advanced ceramics will increase tenfold in the next few years if engineers are made aware of their potential and can free themselves from the traditional "tried and tested" approach to materials selection, says a recent report.

A report, from Financial Times Business Information, concentrates on alumina, zirconia, silicon oxide and carbide, and the sialons. It lists the advantages of these materials as:

- Long service life;
- Resistance to wear, high temperatures, thermal cycling and corrosion;
- High cutting speeds; and
- Improved control of combustion processes.

Although the main markets for advanced ceramics - refractories, abrasives and cutting tools - are static at present, there is potential for new applications, says the report, on a wide range of industries from agriculture to communications and from food processing to mining. Thousands of companies, it adds, are already using ceramics.

The report, which outlines the development of ceramics from the first surge of interest during the oil crisis of the early 1970s to the present day, points out that although ceramics are costly to produce, they are made from some of the most abundant raw materials on Earth, and their increased use would allow industrialized countries to reduce their dependence on strategic metals like chromium, nickel and cobalt.

There is also a warning that the materials must be used in the right way. Ceramics cannot be directly substituted for metals or plastics. They are brittle and so the component usually needs to be redesigned to account for this. The report does point out, however, that most ceramics component manufacturers provide good design and consultancy services to help with this.

A useful aspect of the report is its inclusion of a series of case studies, giving examples of typical applications of ceramics and the advantages gained from using them. These case studies include furnace linings, riser stalks in low-pressure diecasting, cutting tools for machining titanium, pumps for the chemicals industry, and seed drill coulters. There is also a review of ceramics R & D programmes in Europe, the US and Japan; production figures for the leading advanced ceramic materials; and an outline of some of the commercial activity involving ceramics around the world. The report, priced at 187, is available from FT Business Information, 102 Clerkenwell Road, London EC1M 5SA. (Source: Engineering, September 1987)

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Broaching specialist Lapointe bought out by Gaston Marbaix

A new machine tool company, Marbaix Lapointe, has been formed after the buyout of Watford broaching specialist, Lapointe, from Staveley Industries by Hampshire machine tool builder Gaston Marbaix.

The £6 million deal will almost double Marbaix's turnover to around £22 million, and the combined workforce will total more than 300.

Marbaix already has machine divisions at Basingstoke and Luton. The Basingstoke headquarters produce linear rack rolling machines under licence to Anderson Cook of America, and these are sold to most car producers in Europe for spline and thread production.

It also makes computer-controlled rack grinding machines, track milling and grinding machines for constant velocity joint manufacture, and rebuilds machine tools.

Belisle coolant filtration equipment is produced at Luton along with disintegrators for removing broken drills and taps.

Marbaix's rack product line is reckoned by the new machine tool division's MD, Mike Gallagher, to complement Lapointe's broaching technology, and all sales and marketing for machine tools - including the agencies, which are unchanged, for Italian systems and grinding machine builder Saimp, and surface and creep feed grinding specialist Magerle - will be based at the Watford site.

However, an interchange of manufacturing between Basingstoke and Watford sites is planned, with no job losses, to suit each plant's facilities and to especially make full use of the heavy lifting equipment available at Watford.

And Marbaix Lapointe, Watford, will now be the centre for all tool grinding, including racks and broaches.

One result of the move will be to broaden the application of broaching into sectors such as automotive. Over the past few years, Lapointe has concentrated on the aerospace sector, and has exported 75 per cent of production. (Source: Machinery and Production Engineering, 18 March 1987)

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The shaping of things to come

During recent years, when many UK machine tools companies have been struggling in the face of strong overseas competition, one manufacturer has been going from strength to strength. Wellingborough-based Design Technologies (DTL) has achieved this by concentrating on specialist cutting and shaping applications, particularly for advanced composite materials.

Cutting fibres fast

DTL is unusual in that its computer numerical control (CNC) machines are designed to use four principal cutting methods: ultrasonic knife, high-speed routing, water jet, and laser. The ultrasonic knife has been developed and refined by the company to provide a very effective way of cutting reinforcing fibres for composite materials. A specially-designed tungsten carbide knife is mounted at the bottom of an ultrasonic horn and vibrates at a frequency of 20 kHz. It can accurately cut single-ply carbon or glass fibre pre-pregs (fibres pre-impregnated with part-cured resin) at a speed of 40 m/min without tugging at the fibres.

The first ultrasonic knife system supplied by DTL went to Westland Helicopters of Yeovil where it is being used to cut carbon, glass and Kevlar aramid fibre for the manufacture of rotor blades for the EH 101 helicopter. Ultrasonic knife cutting was selected in preference to water jet cutting since the water used in the latter method can mix with the resin in the laminate. The machine has allowed Westland to produce reinforcing pieces on demand and eliminated the need for refrigerated storage and complex stock control.

Another ultrasonic machine was delivered to the Cessna aircraft company in Kansas, USA, in September of last year. This machine differs from the Westland system in that many more parts need to be cut and Cessna is aiming to reduce wastage of the very expensive raw materials by 20 per cent. In order to achieve the most cost-effective cutting pattern arrangement, a large area of material needs to be cut and therefore a larger cutting machine was specified. The DTL units supplied to Cessna measure 15 x 2.1 x 1.3 m^3, weighs 5 tons and has an X-axis stroke of 13 m and a Y-axis stroke of 1.5 m.

The knife blade is powered by a Branson ultrasonic generator and an Allen Bradley 8600 CNC is used to give a cutting accuracy of 0.25 mm. The controller is equipped with a forward feed velocity system which improves the profiling speed versus radius characteristic. An important advantage of ultrasonic cutting is the ability to accurately control the depth of the cut. In this case the non-contact height following system works by detecting eddy currents in the work table under the polyurethane top surface. This surface is virtually "self-healing" when cut and prevents the knife coming into contact with the metal support table.

Cut and place

DTL is also working with the National Engineering Laboratory (NEL) in East Kilbride, Glasgow, to develop an automatic pre-preg cutting and handling system. DTL's ultrasonic cutting process can be used to cut through just the pre-preg and leave the protective backing layer intact. The NEL has developed two needle-gripper designs which can lift cut pre-preg shapes from their backing and transfer them to the tool. The organizations are examining the best ways of combining these two processes to produce a fully automatic cut and place system. Two gantries are needed - one for each of the processes - and the gantry with the grippers must be able to move outside the cutting area to reach the tool.

A consortium including DTL, the NEL and several potential users, hopes to develop the system with financial support from the Department of Trade and Industry. Before a prototype can be built several problems need to be overcome. These include: programming and controlling the grippers; automatic smoothing and consolidation of the layers once they have been placed in the tool; system integration; and the assessment of the tolerance of various materials to needle penetration. Once the prototype has been developed at least two specific products will form the test program.

An interesting spin-off from using ultrasonic cutting for composites can be found in a project which DTL is carrying out for Jaguar. When the Coventry-based car company approached DTL about a system for cutting leather for interior trim, the initial ideas were to use water jet or laser cutting. It was later found that an ultrasonic knife was a simpler solution that gave high reliability and excellent results. The project is now in the design phase and is leading to further spin-offs: a refined blade developed especially for this application has also turned out to be particularly suitable for cutting Kevlar, which is one of the most difficult fibres to profile in pre-preg form.

High-speed router

While ultrasonic methods are proving successful for cutting pre-pregs, other composite components require different techniques. For example honeycomb structures, which are used in sandwich constructions particularly in the aircraft and aerospace industries, are being cut using high-speed routers. The router carves its way through the honeycomb to give accurate profiles. DTL has supplied two such systems to British Aerospace. At BAe's space and communications division at Stevenage a very large five-axis router is being used for cutting the honeycomb materials used in European space satellites and space booster rocket casings. This profiling work was originally subcontracted to the aviation division at Preston which also has a DTL five-axis router. Now the Stevenage plant can carry out its own work and also does subcontract work for other companies.

The plant's router, which measures $7.2 \times 7.2 \times 4.2$ m^3 and weighs 35 tons, can achieve cutting speeds up to 35 m/min. An Osai Allen Bradley CNC system is fitted and enables complex double-curvature profiles to be produced automatically at high speeds and with high accuracies. At British Aerospace's Preston plant the 5-axis router is additionally being used for profiling cured carbon fibre reinforced composites and at the Hill Airforce base in Utah, USA a similar machine is being used for repairing aircraft panels and cutting new panels in aluminium and composite materials.

Foam to foodstuffs

At Ciba-Geigy's Duxford plant, DTL routing machines are being used to cut Nomex honeycomb. One application is profiling the cores for the EH 101 helicopter blades. These are then laminated to the pre-pregs cut by Westland using the DTL ultrasonic cutter described earlier. Ciba-Geigy also uses the routing technique to shape pieces for the panelling and flooring of aircraft.

Another application of DTL's routing machines is for model-making. Here digitizing control units from an Italian company, Fidia, are used on conjunction with DTL's four or five-axis machines which can handle material up to $8 \times 3 \times 1$ m^3 in size. Models can be made from many different materials including wood, plastics and rigid foam.

Among the users of DTL's CO_2 laser profiling machines is Gloster Saro, a member of the Hawker Siddeley Group. One of the company's products is thermal insulation for use in aircraft. This is made from a laminate of metal skins and insulation material and the laser is used to cut both of these materials. It has increased productivity and improved material utilization.

The company's water jet cutters pressurize water up to 4,500 bar and discharge it through a tiny orifice machined in an industrial sapphire. The machines are being used to cut materials ranging from PTFE to the honeycomb centres of Crunchie bars. (Excerpt from an article which appeared in Engineering, April 1988)

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Hard ceramic coatings

Recent developments in physical vapour deposition (PVD) processes make it possible to deposit ultra-hard ceramic coatings on to a wide range of engineering components.

This has important implications for the design engineer interested in wear, friction and corrosion control.

Ceramics are usually very hard materials having excellent chemical and thermal stability. These properties make them suitable for engineering products designed to operate under harsh conditions. Bulk materials incorporating ceramic phases, such as the cemented carbides and silicon-aluminium oxynitrides, have been developed specifically to obtain these surface properties, but it is often preferable to deposit such ceramics onto conventional metallic materials, thereby combining good bulk toughness and load support with the desirable surface properties, and also making the forming of complex shapes easier.

Initially, there was only one commercially available technique for the deposition of pure ceramics - chemical vapour deposition (CVD). Unfortunately this was typically carried out at temperatures over 1,000°C which meant that its use became restricted to those products which could withstand such temperatures without softening (eg. cemented carbide tools), or to products and materials which could tolerate thermal distortion and/or be hardened after coating. Physical vapour deposition coating techniques have substantially removed these constraints, and are now widely used on high-speed steels and hot-working tool steels, as well as other substrate materials.

Lower temperatures

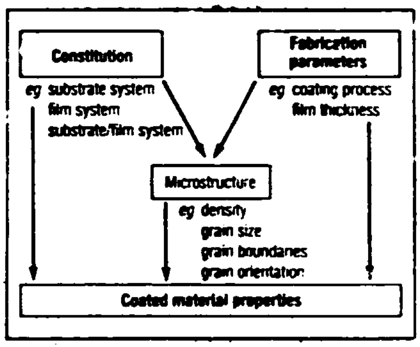
The breakthrough in PVD technology which has permitted these improvements is the use of a highly-ionized environment within the vacuum coating chamber. The components to be coated are negatively charged and thus receive intense positive ionic bombardment prior to and during deposition. This ensures excellent atomic pre-cleaning and results in coatings being densified by the action of the high-energy depositing species. In the case of titanium nitride deposition, nitrogen is fed in gaseous form and the titanium is vaporised from solid within the coating chamber. This method of coating deposition gives a number of advantages:

- Excellent adhesion;
- Good thickness uniformity;
- No finish machining needed after coating (usually);

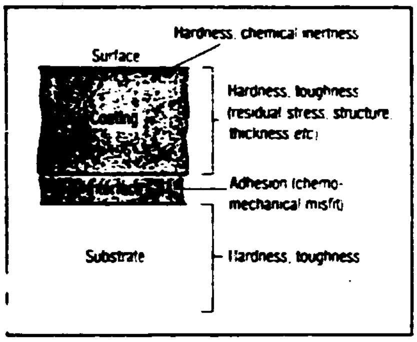
- Reduced deposition temperatures;
- Minimal effluent or pollutant products;
- A wide range of possible coating and substrate materials;
- No hydrogen embrittlement problems; and
- Coating structure and stoichiometry can be closely controlled.

In particular, the PVD techniques offer an unrivalled capability to "surface engineer" the coating/substrate system properties.

Figure 1 postulates, how PVD methods theoretically allow the three variables, constitution, fabrication parameters and microstructure, to be controlled to give particular properties. Ceramics can be combined, depending on their primary bonding mechanisms, to optimize the coating properties for the three main regions in figure 2.



1 Factors influencing the properties of physical vapour deposition ceramic coatings



2 The requirements of the surface, coating, interface and substrate

The achievement of this objective is commonly referred to as the "third generation" ceramic coating initiative, and is currently the main goal of researchers in this field. At the present time, the PVD ceramic coating market is dominated by titanium nitride which typifies the optimum single-phase solution to the majority of wear problems.

Currently there are three main PVD ceramic coating processes being operated in the UK, by Balzers High Vacuum, Multi-Arc (UK) and Tecvac respectively. The latter two companies have also supplied coating equipment to J.J. Casting Investments and Holt Brothers (Halifax), both of which operate coating services.

Balzers and Tecvac utilize electron beam evaporation of the titanium, while Multi-Arc uses arc evaporation. Other techniques exist, such as the hollow cathode discharge (HCD) electron beam gun system used by the Ulvac company of Japan, and "sputter" deposition systems - particularly the one offered by the Leybold-Heraeus company of the Federal Republic of Germany and another developed at AERE Harwell. There are also two other companies offering arc-source based systems not presently represented in the UK; these are VacTec of the USA and Hauzer Techno Coating Europe of Holland.

It has been estimated that there are now over 125 PVD titanium nitride coating plants in operation throughout the world. In Japan the majority of gear cutting tools were already being coated five years ago. On Balzers' machines alone, the number of tools coated to date has been estimated at over 40 million.

Gear cutting

Perhaps the most successful use of the coatings has been on gear cutting tools. In one reported application by David Brown Gear Industries, a change in substrate from M2 to ASP 23 was used, together with a titanium nitride coating. The total increase in tool cost was 89 per cent and the increase in output with the hob was over 1,000 per cent. It is not, however, the increase in tool life that is important; it is the increase in productivity from the tool that users find most advantageous.
Jorg Vogel of Balzers notes that coated HSS milling cutters are typically used at twice the uncoated speed. When their geometries are further modified to suit a PVD coating they can almost achieve the cutting speeds used for solid carbide tools. In fact the PVD process is even being used on carbide tools - previously the domain of CVD coatings; PVD is said to avoid the brittle interface layer which can result during CVD. One cautionary note about the use of PVD coatings over extended periods on tools is needed however. Whereas in the normal course of events uncoated tools are reground fairly frequently, this is not the case with coated tools. With uncoated tools, the regrinding process will remove any surface cracks that may have been initiated - thereby reducing the risk of fatigue failure of the tool. With coated tools this may not happen, and occasionally users have reported bulk tool failure after extended usage, due to crack growth, particularly in interrupted cutting applications. This will be overcome with the developments outlined earlier, and with the use of improved substrate materials - in the same way that other potential "problems" have been substantially removed.

There have also been many examples of applications on forming tools, such as in the cold backward impact extrusion of copper components. In one example the tool was nitrided prior to coating and the number of components produced per tool increased from less than 70,000 to more than 300,000.

Press forming and can wall ironing are operations in which the coating's anti-sticking properties provide real important benefits, pick-up and scoring are avoided. Plastics processing machinery is also now extensively PVD coated. Injector screws are often subjected to extreme abrasion and chemical attack - particularly when used with filled plastics. Their life is typically extended by an order of magnitude when coated. Plastics' moulds can show a similar life increase. (Excerpt from an article which appeared in Engineering, December 1987)

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Market developments

Cutting tools and wear parts growing, but not as fast as bioceramics

Throwaway cutting tools inserts shape rotating metal workpieces by chipping or shaving them. Cast iron and superalloys account for about half of all materials machined, and for materials most commonly machined with ceramics.

Machinists both boost productivity when they increase cutting speed and reduce tool wear so they need less downtime to change bits. High speeds and long periods of use produce high temperatures that cause tools to lose their rigidity and to react chemically at the cutting edge. Liquid cooling can cause thermal shock fracture. Machine vibration may fracture or chip tools.

Throwaway tools account for about one third of the total insert market. Of that, more than 95 per cent are cemented carbides, tungsten carbide cemented with cobalt binder and often coated with such wear-resistant ceramics as titanium nitride. They are used to machine cast iron and nonferrous alloys and cost about $5/insert. Compared with ceramics, cemented carbides are stronger and more resistant to fracture and thermal shock, but they start to creep (lose rigidity) at 600°C.

Compared with carbides, ceramics retain hardness and strength better at temperatures over 600+°C, run longer without wear or abrasion, and creep (deform) less. They excel under high-heat conditions created by more productive high-speed machining. The difference shows up very quickly when cutting a typical 10 cm-dia. x 27.5-cm steel shaft.

(1) There are several classes of cutting tools. Alumina-based tools trace their pedigree back many years. The addition of titanium carbide and/or partially stabilized zirconia (PSZ), and reinforcement with silicon carbide whiskers, overcame the poor fracture toughness and thermal shock resistance that limited alumina's use in the past. Even now, alumina cannot be cooled without fracture. Alumina works best on cast iron and superalloys.

(2) Silicon nitride cutting tools are newer. They are actually made of sialon (silicon-aluminium-oxygen-nitrogen), and are used where mechanical and thermal stress is high. Applications include finishing cast iron for auto engine blocks, nickel-based superalloys for aerospace and corrosion use, and hard steels. Sialon is more thermally shock resistant than alumina, and can be used with coolant.

CERAMIC CUTTING TOOLS AND WEAR PARTS
US CONSUMPTION: 1985-2000*

	1985	1990	1995	2000
Cutting Tools	$18	$45	$110	$230
Wear Parts				
Bearings	2-4	40	100	200
Seals	2-4	25	60	120
Nozzles	-	5	10	15
Other	1	5	10	20
Total	$22-27	$120	$290	$585

* Source: High-Tech Materials Alert.

Alumina and sialon account for most ceramic tools. Cubic boron nitride (CBN), an extremely inert, high-temperature material, is increasingly used for hardened tool steel and cast iron, but is very expensive. Cemented diamond tools are used with aluminium silicon alloys, brass, and bronze, but react chemically with nickel and ferrous-based alloys.

Several factors will limit acceptance of ceramic tools. First, they cost more than carbide tools. In the early stages, ceramic tools will be more expensive. Second, they require more powerful and rigid cutting machines that do not vibrate and fracture the ceramic inserts. Since machines are replaced only gradually, the size of the potential market for ceramic tools is limited.

Third, ceramic tools are still not highly reliable. Computer numerical control (CNC) sensors still cannot predict tool failure, and broken tools can ruin a work-piece. Fourth, the practice of coating carbide and high-speed steel inserts with hard ceramics offers many of the advantages of monolithic and composite ceramic inserts. Titanium nitride and titanium carbide coatings both improve hardness, wear, temperature resistance, and chemical inertness, and lower friction. Diamond and CBN coatings may soon be available too.

We estimate the throwaway insert market was about $650 million in 1985. Ceramics accounted for 8 per cent to 10 per cent of that. If the market grows 2.5 per cent annually, it will reach $950 million by the year 2000. We assume that the number of turning and milling machines powerful and rigid enough to use ceramic will grow from 15 per cent in 1985 to 25 per cent by 1990, 40 per cent by 1995, and 60 per cent by the year 2000. If ceramic cutting tools (whose performance will merit a price premium) penetrate 60 per cent of that potential market, then the business could be worth from $340 to $450 by the year 2000. (Extracted from High-Tech Materials Alert, August 1987)

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Superabrasives: diamonds, cubic boron nitride use continues to grow; new film routes could alter cost structure

Superabrasives are much harder than conventional abrasives and retain their cutting edges much longer, so you can run them with less machine downtime. They are small, sharp diamond or cubic boron nitride particles embedded in a matrix, attached to a wheel or shaped into a machine tool bit, and used to saw, grind, or machine hard or difficult materials.

Diamonds. Conventional abrasive grinding and cutting wheels are made from alumina (Knoop hardness of 21,000) and silicon carbide (2,400). In 1957, General Electric synthesized the first man-made diamonds (Knoop = 7,000) by a high-presure, high-temperature process. The first synthetic diamond grinding wheels were introduced in 1959.

Manufactured diamonds dominate superabrasive use because producers can control diamond grit shape and friability (ability to self-sharpen by microfracture and cleavage). And diamond is cheap ($2 to $10/carat for friable grades). It is used to work stone (marble, granite), tungsten carbide, concrete, ceramics, and glass. Diamond cannot be used with ferrous metals because its carbon reacts with iron, which dulls its cutting edge.

GE and DeBeers account for 85 per cent to 90 per cent of all man-made diamonds. Other producers include Cogema (France), Magadiamond (Division of Smith International, United States), US

Synthetic, and several small Japanese producers. Diamond prices have fallen over the past decade. The largest diamond application is cutting stone, followed by metal and glass grinding, then machining.

<u>Cubic boron nitride</u>. In 1959, GE synthesized cubic boron nitride (CBN) by the same process it used to make diamonds. CBN, an entirely man-made material, shares diamond's tetrahedral structure and is the second hardest known material (Knoop = 4,700). Technical problems delayed the introduction of commercial CBN wheels until 1969.

CBN costs more than diamond, but does not react to ferrous alloys. It became the abrasive of choice to cut M and T series high-speed tool steel and high-nickel and high-cobalt superalloys. It is a contender for ferrous materials with Rockwell hardness greater than C50 and parts that require tight tolerances or fine surfaces. CBN may also be economical to rough grind soft steels (down to C22).

Norton, the world's third largest diamond grinding wheel manufacturer (behind Asahi Diamond Wheel and Osaka Diamond), figures CBN could be economically viable for 25 per cent of all precision grinding, but its share of the market is only about 5 per cent. CBN has been used most successfully for high-speed steel tool resharpening, though it accounts for only 20 per cent of the business.

<u>New processes</u>. The economics of superabrasive could be changed by the development of chemical vapor deposition processes to produce polycrystalline diamond thin films (and perhaps CBN). This is an inherently less costly process than the high-pressure/ temperature route developed by GE. Crystallume, one of the early diamond-film startups, figured it could make industrial diamonds for 25 per cent of the cost of conventional material. This would drive down diamond wheel and tool bit cost-benefits and open up applications where diamond is now too expensive.

DIAMOND AND CBN MARKET VALUE
($ millions)

Market	1988	1993	1998	2003
Grinding				
Resin	50	65	95	125
Other	25	35	60	85
Tool bits	35	50	70	85
Total	110	150	225	295

Source: <u>High-Tech Materials Alert</u>^{R}

The technique can only grow fine ($\lesssim 2\mu$) diamonds on a limited range of substrates. When researchers learn to make larger diamonds, they could be removed from the substrate and applied to wheels or tool bits in a conventional manner. Ultimately, though, researchers would like to deposit them directly onto wheels or bits. Because the technology is so accessible, many tool makers may eventually enter the diamond synthesis business.

<u>Selling productivity</u>. A CBN wheel might cost 100 times more, and a diamond wheel 10 to 50 times more, than a comparable wheel made of conventional abrasives. What do superabrasives offer to inspire a machinist to pay the difference?

The key advantage of superabrasives is that they hold their cutting edges much longer than other materials. That means wheels and tools wear very slowly, and do not need continuous adjustment to stay within specifications. They produce parts that are consistently within specifications, and that need less inspection and sorting down the line. Low wear lets you run machines with little downtime to replace tool bits, or to true and dress grinding wheels. That lets you leverage your labour, since one person can attend more machines. Superabrasives also yield shorter cutting and grinding cycles, and less metallurgical damage (burn) caused by dull cutting edges.

<u>Grinding/sawing</u>. Superabrasive wheels and shapes that grind and saw are by far the largest market. In fact, roughly 60 per cent of all man-made diamonds are used to make circular saws to cut concrete and decorative stone, such as granite, marble and limestone.

The rest is used to remove small amounts of material to bring a part to exact spec. Most grinding wheels and shapes are custom-made. Norton, for example, sells 250,000 types. Grinding wheels are classified by how the abrasive is bonded to the wheel.

Resin: Phenolic resin is the matrix that accounts for most diamond and CBN wheels. It is easiest to true and dress, and runs with or without coolant. On the down side, the resin's tenuous hold on the grit limits metal removal rates, and high grinding heat degrades the matrix. The largest use of diamond/resin wheels is to resharpen tungsten carbide (WC) machine tool bits and grind WC wear parts.

Vitrified: Vitrified bonds keep grit in place with glassy clays. They are unaffected by grinding heat, and have pores that conduct fluid onto the workpiece and whisk chips off. Once trued, they do not need to be dressed, and they have potentially longer life than resin wheels. But they crack easily and are unforgiving. Vitrified/diamond is used for wet grinding of carbides, diamonds, and ID grinding of ceramic tubes. Vitrified/CBN is used for inside diameter (ID), crush-true, and creep-feed grinding.

Metal: Diamonds and CBN can be bonded to grinding wheels by powder metallurgy. They are the stiffest, most durable, and most thermally conducive. But they need more power to overcome metal bond-to-metal friction, and they are tricky to true and dress. Bronze/diamond's high rigidity permits ultrathin wheels to cut expensive electronic materials, such as silicon (a boule costs $7,000), without wasting precious material. Bronze wheels are also used for cemented carbides, and glass (lenses, mirrors, plates). WC/diamond, the most durable combination, is used to slot concrete highways to prevent hydroplanning, grind refractories, and cut glass. Metal-bonded CBN works best for production honing, slotting/grooving, and high precision cutoff.

Plated: Plated wheels have a single layer of coarse grit attached to a precision-machined steel form. They are designed for very fast metal removal. When the grit is worn down, the form is replated or ditched. Plated diamond is also used for engineering plastics and composites; plated CBN, for high-nickel alloy, jig and slot/groove grinding.

<u>Machining</u>. Machine tools remove material in chips. They are used to shape workpieces, mine minerals, and dig for oil and gas. Diamond and CBN compete chiefly with tools made of whisker-reinforced alumina and tungsten carbide. As hard as WC is

(Knoop = 1,900), diamond will last up to 100 times longer. Diamond tools have been widely accepted by the high-silicon aluminium market, and are also used on glass and other nonferrous metals.

CBN has much higher edge strength than even whisker-reinforced alumina tools, so there are fewer burrs. It performs best on cast iron, while SiC/Al_2O_3 works better with superalloys. SiC/Al_2O_3 tools also cost less, about $10 to $12, compared to $150 to $200 for CBN. Both need rigid vibrationless machines to run their best. (Source: High-Tech Materials Alert, August 1988)

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8. PUBLICATIONS

New textbook on metalcutting theory

A new textbook for teaching metalcutting at the undergraduate or community-college level, Application of Metal Cutting Theory by Fryderyk E. Gorczyca, has been published by Industrial Press Inc. (200 Madison Ave, New York, NY 10016). The 300-page text is based on the author's teaching of tool engineering at Southeastern Massachusetts University.

The five chapters cover economic considerations, a simplified model of the cutting process, cutting-tool materials, mechanics of the cutting process, and tool wear and affiliated production costs.

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PM tool steels

Brochure details chemical analysis, wear resistance and toughness of four CPM (Crucible Particle Metallurgy) tool steels designed to help increase tool life and decrease downtime. Crucible Specialty Division, or Crucible Materials Corporation, Syracuse, N.Y., 4 pp.

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Quality control, tooling book

Quality control products, machine tools accessories, specialized adhesives, and safety equipment are the focus of this detailed 265-page catalogue. Over 500 different products are featured, including surface finish comparators and gauges, inspection lights and magnifiers, replica and proofing compounds and alloys, electronic gauges, data collectors, machine tool safety guards, and gauge stands. Catalogue 687 provides technical, application, selection, and ordering data. Flexbar Machine Corp., 250 Gibbs Rd., Central Islip, NY 11722, USA.

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Silicon nitride cutting tools

Brochure highlights the benefits of Iscanite silicon nitride cutting tools. It presents machining capabilities and tips for increasing productivity as well as production rate and tool life comparisons between Iscanite and other cutting tool materials. A chart on standard Iscanite inserts also is included. Iscar Ceramics Inc., 6 pp.

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High technology ceramics

Packet of data sheets supplies information on alumina, zirconia, and beta-alumina ceramics, plus ceramic cutting tools and packaging. Each data sheet lists complete product specifications. Ceramatec Inc., Salt Lake City, Utah, USA.

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Metal cutting tool handbook seventh edition

By Metal Cutting Tool Institute, Publication Date: January 1988, 900 pp. (approx.), ISBN 0-8311-1176-3.

The long-awaited revision of a classic reference is here. Current and comprehensive, the Seventh Edition covers advances in technology, tooling, materials and designs with up-to-the-minute information on twist drills, reamers, counterbores, taps, dies, milling cutters, hobs, gear shaper and shaving cutters.

The book contains nine sections that reflect the experience of specialists continually exposed to industry problems in everyday manufacturing operations in the cutting tool fields. A detailed table of contents is included in each section, allowing readers to easily access important topics. And an engineering data chapter at the end of the book provides useful tables and formulas on gears, splindle noses and arbors, tapers and angles, milling, shanks, and much more.

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ASM International (Metals Park, Ohio) has recently published two useful volumes of conference papers on machining.

Tool Materials for High-Speed Machining, edited by J.A. Swartley-Loush, consists of 16 papers from the Scottsdale, Ariz, February 1987 conference of the Society of Carbide & Tool Engineers. Papers on the application of ceramic, cermet, CBN, and diamond tool materials as well as ion implantation and coatings intended for both conventional and high-speed machining are supplemented by papers on tool-condition monitoring. This collection will help in keeping up with the ongoing industrial revolution in cutting-tool materials.

Strategies for Automation of Machining: Materials and Process comprises nine papers on the machinability of ferrous workpiece materials, five on the use and wear behaviour of cutting-tool materials, and five on process conditions and sensor technology for tool wear and breakage. The papers were delivered at the May 1987 Orlando, Fla, conference organized by the Machinability Committee of ASM.

The American Society of Mechanical Engineers (New York City) has published the Proceedings of the Fourth US Water Jet Conference. Five of the 25 papers from the conference, held in August at the University of California, Berkeley, deal with manufacturing- related applications.

Annual Review of Materials Science, Vol. 16 and Vol. 17. (ISBN 0-8243-1717-3,. Edited by Robert A. Huggins, Joseph A. Giordmaine, and John B. Wachtman, Jr. Annual Reviews, Inc., 4139 El Camino Way, Box 10139, Palo Alto, CA 94303-0897. 1986. viii, 573 pp., ISBN 0-8243-1716-5.

This, volume 16 in the Materials Science series, follows the high standards of previous volumes. It contains 23 review articles, of 15 to 35 pages each, and is recommended for scientific libraries.

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Tomorrow's materials

Ken Easterling, Book 414, ISBN 0 901462 40 3, Marketing Services Officer, The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB.

Part 1 Fundamentals

Introduction
Order versus chaos in the world of materials
Composite and cellular materials
Why metal bends, glass breaks and rubber stretches
Materials selection
Further reading

Part 2 Applications

Structural materials
Lightweight materials
Wear and heat resisting materials
Optical materials
Electronic and magnetic materials
Further reading

This book begins with an introduction to the fundamentals of materials science and investigates such new materials as aluminium-lithium alloys and fibre/polymer composites for aircraft frames and skins, rolled structural beams made by toughened concrete, new engineering polymers that may soon displace metals, advanced ceramics that promise to revolutionize the machine tool, electrical and automobile engine industries, fibre optical materials networks which will shortly span the world, new generations of transistor and a new superconducting ceramic with applications in computing, medical scanners and levitating trains.

A comprehensive glossary of words and terms used in materials science is also included, thereby making its content accessible to non-specialists of the subject.

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Looking Ahead for Materials and Processes. Vol. 41, Materials Science MonOgraphs. Proceedings of the 8th International Conference of the Society for the Advancement of Material and Process Engineering, European Chapter, La Baule, France, 18-21 May 1987. Edited by Jacques de Bossu, Guy Briens, and Pierre Lissac. Elsevier Science Publishing Co., Inc., 52 Vanderbilt Ave., New York, NY. 1987. xii, 496 pp., ISBN 0-444-41685-4.

This proceedings volume is a collection of 47 papers dealing with the development and application of metallic and nonmetallic materials in such diverse fields as aeronautics, space, marine, industry, transportation, biomedicine, and leisure activities. The subject-matter is concentrated in fibrous composites, emphasizing fibre processing and properties, matrix processing and characterization, composite formulation and properties, as well as many specific applications.

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The technology and applications of engineering materials. Ray, Martyn S. Englewood Cliffs, NJ: Prentice-Hall, 1987. 736 pp. 86-5088.
ISBN 0-13-902099-3.

Materials science. Iron and steel. Non-ferrous metals. Polymers and ceramics. Corrosion. Applied mechanics and materials testing. Joining processes. Fabrication processes. Engineering design.

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New materials database

Lawrence Berkeley Laboratory scientists have created a prototype materials database that should be commercial by next year. It is called MIST (Materials Information for Science and Technology). Developed specifically to meet the needs of scientists (most databases are designed for business use), it contains: (1) an active thesaurus and glossary to interpret diverse nomenclature (as in, ordered materials = intermetallic = ordered intermetallic); (2) standardized data presentation; (3) choice of presentation formats, including facsimiles of published tables and graphs; (4) beginner interfaces and expert commands; (5) ability to search for materials by name, property, or other variable; and (6) automatic conversion of measurement units.

It is part of a joint programme by the National Bureau of Standards and US Department of Energy to improve research and engineering productivity, in this case by getting the latest data to those who need it. Several national and international organizations already input data into MIST, and their number will grow in the future. Stanford University's Data Center will take over operational responsibility next year, when it becomes a full production system. Researchers are also developing innovative ways to plug Apple Macintoshes into the system. (Lawrence Berkeley Laboratory, Mail Code 50B-3238, 1 Cyclotron Road, Berkeley, CA 94720, USA)

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Engineered materials translations

A translation series, covering polymers, ceramics, and composites, has been made available by Materials Information, a joint service of the Institute of Metals, London, UK, and ASM International, Metals Park, OH. Series C, the current series, joins Series A (Nonferrous Metals) and Series B (Ferrous Metals) in offering low-cost translations of some of the most significant non-English-language articles on the engineering applications of those materials. The translations collection includes articles originally published in Japanese, German, French, Russian and Italian. A list of new translations added to the engineered materials collection is released six times per year and is available free of charge.

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Ceramic materials for electronics: processing, properties and applications

Edited by R.C. Buchanan, Marcel Dekker Inc., New York. 1986. 496 pp.

Nine US authors have contributed under the editorship of one of them; seven write from industry and only two from academie. The first two chapters summarize the properties and range of materials used in insulators and capacitors and form a basis for the other six chapters. These deal respectively with: piezoelectric and electro-optic ceramics, ferrites, ceramic sensors, ZnO varistors, multilayer ceramic technology, and conducting ceramics. Each chapter finishes with a comprehensive list of references and, throughout, the emphasis is on the transfer of laboratory knowledge to successful device fabrication; manufacturing methods and the design of commercial devices are described in some detail.

The book is thoroughly recommended to all students in the field of materials. It forms a valuable survey which will be particularly useful for all workers entering the electronics industry.

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Advances in ceramics, Vol. 13. New developments in monolithic refractories

Edited by R.E. Fisher, American Ceramic Society, Columbus, Ohio. 1985. 424 pp.

This volume, which is the 13th in the Advances in ceramics series, contains 32 of the papers given at an international symposium held in conjunction with the 86th annual meeting of the American Ceramic Society in 1984. The papers given at the meeting were devoted to the use of monolithic materials in the metals industries and there is only a one-line reference in a single paper to the use of these materials in the glass industry. However, the papers indicate that significant advances have been made with the compositions of monolithics, such that in the Japanese steel industry some 50 per cent of the refractories are now made of these materials.

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Glass-ceramic materials

By Z. Strnad, Elsevier Science Publishers, Amsterdam. 1986. 268 pp.

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Thermoforming - a plastics processing guide

By G. Gruenwald, Dr.-Ing., P.E., Gannon University, 1987, 224 pages.

This is a comprehensive guide and reference to the thermoforming process, with detailed coverage of basic principles, materials, processing steps and equipment. Special attention is given to important recent areas of development and applications. Well illustrated with more than 100 photographs and schematics.

Contents: (1) Introduction; (2) Heating of the Plastic; (3) Thermoforming Mold; (4) Vacuum, Air Pressure and Mechanical Forces; (5) Cooling of Thermoformed Parts; (6) Trimming of Thermoformed Parts; (7) Thermoforming Equipment; (8) Materials Suitable for Thermoforming; (9) Forming Processes; (10) Design Considerations; (11) Related Forming Process; (12) Processes Competing with Thermoforming.

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Polyurethanes World Congress: 50 years of polyurethanes

Co-sponsors: The Society of the Plastics Industry, Inc., Polyurethane Division (USA) and Fachverband Schaumkunststoffe e.V (Federal Republic of Germany); 1987, 974 pages.

The most comprehensive compilation of new polyurethane/polyisocyanurate technology presented in one volume. Almost 1,000 pages, it includes more than 150 original new technical reports from the recent international congress. Illustrated with hundreds of photos and schematics; extensive data in tables.

Contents: (1) Processing Innovation; (2) Thermal Conductivity and Chlorofluorocarbons; (3) Specialty RIM and Sports; (4) Thermoplastic Polyurethanes; (5) Polyurethanes and the Environment; (6) Automotive; (7) Construction/Electrical; (8) Chemical Innovation; (9) Automotive/Transportation; (10) Construction; (11) Chemical Innovation; (12) Automotive; (13) Footwear; (14) Chemical Innovation; (15) Automotive; (16) Refrigeration; (17) Furnishings; (18) Chemical Innovation; (19) Processing Innovation; (20) Furnishings.

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Whittington's Dictionary of Plastics

Sponsored by the Society of Plastics Engineers, 1978, 344 pages.

This is probably the most widely used reference book on plastics technology. More than a dictionary, it is a mini-encyclopedia of plastics technology. Listed in alphabetic order, with definitions and descriptions, are more than 3,000 terms, including:

. Plastics and other polymeric materials;

. Plastics chemicals - raw materials, additives, fillers, reinforcements, colourants, lubricants, catalysts, etc.;

. Processing and fabrication methods including machinery and equipment;

. Properties (chemical and mechanical) and characteristics;

. Terms relating to tests, flammability, regulatory and environmental aspects, and applications. In addition to coverage of all commercial plastics, there are also definitions of other synthetic polymeric materials - adhesives, elastomers, coatings and fibres.

High-performance plastics

Line of high-performance plastics for injection molding is featured in this six-page colour brochure. Table with trade names, materials, and suppliers for precision molded parts highlights the properties of 21 different types. Also included is a summary of company's molding, quality control, machining, and secondary operations for precision molded parts. Allegheny Plastics Inc., Thorn Run Road, Coraopolis, PA 15108, USA.

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High-performance plastics

Illustrated brochure highlights manufacturing capabilities of precision plastic parts, as well as experience in compression molding, custom machining, isostatic molding, and automatic screw machining of fluoropolymers. Norton-Performance Plastics, Wayne, N.J., USA, 8 pp.

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Fibre-reinforced plastics

"Glassline Review" studies the contributions to life-styles by fibreglass reinforced plastics.

Colour publication includes several articles detailing the impact of composite materials, contributions to fibre optics, and new applications in the fields of medicine and recreation. Discussion also gives background data on material characteristics, performance expectations, design advantages, and processing. Fibre Glass Reinforcements Division, Certain Teed Corp., Valley Forge, PA 19482, USA.

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Physics, technology and use of photovoltaics

By R.J. van Overstraeten and R.P. Mertens. Adam Hilger, 1986.

This book is very well written and covers all concepts of photovoltaic-theory and applications in 10 chapters. The chapters are arranged in such a way that one leads naturally into another. Starting with general physics and photovoltaics followed by the physics of solar cells where monocrystalline silicon, semicrystalline silicon, amorphous silicon and heterojunction and thin-film cells are fully covered. Crystalline silicon and the technology of thin-film solar cells were covered in chapters four and five. The use of concentrators in photovoltaic applications is covered in chapter six. Chapters seven to ten deal with characterization and testing of cells and modules, photovoltaic module operation, photovoltaic systems, and existing photovoltaic systems applications.

The book also contains two appendices, concluding remarks, references and a subject index.

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Conference on advanced composites

(2nd: 18-20 November 1986: Dearborn, Michigan). Advanced composites: the latest developments. Dearborn, MI: ASM International, 1986. 311 pp. 86-072181. ISBN 0-87170-241-X.

This set of proceedings is part of a continuing series on research and development involving composites so as to increase opportunities in industries other than aerospace, defence, and automotive applications. Areas involved for discussion include design, manufacturing, joining, and materials science.

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Friction and wear of polymer composites

Edited by Klaus Friedrich. NY: Elsevier, 1986. 465 pp. (Composite Materials Series, 1) 86-2059. ISBN 0-444-425241.

Interfacial friction of polymer composites. General fundamental principles. Tribological properties of selected polymeric matrix composites against steel surfaces. Friction and wear of metal matrix-graphite fibre composites. Wear of reinforced polymers by different abrasive counterparts. The wear and friction of commercial polymers and composites. Self-lubricating composites for extreme environmental conditions.

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Technomic Publishing Co., Lancaster, PA, has made available the Proceedings of the American Society for Composites - Second Technical Conference. The book (583 pp., hardback) contains 63 papers presented at the 1987 conference, held at the University of Delaware. These papers cover a wide range of topics in processing science, materials science, characterization, mechanics, design and analysis, durability, and nondestructive evaluation.

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ASM International, Metals Park, OH, USA has made available Composites, Volume 1 of the Engineered Materials Handbook. The Composites volume (960 pp.) intends to make aerospace composites technology available to industry as a whole. The book's 13 major sections contain 160 articles written by 184 authors and critically examined in more than 800 reviews. The result is an in-depth review of the latest information about resin-matrix structural composites for engineering applications, as well as metal-matrix, ceramic, and carbon-to-carbon composites. All phases of advanced-composites technology are described, with particular emphasis on engineering properties and manufacturing.

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Metal and polymer matrix composites

J.A. Lee and D.L. Mykkanen, New Jersey: Noyes Publications 1987. Pp. i + 205, ISBN 0 8155 1111 6.

The book is divided into two parts: the first is a technical summary (35 pages) covering selection criteria, applicable materials and cost projections all very much aimed at advanced interceptor structures. The second and much longer part consists of a review of materials properties. This is further subdivided into reinforcements and fabrication methods (22 pages), metal-matrix composites (54 pages) and polymer matrix composites (70 pages).

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"A Guide to Statically Conductive Advanced Material Composites" discusses the phenomenon of electrostatic discharge in plastics, then details several conductive additives for improved surface resistivity features. The design profile, Bulletin 223-388, includes reference tables showing physical and performance properties for several grades formulated from nylon, polycarbonate, polypropylene, and melt-processible fluoropolymers. LNP Engineering Plastics, 412 King St., Malvern, PA 19355, USA.

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Advances in surface treatments; technology - applications - effects. Vol. V.

Edited by A. Niku-Lari. NY: Pergamon Press, 1987. 522 pp. ISBN 0-08-034923-4.

Thermal and thermochemical surface treatments (nitriding, nitrocarburizing, induction hardening, chromizing, phosphatizing). Mechanical surface treatments and their effects (abrasive flow machining, shot peening). Quality control of surface-treated materials (residual stresses, surface roughness, control of surface morphology). Surface finishing (machining, magnetabrasive finishing, grinding). Laser surface hardening of materials. Surface treatments and the environment (wastewater treatment, air purification).

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Technology Advance Centre, Madras (TAC, Madras) releases its first book-Introduction to Corrosion Control

Edited by Dr. K.S. Rajagopalan, Ex-Director, Central Electrochemical Research Institute, Karaikudi. Printed and Published by Colour Publications Pvt. Ltd., Bombay.

Book written by TAC experts to help those who invest in corrosion control to do so with that knowledge of Corrosion and its Control which would help them most.

The book has 12 chapters on (1) Forms of corrosion; (2) Corrosion failures; (3) Metallographic examination and microstructure of metals and alloys; (4) pH-potenmtial diagrams; (5) Polarization diagram; (6) Protective coatings; (7) Alloying for corrosion resisting; (8) Surface modification; (9) Passivity and corrosion inhibition; (10) Electrochemical protection; (11) Analysis of cost of corrosion; (12) Engineering of corrosion control measures.

All the 12 chapters written by well-known authorities on the subject of corrosion control in this country.

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Corrosion handbook

12 large format volumes. 2 volumes per year, the first late in 1987.

The Dechema Corrosion Handbook - a series of at least 12 large format volumes (21 cm x 28 cm) describes the corrosion behaviour of technically important and often applied materials, and shows possible ways to prevent and fight corrosion.

The handbook is a comprehensive, reliable and up-to-date reference work not only for the construction engineer in the chemical industry but also construction and process engineers in other branches of industry as well as for materials scientists in research and teaching.

The comprehensive, reliable and up-to-date reference work for everybody involved in preventing and fighting corrosion. Approximately 350 pages per volume. For more information please contact VCH Verlagsgesellschaft, P.O. Box 1260/1280, D-6940 Weinheim, FRG.

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Nondestructive testing of high-performance ceramics

Edited by Alex Vary and Jack Snyder. Conference Proceedings, 25-27 August 1987, Boston, MA. The American Ceramic Society, Inc., 757 Brooksedge Plaza Dr., Westerville, OH 43081-6136. 1987, 546 pp. ISBN 0-916094-98-7.

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ASTM, Philadelphia, PA, USA is offering the 1988 ASTM Directory of Testing Laboratories. This edition features 1,000 laboratories, the majority located in the USA and 40 in Canada. Searching is aided by detailed subject and alphabetical indices. The laboratories are in the business of performing services for a fee and are not certified or endorsed by ASTM.

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Advanced materials tests

Special materials require new testing procedures as outlined in this informative 16-page colour brochure. Text stresses test methods, results, effects on technology, and characteristics of advanced ceramics and composites. Test equipment and accessories are highlighted. Several photographs show process steps. MTS Systems Corp., Box 24012, Minneapolis, MN 55424, USA.

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Aluminium and its alloys

King, Frank. NY: Halsted Press, 1987, 313 pp. 87-3983. ISBN 0-470-20849-X.

Introduction and basic properties of aluminium. Occurence and extraction of aluminium. Refining of aluminium. Aluminium alloy systems. Properties of aluminium alloys. Production of semi-fabricated forms. Manufacturing processes. Economic factors. Applications. Index.

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Zinc-aluminium alloys

"ZA Alloys Meet the Automotive Challenge" is an eight-page technical paper that explores the advantages of zinc-aluminium alloys for automotive applications. Several photographs show typical alloy parts, while data charts give properties, chemical composition, energy requirements, and related information. Text covers specific automotive part features and production information. A list of references is included. Certified Alloys Co., 5463 Dunham Road, Maple Heights, OH 44137, USA.

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Superconductivity: the threshold of a new technology

By Jonathan L. Mayo, Tab Books, 1988, 144 pages, 7 1/2" x 9", paperback, ISBN 0-8306-9322-X.

This book is designed to serve as a thorough introduction to superconductivity for readers with diverse backgrounds and interests. The full spectrum of superconductivity, from the scientific aspects to the applications to the business and financial aspects, is covered. No specific technical knowledge is required to comprehend the information contained in this book. By the time you are finished reading this book, you should have a good understanding of not only what superconductivity is but also how it is, and can be, used. (Science News Books, 1719 N Street, NW, Washington, DC 20036, USA)

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9. PAST EVENTS AND FUTURE MEETINGS

August 1988

22-26, Sydney, Australia	International Ceramic Conference and Trade Exhibit "AUSTCERAM 88" (N.S.W. Institute of Technology, Department of Materials Science, Box 123, Broadway, N.S.W. 2498, Australia)

22-27, Chatsworth, California, USA	Photovoltaic Technology and System Design (ARCO Solar Inc., 465C Adohr Lane, Box 6052, Camarillo, California 93010, USA)

September 1988

4-10, Szczyk-Bila, Poland	4th International Conference on Physics of Magnetic Materials (Institute of Physics, Polish Academy of Sciences, Al. Lotnikow 32/46, PL-02 668 Warsaw, Poland)
5-9, Newcastle upon Tyne, UK	International Conference on Coatings and Surface Treatment for Corrosion and Wear Resistance (Prof. K.N. Strafford, Newcastle upon Thyne, Polytechnic, UK)
6-8, Oxford, UK	Medical Plastics '88 (Society of Plastics Engineers, P.O. Box 91, DK-1003 Copenhagen, Denmark)
7-9, University of Bradford, UK	5th International Conference on Reactive Processing of Polymers (Reactive Processing Conference, University of Bradford, Bradford BD7 1DP, UK)
7-9, University of Sussex, Brighton, UK	Polymer Degradation Discussion Group, Techniques and Mechanisms in Polymer Degradation and Stabilization (University of Sussex, Brighton BN1 9QJ, UK)
7-15, Chicago, USA	IMTS '88 - Advanced Manufacturing Technology (National Machine Tool Builders Association, 7901 Westpark Dr., McLean, VA. 22102-4269, USA)
8-9, London, UK	Developments in Ceramic, Composites and Coatings (IBC Techn. Serv. Ltd., Bath House, 56 Holborn Viaduct, London EC1A 3EX, UK)
12-13, Rome, Italy	First International Conference on Energy Conservation (New York Institute of Technology, Old Westbury, New York, NY 11568, USA)
12-15, Philadelphia, Pennsylania, USA	Fabricating Composites and Metal Matrix Composites '88 (SME, P.O. Box 930, Dearborn, MI 48121, USA)
12-16, Imperial College, London, UK	Mechanical Testing of Advanced Fibre Composites - Course and Symposium (Composites Centre, Imperial College, Prince Consort Road, London SW7 2BY, UK)
13-15, Dearborn, Michigan, USA	Advanced Composites Conference and Exposition (4th Annual Meeting sponsored by ASM International and Engineering Society of Detroit, USA)
12-17, Wilmington, Delaware, USA	International Symposium on Energy Options for the Year 2000 (Centre for Energy and Urban Policy Research, University of Delaware, Newark, DE 19716, USA)
18-24, Honolulu, Hawaii, USA	International Renewable Energy Conference (Mary Charles & Associates, 2334 South King St., Ste. 205, Honolulu, Hawaii 96826, USA)
19-20, London, UK	New Developments in Moulding Technology (Wolfson Centre for Materials Processing, Brunel, University of West London, Uxbridge, Middlesex UB8 3PH, UK)
19-21, Richland, Washington, USA	Influence of Interfaces on Materials Synthesis and Properties (Pacific Northwest Laboratories, operated by Battelle Memorial Institute, Box 999, Richland, WA 99352, USA)
19-22, Wiesbaden, Federal Republic of Germany	Advanced Composites Meeting; International Congress and Exhibition (Verbundwerk, Demat Exposition Managing GmbH, PF. 110 611, D-6000 Frankfurt, FRG)
19-23, Garmisch-Partenkirchen, FRG	International Conference on Plasma Surface Engineering (Deutsche Gesselschaft für Metallkunde e.V., Adenauerallee 21, D-6370 Oberursel, FRG)
20 September, London, UK	Seminar, Engineering Plastics III: Processing for Profit (Elsevier Seminars, Mayfield House, 256 Banbury Road, Oxford OX2 7DH, UK)
20-22, Niagara Falls, New York, USA	Symposium on the Latest Technology in Reinforced Composites for Corrosion Control (Buffalo Lining & Fabricating Corp., 73 Gillette Ave., P.O. Box 786, Buffalo, NY 14215, USA)
23-28, Reading, UK	World Renewable Energy Congress (Department of Engineering, University of Reading, Whiteknights, Box 225, Reading RG6 2AY, UK)
26-30, Las Vegas, Nevada, USA	20th IEEE Photovoltaic Specialists Conference (Institute of Electrical and Electronic Engineers, 6411 Chillum Pl., N.W. Washington DC 20012, USA)
26-28, Netherlands	Automated Composites (Plastics and Rubber Institute, 11 Hobart Place, London SW1 CHL, UK)
26-30, Saltillo, Coah, Mexico	10th National Congress and Exhibit of the Foundry Industry (Sociedad Mex. de Fundidores, P.O. Box 77-C, Saltillo, Coah, Mexico)
26-30, Lyon, France	Plastexpo Lyon '88 - Plastics an Rubber Exhibition (Plastexpo Lyon, 59 rue Boissière, F-75116 Paris, France)

27-29, Minneapolis, Minnesota, USA	20th SAMPE International Technical Conference/Materials Process (SAMPE, P.O. Box 2459, Covina, Calif. 91722, USA)
27-29, University of Bristol, UK	Autumn Meeting of the Institute of Metals and Conference on "Materials in modern energy systems" (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB)
27-29, Brussels, Belgium	Electroceramics II (Belgian Ceramic Society and Silicates Industriels, Ceramic Science and Technology; Laboratoire Chimie Industrielle et Chimie des Solides, Université Libre de Bruxelles - C.B. 165, Av. F. Roosevelt, B-1050 Brussels, Belgium)

October 1988

2-6, Tsukuba and Miyazaki, Japan	International Superconductor Applications Symposium and Tour (Superconductor Applications Association, 24781 Camino Villa Ave., El Toro, Calif. 92630, USA)
3 October, Atlanta, Georgia, USA	Topical Conference on High-TC Superconducting Thin Films, Devices and Characterization (Synchrotron Radiation Centre, University of Wisconsin-Madison, 3731 Schneider Dr., Stoughton, WI 53589-3097, USA)
3-5, Hirsau-Calw, (Stuttgart), FRG	New Materials by Mechanical Alloying Techniques (Max-Planck-Institut für Metallforschung, Seestrasse 92, D-7000 Stuttgart 1, FRG)
3-6, Saarbrücken, FRG	Third International Symposium on the Nondestructive Testing of Materials (Deutsche Gesellschaft für Zerstörungsfrei, Prüfung e.V., Unter den Eichen 87, D-1000 Berlin 45, FRG)
3-6, Anaheim, California, USA	SAE AEROTECH '88 (Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096, USA)
5-8, Friedrichshafen, FRG	Fakuma 88 - International Plastics Processing Exhibition (P.E. Schall GmbH, Postfach 40, D-7443 Frickenhausen 3, FRG)
5-12, Utrecht, The Netherlands	International Trade Show on Material Flow Control (Koninklijke Nederlandse Jaarbeurs, Postbus 8500, NL 3505 RM Utrecht, The Netherlands)
10-11, Mainz, FRG	International Technical Conference "Fibreglass Reinforced Plastics in the Automotive Industry" (AKV eV, Am Hauptbahnhof 12, D-6000 Frankfurt, FRG)
11-12, London, UK	9th International Conference on Plastics. High Performance Containers (SPE International, Brouwersvliet 5/4, B-2000 Antwerp, Belgium)
12-14, Berchtesgaden, FRG	Second International Conference on Ceramic Powder Processing Science (Pennsylvania State University, 119 Steidle Bldg., University Park, PA 16802, USA)
12-16, Bangkok, Thailand	THAI PLAS 88 - International Exhibition of Plastics and Rubber Machinery (SKH Int. Serv. Ltd., 22/F National Mutual Centre, 151 Gloucester Road, Hong Kong)
13-15, Berlin, FRG	Polymer Conference (Bundesanstalt für Materialforschung und -prüfung, Unter den Eichen 87, D-1000 Berlin 45, FRG)
13-15, Dearborn, Michigan, USA	Advanced Composites Conference/Exhibition (ASM International, Metals Park, OH 44073, USA)
16-18, San Francisco, Calif., USA	Superconductors in Magnetics (Advantage Quest, 1110 Sunnyvale-Saratoga Road, Suite C2, Sunnyvale,Califorina 94087-2515, USA)
16-20, Minas Gerais State, Brazil	43rd Associacao Brasileira de Metais - Annual Congress (ABM, Brazilian Society for Metals, Rua Antonio Comparato, 218 - 04605 Sao Paulo, Brazil)
17-18, Pennsylvania State University, USA	Symposium on Characterization of Polymers (Keller Conference Centre, University Park, PA 16802, USA)
18-19, Vienna, Austria	Seventh Hermann F. Mark Symposium "Heat-stable Polymers" (Österr. Kunststoffinstitut, Franz-Grill Strasse 5, Arsenal Objekt 213, A-1030 Vienna, Austria)
18-19, Philadelphia, Pennsylvania, USA	Materials Futures: Strategies and Opportunities (US-Sweden Joint Symposium, College of Engineering, University of Delaware, Newark, DE 19716, USA)
18-20, Pittsburg, Pennsylvania, USA	International Congress on Technology and Technology Exchange (International Technology Institute, 7125 Saltsburg Road, Pittsburg, PA 15235-2297, USA)
18-22, Munich, FRG	Ceramitec '88 (Kallmann Association, 5 Maple Ct., Ridgewood, NJ 07450-4431, USA)
19 October, Boston, Massachusetts, USA	Superconductivity '88 (Society of Manufacturing Engineers, One SME Dr., P.O. Box 930, Dearborn, MI 48121-0930, USA)

There will be two meetings at the University of Reading, UK:

21-22, Reading, UK	Photovoltaic Meeting on Rural Electrification (Department of Engineering, University of Reading, Whiteknights, P.O. Box 225, Reading RG6 2AY, UK)
23-26, Reading, UK	Renewable Energy World Congress (Department of Engineering, University of Reading, Whiteknights, P.O. Box 225, Reading RG6 2AY, UK)

24-26, Eastbourne, UK	1988 Powder Metallurgy Group Meeting "The Wider World of Metal Powder Technology" (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, UK)
26-27, Brussels, Belgium	Aeroplas '88 - Conference on Polymer Developments for Aircrafts of the Nineties (Corp. Development Consultants Ltd., 13 High Street, Thornbury, Bristol BS12 2AE, UK)
26-28, Faenza, Italy	First National Conference on Advanced Ceramics (IRTEC-CNR, Via Granarolo, 64 Faenza, Italy)

November 1988

30 Oct. - 1 Nov., Monterey, California, USA	High Performance Inorganic Thin Film Coatings (Gorham Advanced Materials Institute, P.O. Box 250, Gorham, ME 04038, USA)
30 Oct. - 1 Nov., Caracas, Venezuela	5th Aluminium Conference (Metal Bulletin Conference Ltd., Park House, Park Terrace, Worcester Park, Surrey, KT4 7HY, UK)
3-4, Bombay, India	International Conference on Polymers, Plastics and Rubber Processing Technology (Alena Enterprises of Canada, P.O. Box 1779, Cornwall Ontario K6H 5V7, Canada)
7-10, Atlanta, Georgia, USA	ASTIM Symposium on Composite Materials and High Modulus Fibres (American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, USA)
7-10, Blackpool, UK	COMPEX '88, Composites/Reinforced Plastics Exhibition (British Plastics Federation, 5 Belgrave Square, London SW1X 8PH)
7-11, Sarajevo, Yugoslavia	International Plastics and Rubber Fair (Centre "Skenderija", Ul. Mice Sokolovica bb, YU-71000 Sarajevo, Yugoslavia)
8-9, Osaka, Japan	Advance Technology of Composite Materials (Osaka Municipal Technical Research Institute, 1-6-50 Morinomiya, Joto-ku, Osaka, 536, Japan)
8-11, Amsterdam, The Netherlands	Corrosion Prevention in the Process Industries (National Association of Corrosion Engineering, P.O. Box 218340, Houston, TX 77218, USA)
10 November, London, UK	Information on New Materials, Seminar (Seminar will look at sources of information including databases, business literature and research centres). (British Library, Science Reference and Information Service, 25 Southampton Buildings, London WC2A 1AW)
10-15, Tokyo, Japan	12th Plastics & Rubber Fair (JP Fair Association, Ginza-Yamagishi Bldg., 2-10-6 Ginza, Chuo-ku, Tokyo 104, Japan)
13-15, Monterey, California, USA	The Global Business and Technical Outlook for High-Temperature Superconductivity (Gorham Advanced Materials Institute, P.O. Box 350, Gorham, ME 04038, USA)
14-16, Monte Carlo, France	Superconductors. Strategic Implication of Application and Opportunities (Strategic Analysis Inc. and European Chemical News, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS, UK)
14-18, Colorado Springs, Colorado, USA	Conference on the Science and Technology of Thin Film Superconductors (Solar Energy Research Institute, 1617 Cole Blvd., Golden, CO 880401-3393, USA)
15-18, Los Angeles, California, USA	Advance Polymer Composites for Structural Applications (Advanced Polymer Composites Division-in-Formation of Society of Plastics Engineers; R.T.P. Company, 650 Tamarack No. 1002, La Brea, CA 92621, USA)
15-18, Hangzhou, People's Republic of China	Symposium on Refractory Raw Materials and High Performance Refractory Products (Refractories Society of Chinese Metals, Luoyang Institute of Refractories Research, Louyang, Henan Province, People's Republic of China)
22-23, Würzburg, FRG	Symposium "Plastics in Growth Areas" (Süddeutsches Kunststoff-Zentrum, Frankfurterstrasse 15, D-8700 Würzburg, FRG)
23 November, Paris, France	Seminar "Plastics in Agriculture (Société Française des Ingénieurs Plasticiens, 65, rue de Prony, 75854 Paris Cedex 17, France)
23-24, Baden-Baden, FRG	Conference "Polymer Reactions, Continuous Reactive Compounding" (VDI-Gesellschaft Kunststofftechnik, Postfach 1139 D-4000 Düsseldorf 1, FRG)
27-30, Las Vegas, Nevada, USA	Third International Symposium on Ceramic Materials and Components for Engines (American Ceramic Society, 757 Brooksedge Plaza Dr., Westerville, OH 43081-6136, USA)
28-29, Salzburg, Austria	SPC Conference on Engineering Plastics: Interdisciplinary Views (Volkswagen AG, D-3180 Wolfsburg 1, FRG)

28-30, Zürich, Switzerland	Specialty Plastics Conference 1988 "Polyethylene and Polypropylene Resins, Markets and Applications" (Maack Business Services, Seestrasse 308, 8801 Zürich, Switzerland;
28 November - 3 December, Boston, Massachusetts, USA	Materials Research Society Autumn Meeting (Materials Research Society, 9800 McKnight Road, Suite 327, Pittsburg, PA 15237, USA)

<u>December 1988</u>

5-6, National Physical Laboratory, Teddington, UK	Wear of Ceramics - Test Methods and Mechanisms (Materials Engineering Committee of the Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, UK)
14-16, Bologna, Italy	7th International Symposium on Ceramics (Centro Ceramico- Bologna, Via Martelli, 26-40138 Bologna, Italy)

<u>January 1989</u>

4-6, Kanpur, India	International Conference on Advances in Chemical Engineering (Department of Chemical Engineering, Indian Institute of Technology, Kanpur, 208 016, India)

<u>February 1989</u>

6-10, Dallas, Texas, USA	44th Annual Composites Institute of the Society of Plastics Industry (Composites Institute, SPI, 355 Lexington Ave., New York, NY 10017, USA)
28 August - 1 September 1989, Neuchatel, Switzerland	Third International Conference on Surface Modification Technologies (Metallurgical Society of AIME, co-sponsored and hosted by Centre Suisse d'Electronique et de Microtechnique S.A., Neuchatel, Switzerland. (Dr. T.S. Sudarsha Materials Modifications, Inc., P.O. Box 4831, Falls Church, VA 22044, USA)

PREVIOUS ISSUES

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Resources available

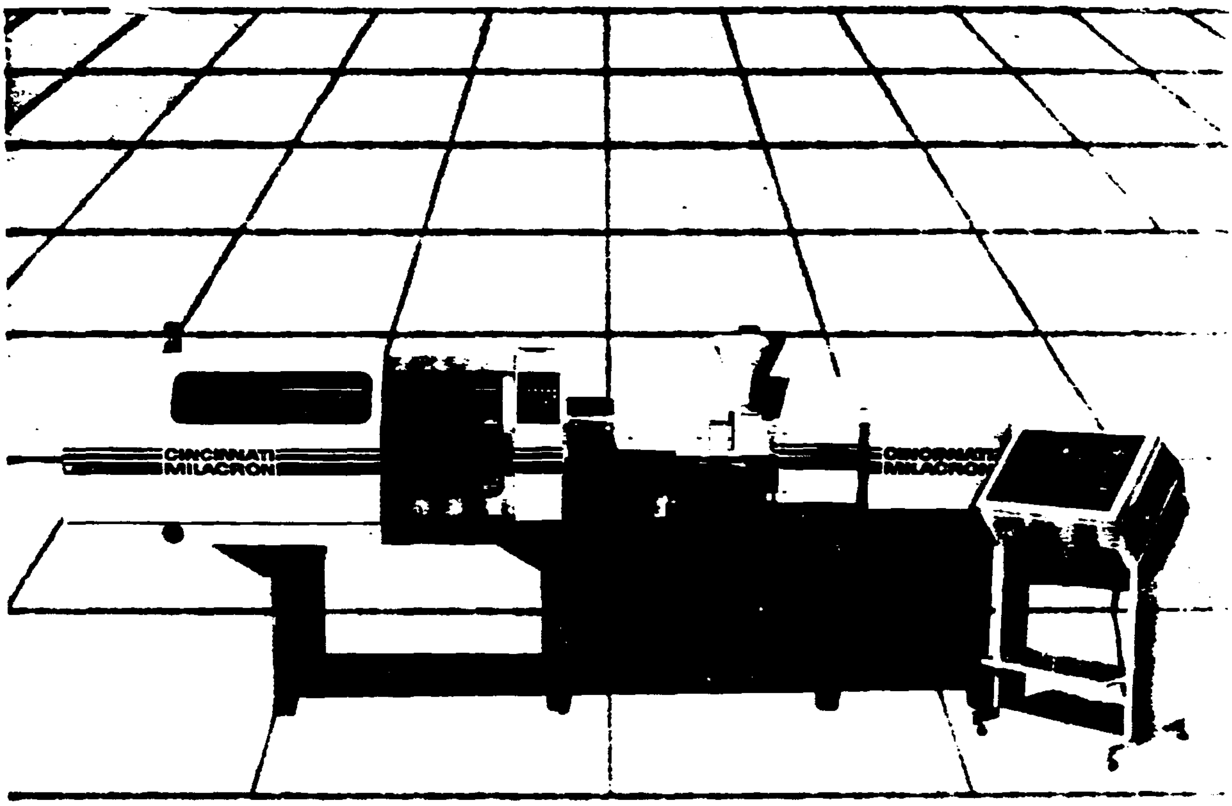
Know-how, designs and licences offered to manufacture drilling machines for water wells of up to 2.5-m diameter and 80-m depth and for concrete-injected piles of up to 2-m diameter and 45-m depth. Claude Bourg, Drill-France, B.P. 15, Le Haillan 33160, France.

Know-how available to manufacture synthetic ceramic from mineral wastes, sand and a binding synthetic resin for use as sanitary ware, material for furniture, decorative items etc. L. Valette, Administrateur Gerant, Science, 98 avenue de Tervueren, 1040 Brussels, Belgium.

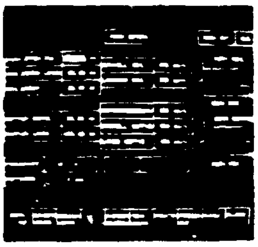
Manufacturers of various metal powders offer know-how for the production of electrolytic copper and iron powder, atomized aluminium powder and synthetic iron oxide. R. Devroy, Radar International, Post box No. 2014, Calcutta 700 001, India.

Technical know-how and complete turnkey plants available for the production of mono-crystalline and poly-crystalline solar photovoltaic cells and modules and integration of systems, such as photovoltaic powered pumping, refrigeration, communication and water purification systems. N. R. Jayaraman, Vice-President, TPK International Inc., 36 Bentley Avenue, Nepean, Ontario K2E 6T8, Canada.

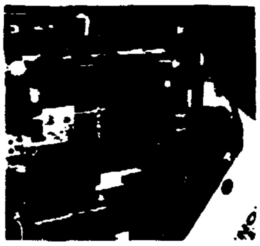
Technology and licensing available for manufacturing polyurethane from saturated polyester polyols, polyether polyols, isocyanate intermediates, one- and two-component polyurethane systems. Capacity tailored to requirements, from 2,000 tonnes upwards. Application: flexible, semi-rigid polyurethane foams, industrial and domestic appliance insulation, shoe soling, coating and sealants. Synthesia Inter AG, Tigerbergstr. 2, CH-9000 St. Gallen, Switzerland.



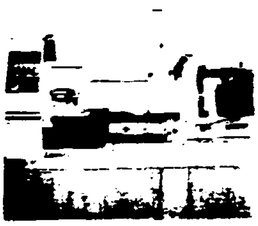
Fully electronic plastic injection molding machines "ACT" provide versatile, high-precision molding.



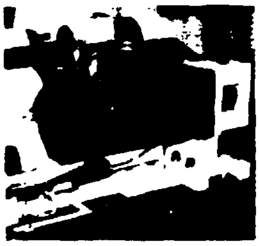
All "ACT"-models come equipped with advanced CNC controllers as well as AC servo motors Fast easy setting of parameters using a versatile 14" colour graphic CRT Without need for setting limit switches valves and other mechanical adjustment All molding parameters are recalled within seconds from the built in memory With additional external memory capacity can be expended up to 240 molds CNC controllers and AC servo motors provide high precision molding



The "ACT" clamping unit features a double-toggle design It ensures high speed and repeatability An AC servo motor is also used in the ejector mechanism Programming from CRT, number of strokes length speed and starting position provides maximum flexibility Each AC servo motor operates with a precision of 0 01 mm for each movement and also during movement All AC servo motors are maintenance free and carbon brushes are not required



The ACT's combined use of powerful AC servo motors and precision ball screws has enabled exact control of injection screw positions and injection speeds The ACT's extra heavy-duty AC servo motor features advanced phase control technology which maintains powerful torque even in the higher speed range In addition a pressure sensor is mounted at the base of the screw to provide pressure control accuracy



The AC servo motors utilized in the ACT are extremely efficient since they run only when needed and only to the extent needed They thereby result in a significant saving in energy Power consumption is reduced by up to 75% Oilless bushings are used in the toggles and platen guides As a result molded products are kept free of oil and the work environment is kept extra clean All "ACT" models from 150 kN up to 3000 kN with direct drive by AC servo motor make for extremely quiet operation and a clean pleasent work environment Ideal for clean room applications

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Postfach 111 A 1232 Wien Austria
Tel (0 22 2) 67 76 11 0
Telex 131518 cmaw a
Telefax (0 22 2) 67 22 72

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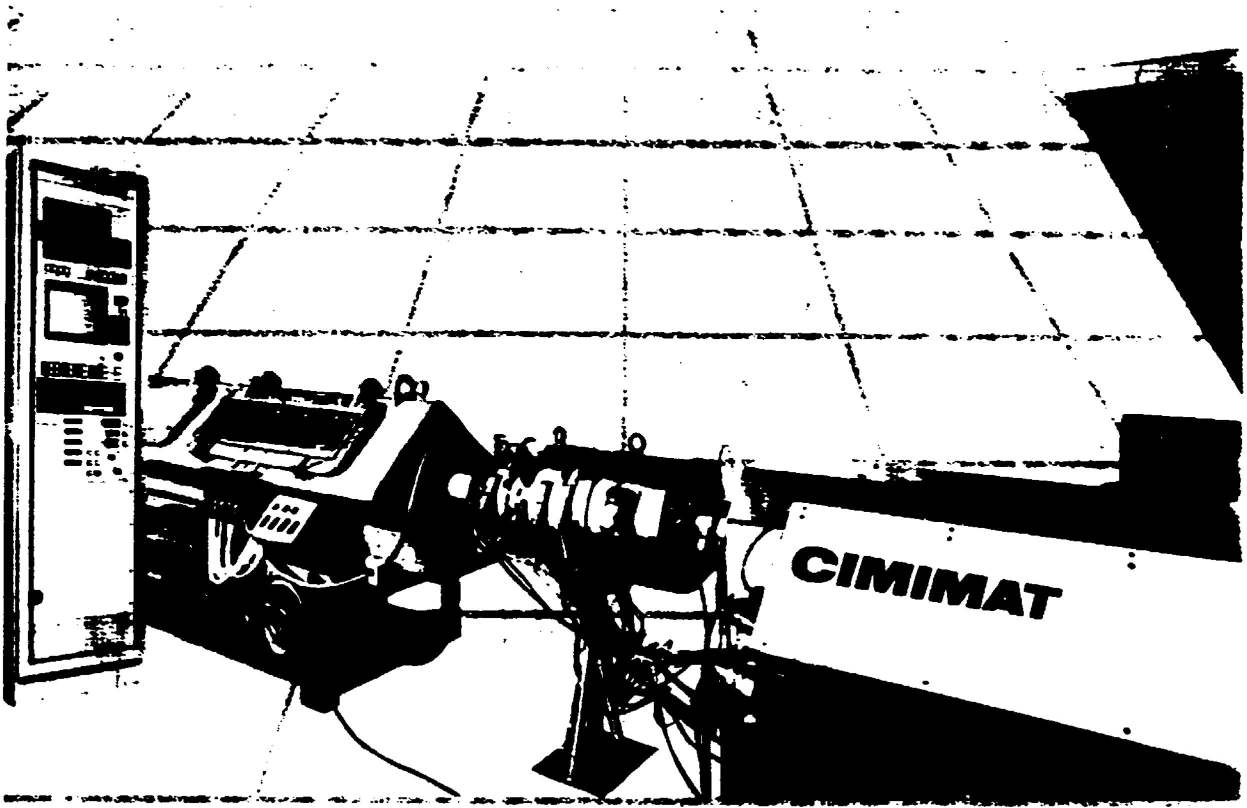

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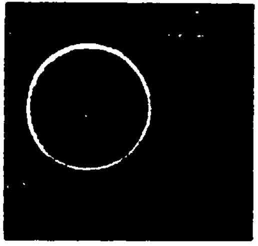

Because:

You will be able to control wall thickness tolerances not only over the full pipe length but over pipe circumference as well.
This feature yields wall thickness tolerances of below [illegible] of those admitted by DIN standards, and you save expensive raw material.
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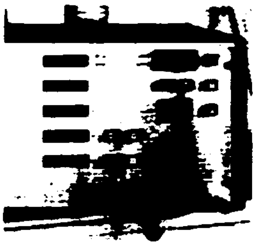

Because:

You will be fully independent of fluctuations in different raw material compounds.
The new weighing system SAVEOMAT controls the precise material consumption of the extruder. When employed in standard pipe plants, the SAVEOMAT system makes for controlling haul-off speed so as to reach contant meter weights. And when employed in a CIMIMAT® pipe line, the data acquired are used for automatic gauging in ultrasonic wall thickness measuring.
In this way you are independent of temperature fluctuations and the wall thickness meter will control haul-off and centering units to minimum wall thickness.

Because:

The automatized pipe extrusion line CIMIMAT® is equipped with the thermal pipe centering system CIMICENT®.
This is replacing a complicated and mechanically sensitive die head construction.
The thermal pipe centering system CIMICENT® works faultfree and is able to centralise thin or thick areas by equalising oposing sides.
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Microprocessor control CIMICRON 9/16 guarantees pipe production within closest tolerances and it warrants moreover that once optimized process parameters are reliably reproducible.
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Advances in Materials Technology: Monitor
Reader Survey

The Advances in Materials Technology: Monitor has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this newsletter. Kindly, therefore, answer the questions below and mail this form to: The Editor, Advances in Materials Technology: Monitor, UNIDO Technology Programme at the above address.

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Which section in the Monitor is of particular interest to you?

Which additional subjects would you suggest be included?

Would you like to see any sections deleted?

Have you access to some/most of the journals from which the information contained in the Monitor is drawn?

Is your copy of the Monitor passed on to friends/colleagues etc.?

Please make any other comments or suggestions for improving the quality and usefulness of this newsletter.

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Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the 12th issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.

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