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RECENT DEVELOPMENTS IN ADVANCED MATERIALS TECHNOLOGY: CAD/CAM APPLICATIONS

A REPORT

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New material technologies demand new production technologies. The compound casting of light metal and ceramics in the form of fibre compound using directional long fibres opens up a new range of possibilities. Improvements in the thermal stability and resistance to corrosion can be achieved by new magnesium alloys. At room temperature, the fracture toughness and Young's modulus can be doubled, and at elevated temperatutures it is now theoretically possible to increase both values by a factor of 10, in comparison to non-reinforced light metal. These are, but a few instances, wherein CAD/CAM applications have played a decisive role in the evolution of new material technologies. The era of fast-desk top computer with parallel processing offers unprecented opportunities to make a quantum leap forward in the efficiency of materials useage. The current needs for greater productivity also have added new demands on the design process to exploit the CAD/CAM methods while being more responsive to the overall production process.

In this paper, initally, the generally understood meaning of CAD/CAM is presented, followed by a review of the state-of-the-art of some of the CAD/CAM applications, especially with regard to castings. Each section is followed by a brief report on the future trends.

1. WHAT IS CAD/CAM:

A: What is CAD:

Computer aided design (CAD) is a technique in which man and machine are blended into a problem- solving team, intimately coupling the best characteristics of each. The result of this combination works better than either man or machine would work alone, and by using a multi- disicipline approach it offers the advantage of integrated team-work.

CAD implies by definition that the computer is not used when the designer is more effective, and vice versa. This being so, it is therefore useful to examine some individual characteristics of man and computer in order to identify which processes can best be seperately performed by each, and where one can aid the other. Table 1 compares the capabilities of man and computer for a range of tasks. It can be seen that in most cases the two are complementary, that for some tasks man is far superior to the computer, and that in others the computer excels. It is, therefore, the marriage of the characteristics of each which is so important in CAD. These characteristics affect the design of a CAD system in the following areas:

a) Design construction logic: The use of experience combined with logic is a necessary ingredient of the design process. The design construction must therefore be controlled by the designer. This means that the designer must have the flexibility to work on various parts of the design at any time and in any sequence, and be able to follow his own design logic rather than a stylised computer logic. The computer cannot cope with any significant learning. This is left to the designer, who can learn from past designs. The computer can, however, provide rapid recall of old designs for reference. Thus, in some ways the designer can pass on his experience to the computer, and other designers can then have access to it.

b) Information handling: Information is required from the specification before the design solution stage can proceed. Similarly, when the design solution is complete, information must in turn be output to enable the design to be manufactured. Fig.1 shows the application of this process to manual design. Information is assimilated by the designer from the input specification. The design solution process then takes place, whereby, information is passed from the designer to the paper and back again in the form of drawings and instructions is produced. Fig.2 shows the process extended to the combination of designer and computer. The design solution now includes a flow of information betweeen the designer and computer in the form of graphics and alpha-numeric characters. The initial specification must be input to the designer in order that selected parts can be communicated to the computer in a form that it can understand and use. The first role of the computer is to check the information for human errors, which must be corrected by the intervention of the designer.

c) Modification: Design descriptive information must frequently be modified to make correction of errors, to make design changes, and to produce new designs from previous ones. The computer has the ability to detect those design errors which are systematically definable; whereas man can excersise an intutive approach to error detection.

d) Analysis: A computer is very good at performing those analytical calculations of a numerical analysis nature which man finds time-consuming and tedious. As much as possible of the numerical analysis involved in the design should be done by the computer, leaving the designer free to make decisions based on the results of this and his own intutive analysis.

It can thus be seen that there exists a clear division between the functions of man and computer in CAD:

The computer SERVES as an extension to the memory of the designer, ENHANCES the analytical and logical power of the designer and RELIEVES him from repetative and routine tasks.

The designer CONTROLS the design process in information distribution, APPLIES creativity, ingenuity and experience and ORGANISES design information.

B. What is CAM:

The fields of manufacture and design are invariably separate, but it is a natural step to decrease the gap between the drawing board and the manufactured item. The way to achieve this is to ensure that work carried out in the design process is not needlessly repeated during manufacturing. Thus, many companies are turning to computer aided manufacturing (CAM) techniques, mainly in the form of numerically controlled (NC) machines, in order to provide greater flexibility in production.

Computer graphics facilities and the availability of supporting software have given the designer the tool they need to produce computerised geometrics, and several interactive graphics have been developed. In the case of a NC, a part-programmer will be given an engineering drawing of the required object and will produce a part programme manuscript. This involves the coding of the geometry of the item, followed by the coding of the statements to describe the tool motions required to carry out machining. The manuscript, when complete, will be processed by a NC processor, and if no errors are detected, a control tape will be produced. NC instructions are written in control langauges such as APT. This term APT stands for automatically programmed tools and refers to both a langauge as well as a computer programme. The APT langauge describes the sequence of operations to be performed by the NC machine. Today, systems have been developed in which NC machine tools are directly driven from the minicomputer without the need for the APT system. Such systems are called CNC or computer numerically controlled systems. A more sophisticated system is a DNC (direct numerical control) system which networks several minicomputers to a central mainframe computer. The main advantage for this configaration is that when the main-frame is temporarily down, the machine tools can continue to run off the memory of the minicomputers. Modern computer technology now makes creation and verification of the NC instructions more effecient. By checking the tooling programme with a visual CRT, for example, less machine tool time is spent in verifying cutter paths. Perhaps, more important, is that the computer itself can now generate a NC programme directly from a geometric description of the part.

C: What is CAD/CAM:

CAD/CAM involves the creation of the mathematical description of the parts or shape in 3-D space within a data base. This mathematical description can be used for the verification of fit and interference within an assembly, structural intergrity, volumetric and area properties, producing shrink factor for more concise net part production, automatic drawing creation, jig and fixture development and so on. Furthermore, this defined geometry can be used by the manufacturing personnel to simulate graphically tool motion, cutter paths etc. This simulation provides a cost effective way of getting the job done in several ways. Firsty, it provides NC/CNC information more economically than any other method. Secondly, it eliminates duplication and communication problems between the designer and the part programmer and thirdly, eliminates the need for unnecessary rework of prototypes and tryouts.

Having thus got a general idea of CAD/CAM, we shall take a look at the current state-of-the-art of its applications. But before that it must be understood that CAD/CAM is just a part of a broader Computer Aided Engineering (CAE). It is also referred to as a part of Computer-Integrated Manufacturing (CIM).

2. STATE-OF-THE-ART:

2.1 Introduction:

The past few decades has witnessed rapid strides in technology. In keeping with the technological advances, materials development and manufacturing process engineers are increasingly turning to computers as a answer to their manifold problems. One of the most spectacular developments has been in the area of CAD/CAM applications.

Today, it is common place to find arrays of graphics workstations and networks of computers in design offices, which have revolutionised drawing office practices in the design of structures and components. Thus, products can be designed and analysed 'ad infinitum' long before prototypes are manufactured and tested.

The need and availability of new materials like ceramics, metal-matrix composites etc., have brought specific challenges to the materials engineers in terms of appropriate testing procedures to be developed, interpretation of the subsequent materials data and modelling the performance of advanced materials. Effective modelling can be used to identify the potential sites of failure in the end product caused by stress or the formation of defects during manufacture.

Simulation programes enables new techniques or components to be tested at relatively low cost without incurring time penalites for the production of equipment or cost of manufacture. Manufacturing process are however, inherently non linear and involve large plastic work and/or changes in shape, making calculations very complex. To solve such problems numerically, requires the use of extremely powerful computers and unobstructed access to them. In recent years, very powerful super-work stations and mini-supercomputers have arrived on the market and has,at last, brought affordable computing to those who need it for purposes of simulation. It is possible to simulate a wide variety of forming process, from casting through forging to pressing, rolling and drawing. The most recent simulation includes the joining of metal-matrix composites. Weldability assessement of cast superalloys for turbo engines, investigations on the welding properties of titanium aluminide alloys for aerospace applications and studies on the effects of thermal and mechanical shock and/or fatigue on metal matrix composites, superalloys and other aerospace materials are also being attempted using such techniques. Thus, physical simulation techniques play an important part in materials fabrication and production and makes the possibility of meeting the demands of maximum efficiency. minimum downtime and improved quality, a reality.

As the price of CAD/CAM systems, in terms of computer horsepower and software facility, has tumbled in recent years, more and more companies are willing to look at the capabilities of these systems beyond straight design-drafting. Among the attention drawing areas are inspection and testing. Concurrent with this widening of intrest areas has been the increasing importance of quality control. It is inevitable that these two areas would be examined concurrently. The application of CAD/CAM to inspection and testing has already achieved benifity beyond what has been thought possible . CAD/CAM's implication are not a 'pie in the sky' but a 'down to earth' enhancement to the efforts of professionals in achieving their goals. We shall now review some of its recent applications.

2.2 CAD/CAM applications to castings:

With the ever changing needs in today's market place-new technology, competition, and increased regulations-each business firm must continually seek better ways of conducting its varied activities if it is to survive and prosper. The foundry industry is not far behind in applying CAD/CAM techniques to castings and casting production. There are a variety of economical and technological benefits which the foundryman can derive from it.

There are, however, several major scientific or engineering related 'roadblocks' to the application of computer technology in casting design. These impedimiments pertain to the geometric modelling/physical simulation problems, the provision of thermal transport data, the problem of filling transients associated with the pouring of castings, the modelling of the interfacial phenomenon, the accurate description of the interaction of the moulding medium and the solidifying casting and finally the computation system itself.

There are a variety of specialised steps in the production of casting, namely:

1) consideration of the castability of the product design itself,
2) consideration of the tradeoff between the product design objectives and castability,
3) design of the moulding technique to incorporate features of casting including the use of cores, location of parting lines, etc.,
4) design of casting rigging items and theirlocation, such as risers, gating system, use of chills, etc.

The optimum combination of these design considerations bear directly upon the productivity of the metalcasting industry, a critical industry not only in terms of its size, but also as it is highly energy intensive and many of the engineering products can be produced on an economical basis only through the castng route. Inappropriate casting design can lead to a variety of wasteful and unproductive costs, and in certain cases, component failure; unsoundness may require expensive rework or casting rejection; misruns and freeze-offs due to poor casting design result in scrap; surface quality is directly related to overall casting and gating design; and marginal feeding conditions result in sporadic porosity. In the past, and even now in many instances, the process of design decision in this area have resided in the hands of skilled and experienced foundrymen. If a competative position is to be maintained, these skills must be supplanted with a more engineering approach. Simulation of casting solidification provides an opportunity to achieve a degree of design optimisation not hetherto possible which would result in a more efficient and profitable production system. The application of CAD/CAM has been slow in its implementation in the foundry industry principally due to the aforementioned scientific or engineering road blocks.

In the foundry, three forms of CAD/CAM are available:

* CAD systems to assist the drawing office,

* CAM systems which enable conventional drawings or CAD drawings to be intrepreted for manufacture on NC tools, so assisting the planning office,

* CAD/CAM systems which enable the design office to design unique components with parting lines, draft angles and splint planes, which can be analysed and optimised for weight, stress etc., and which then allows both roughing

cutter paths and finish cutter paths to be calculated directly and which assist in tendering, planning, etc.

Let us now take a look at the foundry CAD/CAM system. Fig.3 depicits a typical CAD/CAM system and the flow of information within the various components. Fig.4 illustrates how a CAD/CAM system can be used in a foundry. A graphics terminal essentially consists of a digitiser combined with a CRT (cathode ray tube), a data tablet, a function key board and an alphanumeric key board and a hard copy device for printing alphanumeric or plotting graphical data.

Introduction of CAD/CAM in a foundry can be visualised as a three stage process:

1) Introduction of computer aided drafting: This is to cater to the drafting needs of the foundry. In computer aided drafting, the workstation substitutes the drawing board i.e., the display screen simulates the drawing board. The draftsman, with minimum of training, can create drawings on the display screen using a set of commands. These commands are available through a menu selection board. Further, graphic data can be input to the computer through devices like the digitiser or the light pen. Repetitive types of drawings which often encountered in foundry R&D departments can be generated with utmost ease in this fashion. Simultaneously as the picture is being created on the display, a file is also created, With suitable software, it is possible to save this file for retrieval at a future date. Once the final drawing is created with all the details, hard copies can be had through the plotter.

2) Introduction of computer aided drafting and design: This is to design feeder and gating systems by interaction between the engineer and the CAD system. Here, modelling techniques, for geometric modelling or process modelling are

used. In the foundry, modelling refers to the development of a computational technique which will:

* Design gating and feeding systems for castings,
* Specify optimum mould and pouring temperature,
* Predict residual stresses and hot tearing,
* Predict post casting processing and casting properties,
* Provide the basis for plant scheduling and production planning.

A geometric model can be constructed in three ways,

* A wire frame model in which the edges of a part are represented by lines only,
* A surface model in which a clearer interpretation of curved surfaces is facilitated,
* A solid model which is built out of a set of basic 3-D shapes like a cylinder, prism, cone, etc. These can perform several functions which are not possible using 3-D wire frame models, for eg., they can automatically produce isometric or ortographic views of the component. Mass properties such as volume, centre of gravity etc., can also be determined. Sophisticated software facilities are however required for these.

Process modelling techniques are particularly suited for foundry industries, as fundamental phenomenons like heat and mass transfer, fluid flow etc., are encountered, which can be mathematically described with a fair degree of precision. Simulation techniques using finite element or finite difference approximations are widely used to solve such problems.

3) Introduction of computer aided drafting and design cum manufacture: This is to manufacture dies and patterns. Taking into account the various design parameters and post

casting processes, the designer can prepare a NC tape on the computer, which can be used to machine a pattern or a die. A realistic estimate of the production problems, design deficiencies and production costs can be made.

An example of the benefits of introducing CAD/CAM for computerised die manufacture is given in Fig.5, which shows why CAD/CAM techniques are becoming important to the foundryman. Table 2 gives some recommendations for different types of foundries purely on what CAD/CAM systems can do; the cost effectiveness, however, has to be worked out in great detail. In Tables (3-6) are listed some of the software available for different applications. It appears as though the one developed at Foseco, called SOLSTAR is the most popular among foundrymen. This package can be used to predict and eliminate shrinkage defects in castings. It uses its own solid modeller to generate a full 3-D solid model of the casting shape, feeder and runner system. The programme carries out a combined thermal analysis and solidification simulation, to determine shrinkage defects in the casting, feeder and runner systems.

Ove Arup and partners has been developing software which can deal with specific industrial situatations such as those encountered in metal forming process or the automotive industry. These programmes are 3-D finite element codes, written specifically for the efficient solution of problems involving a high degree of material, geometric and thermal non-linearity. An example of the simulation of the solidification and cooling in a turbine blade casting is shown in Fig.6, indicating parts which solidify first and areas of the cast blade in which voids are likely to form. Fig.7 shows another example of the simulation of solidification in a structural casting.

Solid modelling computer programmes can be applied to further the design of complex castings. A solid modelling programme is similar to a computer aided drafting programme, in that both are used to define the geometry of components. A computer aided drafting performs this in 2-D whereas a solid modeller can create, display, manipulate and modify a component in 3-D.

There are significant benefits that can accure from solid modelling of castings. One feature of a solid modeller is that the component can be readily visualised from different angles. This makes it possible to minimise pattern-making errors and so reduce production lead times. Moreover, most solid modellers permit the component design to be interrogated, allowing design features to be assessed, and appropriate design changes can be made with relative ease and the new model can be redisplayed.

As an example of this approach, Fig.8 illustrates a solid model of an investment casting created from a technical drawing of an aerospace burner nozzle. Various hidden line views of the shape can be obtained and arranged in such a way as to form a first or third angle projection. It is also relatively easy to generate any cross-section of the component, Fig.9. With some solid modelling packages it is also possible to offset faces to allow for casting contraction. When the geometrical information on these views is transferred to a computer aided drafting package, the technical drawing can be dimentioned in the normal way. A solid model of a casting thus contains comprehensive geometrical information that can be automatically manipulated and used to enhance casting design and productivity.

Another novel approach to the design of a golf club head using this technique, is illustrated in Fig.10. This involved producing a club with a larger than standard area, to improve the chance of a golfer hitting the ball near the sweet spot of the club. The sweet spot is an area near the centre of gravity of the club head that the ball must strike to produce a perfect shot. The constraints in producing the new design were as follows: first, to preserve the feel of the club. the new head design had to possess the same weight as the original, second, both the loft angle and the lie of the club had to be preserved and finally the modified design had to be aesthetically pleasing to aid the marketing of the club. To do this, the original club was solid modelled, the front face of the original club was enlarged and excess metal was removed from a raised section and this section was recessed into the back face of the club, as shown in Figs.10a and 10b. Also, the programme could track how the centre of gravity would shift as the design was altered. This illustrates the creative application of solid modelling to advance the design of a cast component for the benefit of the end user.

Mathematical modelling is a relatively new disicipline within the field of materials processing. These techniques are used for the optimisation and on-line control of existing operations and is even more important in designing the new metals and materials processing systems necessary for diversification strategies. Properly used, mathematical models can greatly reduce the experimental component of a process study, and can thus save both cost and the time of implementation.

The design of moulds for casting, die casting and other applications, including metal matrix composites, has been largely empirical and intutive, involving trial and error procedures. Considering the complexities of solidification in moulds - which involves unsteady state fluid flow and heat transfer in complex geometries, as well as thermal contraction with associated shrinkage - a purely empirical approach to these problems is quite time consuming. These issues are becoming increasingly important as new alloys are developed for critical applications where prior empirical experiences are less readily applicable. The fluid contours depicited in Fig.11 represent an important first step in modelling just one facet of these problems, but it is expected that CAD/CAM techniques will become a more significant part of new casting developments.

Fig.12 shows the computed path of tracer particles and temperature fields of a continuous casting machine, generated using this technique. Tundishes play a key role in determining steel quality since a properly designed tundish promotes the floation of inclusions, provides for the dampening of turbulence and allows improved temperature control. The results of the calculations help determine optimal tundish dimensions as well as the optimal placement of wiers and baffles to obtain desired residence time in the system.

FUTURE TRENDS: It is estimated that the introduction of CAD/CAM techniques in foundries would save atleast 10% on the weight of thin walled castings, reduce the average time to get new tooling by 25% and its cost by 10%, and reduce the cost of duplicate tooling by 25%. The cost of tool maintenence would be significantly reduced. The quality of tooling would be significantly improved, interchangeability of components and cores from duplicate tooling would be guarenteed. Collaboration between design and manufacture would greatly improve and the need for skilled pattern and tool makers would be reduced. In general, the introduction of CAD/CAM would increase the control one has over the production of a casting, allowing for a better designed and built quality casting with minimum effort and expense.

Solid modelling has the potential to significantly improve casting design productivity. It allows more complex shapes to be produced correctly first time, it introduces design flexibility and provides a systematic design component development and design. There are several propritary solid modelling codes available and it is difficult to specify what package is most appropriate for any particular firm. Consideration of which programme is more appropriate, whether it is within the budget, and what the payback will be on the investment, is of prime importance. However, the cost of some solid modelling packages is moving within the reach of many modest firms. It is vital to identify what hardware the software can run on, since this will significantly influence the price of the total system. The processing speed, the main memory and the backing store of the computer are, ofcourse, to be considered. Not all hardware and software combinations are fully compatible. As the programme capabilities of solid modelling are being continually extended, there is little doubt that such software will provide a versatile design tool for the future.

Mathematical modelling has no well proven 'recipes' as it is still a new tool and intution and creativity remain the key ingredients in sucessfully completing modelling assignments. The remarkable new development in this field is the availability of software packages which permit computations to be done in a relatively routine manner. Table 7 lists some commercially available software packages, which can be run on both personal computers as well as large machines like minicomputers and supercomputers. The hardware options, including type and capability is listed in Table 8.

2.3 CAD/CAM applications in impression-die forgings:

The conventional methods of designing forging dies are based on empirical guidelines, experience and intution. However, recently developed computer-aided methods may be used to a) predict forging loads and stresses, b) design the performing dies and C) manufacture the dies by NC machining. Once the die design steps are concluded, the forging dies are coventionally manufactured by a) directly machining from a die block b) making a solid model and copy milling or C) making a graphite electrode and electrodischarge machining (EDM) the dies. The graphite electrodes, in turn, can be manufactured by copy milling, abraiding using a special abraiding machine or by NC machining.

Recent applications and developments of new methods for simulating forging operations indicate that CAD/CAM can significantly augument productivity and the skill of the die designer. This is primarily accomplished by computerising area and volume calculations, by predicting the stresses and forging loads for a given die geometry and in some simple cases, by simulating metal flow during forging.

A brief outline of an integrated CAD/CAM approach to hot forging is shown in Fig.13. This approach is general and can be applied to most forgings. The most critical information needed for forging die design is the geometry. The forging geometry, in turn, is obtained from the machined part drawing by modifying this part geometry to facilitate forging. In the process of conversion, the necessary forging envelope, corner and fillet radii, and appropriate draft angles are added to the machined part geometry. Further, difficult-to-forge deep recesses and holes are eliminated.

This geometric manipulation is best done on a stand-alone CAD/CAM system. Such systems are commerically available and have the necessary software for computer aided drafting and NC machining. Such CAD/CAM systems also allow, at various levels of automation, 3-D representation of the forging and the possibility of zooming and rotating geometry display on the graphics terminal screen for purposes of visual inspection. Ideally, these systems should also allow sectioning of a given forging. An example of a 3-D representation of a connecting rod forging die is shown in Fig.14. In this figure, hidden lines are not removed. There are CAD/CAM systems and colour graphics terminals which permit hidden line removal or display of lines on various surface in different colours.

In a typical multi die forging setup, the stresses and loads are higher in the finisher die than in the blocker or preblocker dies. Therefore, it is necessary to predict these stresses and the forging load so that appropriate forging machine can be selected and so that the dies can be designed to avoid breakage. To analyse stresses, the computerised 'slab method of analysis' has been found to be most practical. Recently this software has also been developed for a computervision (CV) stand-alone CAD/CAM system and CV systems can now be used to prepare forging and die drawings, generate forging cross sections and to calculate forging loads and stresses.

Design of blocker dies and preform geometries is the most critical part of forging die design. At present, CAD of blocker cross sections can be carried out using interactive graphics. The main advantages are:

* Cross-sectional areas and volumes can be calculated rapidly and accurately,
* The designer can modify geometric parameters such as fillet and corner radii, web thickness,rib height and width, etc., and can immediately review the alternative design on the screen of the computer graphics terminal, as shown in Fig.15.

* The designer can zoom in to investigate a given portion of the forging (Fig.16) and can perform sectional area calculations for a given portion of the forging, where the metal flow is expected to be localised, and

* The designer may review the blocker positions in the finisher dies at various opening positions to study initial die blocker contact point during finish forging, as seen in Fig.17. The ultimate advantage of CAD/CAM in forging is achieved when reasonably accurate and inexpensive computer software is available to simulate metal flow throughout a forging operation. The plastic deformation phenomenon in hot forging is vey complex and involves nonsteady state flow, nonuniform distribution of strains, strain rates and temperatures in the deforming metal and difficulties in estimating the friction factor and flow stresses. A typical simulation of metal flow and die filling in blade forging is shown in Fig.18.

In recent years, CAD/CAM techniques have been successfully applied to precision forge straight and spiral bevel gears, which were earlier manufactured by machining in special gear cutting machines. The gears could be forged to finish machining tolerences therby eliminating the need for rough machining. The outline of the CAD procedure is given in Fig.19.

FUTURE TRENDS: In very recent years, expert systems have been developed for net-shape forging of axisymmetric shapes and hard-to-work alloys to cut manufacturing costs. In general, it is expected that the present application of CAD/CAM in forging, mainly for drafting and NC machining of forging dies, will continue to increase at a rapid rate. The principle barriers to widespread acceptance of such application seem to be a) apparent high cost of introducing CAD/CAM, b) management inertia and c) lack of trained personnel. However, the world wide forging industry is under considerable pressure to mordernise and to increase the productivity of skilled diemakers, who are becoming increasingly scarce. In addition, CAD/CAM systems are becoming relatively inexpensive. Consequently we can expect to see, in the near future, a very significant increase in the number of forge and die shops in which CAD/CAM is used.

2.4 CAD/CAM applications in hot extrusion:

Structural shapes such as T;L;Z;H;U and other shapes are usually manufactured by direct or indirect extrusion methods. In hot extrusion of of aluminium or copper alloys, container lubrication is not used and the dies are 'flat-face' type, with the die opening imparting the desired section geometry to the extrusion. In extrusion of steels, titanium alloys and other high temperature materials, glass-or-graphite-base lubricants are used. The dies have some sort of a 'smooth entry' design to provide for easy metal flow and to avoid severe internal shear, or a dead-metal zone, during extrusion. 'Smooth entry' dies are also used sucessfully for extruding composite materials.

In today's industrial practice, the design of extrusion dies, whether of the 'flat-face' or the 'smooth entry' type, is still an art rather than a science. To reduce the costs of designing and manufacturing extrusion dies, CAD/CAM systems have been developed for both non-lubricated and lubricated extrusion process.

Many years of experience lie behind the production of extrusion dies with increasing complexity of shape, thiness of section and quality of surface. Some of this experience is rationalised in empirical design rules, but much of the die design is still dependent on personal judgement, intution and experience.

A typical CAD technique for flat-face dies, where the capabilities and application of an interactive CAD programme called ALEXTR, is illustrated in Fig.20. For manufacturing the dies, either conventional EDM or wire EDM is used. In the first case, two EDM electrodes are machined via NC; one for EDM'ing the die openings from the billet entry side and the other for EDM'ing the die bearings from the exit side of the die. In wire EDM'ing, the die openings are machined using a wire electrode, while the bearing areas are machined by EDM or milled in the conventional manner.

Proper die design is critical in lubricated extrusion, especially when noncircular shapes are extruded. An effective die design must ensure smooth metal flow with consistent lubrication. Lubrication reduces load and energy requirements, reduces tool wear, improves surface finish and provides a product with nearly uniform properties. It is desirable to use 'streamlined' dies, which provide a smooth transition for the billet from round or rectangular container to the shaped-die exit.

The use of CAD techniques have been successfully applied, in recent years, for such lubricated extrusions and a typical example of the design of a 'streamlined' die for extruding a T-shape from a round billet is shown in Fig.21.

The surface of a 'streamlined' die is defined as an array of points. The practical method of manufacturing this die is to NC machine a carbon electrode and then to EDM the die. For this purpose, cutter paths for machining the electrode surface must be determined. Computer programmes developed for calculating the cutter paths contain special routines to check for undercutting and gauging. The calculated cutter centre points are plotted on the screen of graphics terminal as shown in Fig.22.

The concept of streamlined dies has been found to be extremely useful in extrusion of difficult-to-form metal matrix composite powder metallurgy materials. Such materials like aluminium alloy 2024 with 20 vol% SiC whiskers, are used for the production of aerospace structures as they weigh considerably less than those manufactured from aluminium alone. However, the sreamlined die concept cannot be used for designing highly complex dies with re-entrent sections. New techniques, like perimeter mapping techniques instead of area mapping techniques are used, and an example of complex die configarations obtained using this new CAD method is shown in Fig.23. These dies will be manufactured by EDM using NC machined electrodes,as discussed earlier.

FUTURE TRENDS : The application of CAD/CAM in extrusion is likely to be on the increase, as more and more extrusion companies are using such techniques for die making and process automation. The implementation of CAD/CAM have the following potential benefits:

* More precise estimation, and reduction in estimation costs.
* Less dependence on skilled workers.
* Reduction in the number of die failures and in die-design and manufacturing costs.
* Improved utilisation of existing press capacity by reducing die trials.
* Continous improvement of die and press technology.
* Increases in material yield and press productivity.

2.5 CAD/CAM applications to sheet metal:

Implementing CAD/CAM technology to sheet metal fabrication installations means relegating more of the time-consuming and tedious jobs to the computer, organising and managing projects better and producing better sheet metal parts in lesser time and cost. Information typically extracted from CAD/CAM data bases include part production counts, sheet utilization rate, percent of scrap material and machine downtime.

Computer aided modelling techniques have been widely used to speed up the design process and to improve the quality of sheet metal parts. This enables alternative die-designs to be explored and trade-offs to be evaluated, before the manufacturing engineer performs the costly and time-consuming steps of fabricating the dies and process tryouts.

Fig.24 shows the application of simulation techniques in sheet metal drawing operations on mild steel. The purpose of simulation was to predict the forces on the tool required to form the the product, the degree of pre-load on the blank-holder necessary to hold the blank without over-constraining it, and the tendency of the sheet metal to tear if friction at the blank holder stopped the materials from drawing properly. Another example is shown in Fig.25. This part represents a typical automobile component and is more irregular and complex compared to the one shown before, and in this case the simulation could help predict the areas of thinning and thickening and the material flow paths.

FUTURE TRENDS : Computer aided modelling and simulation techniques, are widely being employed in sheet metal fabrication. With the falling cost of computer hardware pointing to increased use of these techniques, it is almost inevitable that today's emerging capabilities will be viewed as commonplace in the future.

2.6 CAD/CAM applications in rolling and nozzling:

Rolling, extrusion and nozzling can be visualised as problems arising in the thermophysical processing of solids, in which allowance must be made to take into account structural changes, like grain growth, during the processing operations. In Fig.26 is shown the computed residual stress patterns in a thin aluminium sheet which result from the combined effect of thermal stresses and mechanical work hardening effects.

Nozzling process, as it is applied to a fire extinguisher cylinder is shown in Fig.27. The work piece is formed in the first stage operation using a back-extrusion process and the resulting closed-ended cylinder is the preform for the second stage, in which the open end is heated and then forced into a shaped die to form the nozzle end.

FUTURE TRENDS: Computerised techniques are playing an important role in automating and controlling rolling practices, from the initial breaking down of the ingot on a hot mill to the final cold rolling finishing pass on the thinnest of foils. Computerised strip shape measurements and control systems are now installed on key cold mills, and fast accurate gauging systems monitor and control thickness by computer, enabling tighter tolerences to be offered, typically as ± 0.01 mm in heavier strip gauges. CAD/CAM applications indicate it could be used as the best design aid for assessing the best means of forming high integrity components such as pressure vessels and aerospace components.

2.7. CAD/CAM applications in plastics:

For many years, plastics have been regarded unfavourably by the general public as low quality materials. However, present day uses include many advanced engineering applications, like in the preparation of green ceramic components for such applications like turbine blades. Recent developements in polymer processing have not been in completely new processes, but rather in the refinement of existing process control or better process modelling.

In the field of injection moulding, computer simulation of the mould filling and cooling process is becoming common. The use of computer simulation allows the designer to determine the ideal gating positions and the position of any weld lines. Modelling packages also facilitate the determination of melt pressures within the cavity, so problems such as wrapage, which arise from frozen-in-stresses, can be identified. The main benefit of such modelling process is that the designer has a better chance of getting the mould design right the first time, so reducing the costly waste of time needed to get a mould up and running when it is mounted on an injection moulding machine.

FUTURE TRENDS: The time is now ripe to apply CAD/CAM systems to design, produce, test and provide the necessary information for the manufacture of the tool. Fig.28 shows a computer integrated manufacturing scheme. The advent of microprocessors to machine control, especially in injection moulding, would enable a lot of changes to be brought about in this field.

2.8 CAD in molecular engineering:

The traditional design tools of a chemist are simply, pencil and paper, and molecules are represented by 2-D drawings, such as that of the antibiotic pencillin G in Fig.29. Although effective in expressing the connectivity of the molecules, they can only give a vague idea of the full 3-D shape, which must be the starting point for rational design.

Physical models can be built, but this is time consuming and the result is a poor representation of the real thing. The problem is molecules are generally quite flexible, more like lumps of jelly than frameworks of steel or plastic. Moreover, whereas a lump of jelly will tend to recover its shape after deformation, molecules usually have a number of different shapes into which they may settle. Further, at room temperature the atoms will be continously moving, while the molecules will be constantly cycling between the states. The only way in which this behaviour can be understood is by first, performing lengthy and complicated calculations, and second by finding some means of making the results intelligible to the human eye.

In theory, this has been possible for some time, but at enormous costs. The decreasing cost/performance ratio of mordern computers and the appearance of high-power graphics workstations at prices that are affordable, have led to a dramatic growth in interest in this fascinating area. Today, such state-of-the-art exists that scientists are in a position to engineer and design new molecules and products for the chemical and pharmaceuticals, ushering in a new era of molecular engineering.

A few examples of how CAD has been used, are shown in Figs. 30-33.

FUTURE TRENDS: Computer based molecular modelling (CBMM) show enormous potentials. As an example, there are hopes that a cure can be found for AIDS through this and other biological techniques. Given the structure of the enzyme, there is a good chance that molecules may be designed which will block the active site, disrupt viral replication and effectively provide a cure. Surveying the potential of CBBM, it is impossible to avoid the conclusion that a revolution in chemistry is on the horizon.

3. CONCLUSIONS:

We have taken, but a glimpse into the fascinating area of CAD/CAM and its applications, and that too, in such a very small area of technology. It is, ofcourse, not possible, to cover such a broad area as CAD/CAM applications in so few words or pages; nevertheless, an attempt has been made and it is hoped that this is found to be of interest and throws some light on the current state-of-the-art.

Today, CAD/CAM, computer modelling, artifical intelligence, robotization, expert systems etc., have become frequently used terms in connection with manufacturing operations. We can say that computer-integrated manufactuting (CIM) is the foundation on which manufacturing companies in variety of industries in the world are beginning to build 'the factory of the future'. The factory of the future will find raw materials being unloded and stored by an automated storage and retrieval system (AS/RS). An automated guided vehicle (AGV) will take the raw material to the machine tool, where it is needed, and a robot will remove the workpiece and mount it on the machine tool, unload the completed part and place on the AGV. The AGV will then transport the finished part to the AS/RS or to some area of the plant for further disposition. This may sound like 'science fiction' but such systems are already in use in some places and in the not-too-distant-a-future, it is likely to become common place!

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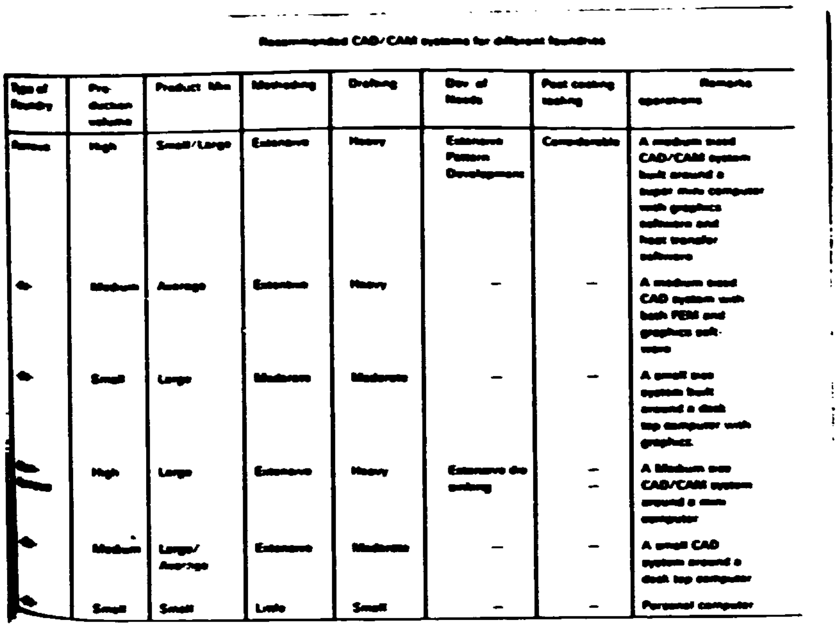
<u>Table 1:</u> Characteristics of man and computer.

		Man	*Computer*
1.	Method of logic and reasoning	Intuitive by experience, imagination, and judgement	Systematic and stylised
2.	Level of intelligence	Learns rapidly but sequential. Unreliable intelligence	Little learning capability but reliable level of intelligence
3	Method of information input	Large amounts of input at one time by sight or hearing	Sequential stylised input
4	Method of information input	Slow sequential output by speech or manual actions	Rapid stylised sequential output by the equivalent of manual actions
5	Organisation of information	Informal and intuitive	Formal and detailed
6.	Effort involved in organising information	Small	Large
7	Storage of detailed information	Small capacity, highly time dependent	Large capacity, time independent
8.	Tolerance for repetitious and mundane work	Poor	Excellent
9	Ability to extract significant information	Good	Poor
10	Production of errors	Frequent	Rare
11	Tolerance for erroneous information	Good intuitive correction of errors	Highly intolerant
12	Method of error detection	Intuitive	Systematic
13	Method of editing information	Easy and instantaneous	Difficult and involved
14	Analysis capabilities	Good intuitive analysis, poor numerical analysis ability	No intuitive analysis, good numerical analysis ability

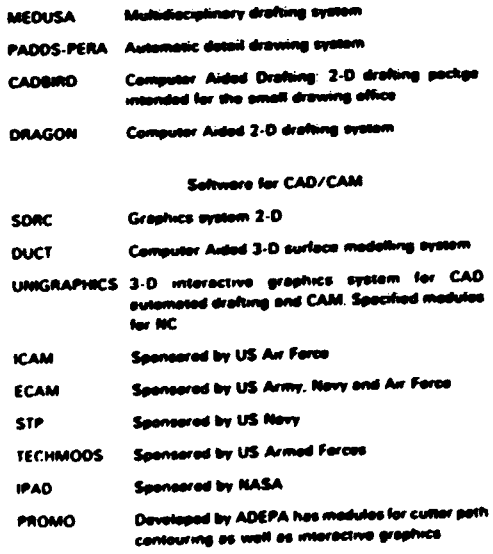
Table 2: Recomended CAD/CAM systems for different foundries.



Recommended CAD/CAM systems for different foundries

Type of foundry	Pro-duction volume	Product Mix	[illegible]	Drafting	[illegible]	[illegible]	Remarks
Ferrous	High	Small/Large	Extensive	Heavy	Extensive Pattern Development	Considerable	A medium sized CAD/CAM system built around a super mini computer with graphics software and heat transfer software
〃	Medium	Average	Extensive	Heavy	–	–	A medium sized CAD system with both FEM and graphics software
〃	Small	Large	Moderate	Moderate	–	–	A small size system built around a desk top computer with graphics
Non-Ferrous	High	Large	Extensive	Heavy	Extensive die making	– –	A Medium size CAD/CAM system around a mini computer
〃	Medium	Large/Average	Extensive	Moderate	–	–	A small CAD system around a desk top computer
〃	Small	Small	Little	Small	–	–	Personal computer

Table 3: Software for drafting and CAD/CAM.



MEDUSA	Multidisciplinary drafting system
PADOS-PERA	Automatic detail drawing system
CADBIRD	Computer Aided Drafting: 2-D drafting packge intended for the small drawing office
DRAGON	Computer Aided 2-D drafting system

Software for CAD/CAM

SORC	Graphics system 2-D
DUCT	Computer Aided 3-D surface modelling system
UNIGRAPHICS	3-D interactive graphics system for CAD automated drafting and CAM. Specified modules for NC
ICAM	Sponsored by US Air Force
ECAM	Sponsored by US Army, Navy and Air Force
STP	Sponsored by US Navy
TECHMODS	Sponsored by US Armed Forces
IPAD	Sponsored by NASA
PROMO	Developed by ADEPA has modules for cutter path contouring as well as interactive graphics

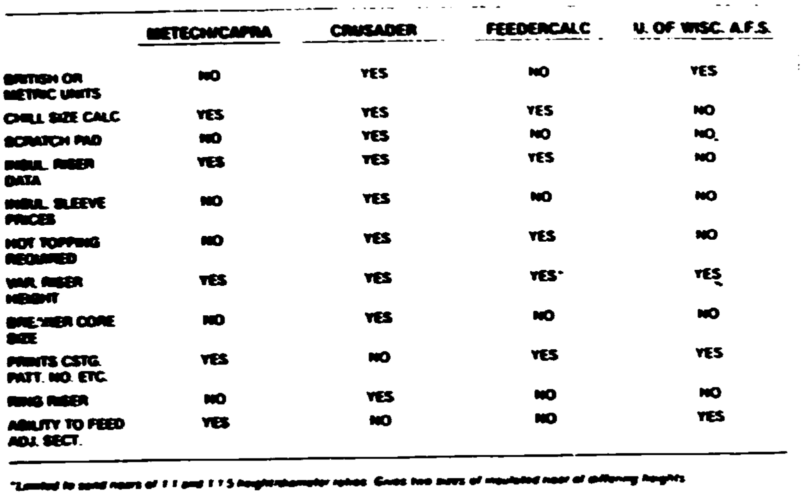
Table 4: Software packages available for heat transfer simulation and finite element analysis.

Name	Developed by	Remarks
ANSYS	Swanson analysis system	FEM
MARC	Marc Analysis Research Corp.	FEM
NASTRAN	NASA	FEM
SINDA	cosmic Library, USA	FEM
SMART II	Stuttgart, West Germany	FEM
ASAS	and W.S. Atkins Inc.	FEM
ASAS Heat		
BASS		continuous syste simulation facilities
FLHE	Lucas Logic Ltd., U.K.	Steady state an transient temp. dist bution in 2, 3-D.
FEMGEN		Finite element me generator

Table 5: Comparison ANSYS, MARC, and MITAS-II with the ideal goal for a metal casting simulation capability.

Feature	Ideal	ANSYS	MARC	MITAS-II
Ability to learn how to run it on a remote computer	Easy	Difficult	Moderately difficult	Moderately difficult
Running cost	Low	High	High	Moderate
Ability to account directly for latent heat	Yes	No	Yes	Yes
Dedicated heat transfer code	Yes	No	No	Yes
Accuracy	Good	Very good	Very good	Very good
Pre- and post-processing capabilities	Good	Good	Good	Poor

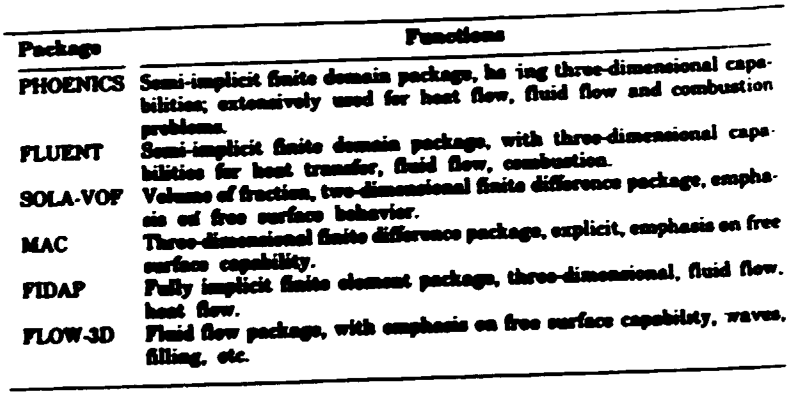
Table 6: Comparision of some complete risering programmes.



	METECH/CAPRA	CRUSADER	FEEDERCALC	U. OF WISC. A.F.S.
BRITISH OR METRIC UNITS	NO	YES	NO	YES
CHILL SIZE CALC	YES	YES	YES	NO
SCRATCH PAD	NO	YES	NO	NO
INSUL. RISER DATA	YES	YES	YES	NO
INSUL. SLEEVE PRICES	NO	YES	NO	NO
HOT TOPPING REQUIRED	NO	YES	YES	NO
VAR. RISER HEIGHT	YES	YES	YES*	YES
BREAKER CORE SIZE	NO	YES	NO	NO
PRINTS CSTG. PATT. NO. ETC.	YES	NO	YES	YES
RING RISER	NO	YES	NO	NO
ABILITY TO FEED ADJ. SECT.	YES	NO	NO	YES

*Limited to sand risers of 1.1 and 1.5 height/diameter ratios. Gives two sizes of insulated riser of differing heights

Table 7: Modelling software.



Package	Functions
PHOENICS	Semi-implicit finite domain package, having three-dimensional capabilities; extensively used for heat flow, fluid flow and combustion problems.
FLUENT	Semi-implicit finite domain package, with three-dimensional capabilities for heat transfer, fluid flow, combustion.
SOLA-VOF	Volume of fraction, two-dimensional finite difference package, emphasis of free surface behavior.
MAC	Three-dimensional finite difference package, explicit, emphasis on free surface capability.
FIDAP	Fully implicit finite element package, three-dimensional, fluid flow, heat flow.
FLOW-3D	Fluid flow package, with emphasis on free surface capability, waves, filling, etc.

Table 8: Hardware options.

Computer	Megaflops[d]	Capability
IBM-AT w/80287[a]	.004-.07	2-D transient heat conduction problems with constant coefficients. No fluid flow; problems under 2000 nodes.
IBM-AT w/MAP[b]	.5	3-D transient heat conduction with fluid flow, constant coefficients. Limited only by memory and user's patience.
VAX 11/780 w/FPA	.12	Small 3-D transient heat conduction; problems under 6000 nodes.
VAX 11/785 w/FPA	.20	Moderate 3-D transient heat conduction problems; 2-D transient heat conduction with fluid flow; small 3-D fluid flow with no heat transfer; problems under 10000 nodes.
VAX 8600	.80	Medium or moderately sized 3-D transient heat conduction with fluid flow; problems under 20000 nodes.
Apollo DN10000	15	Same as [illegible]; problems under 6000 nodes.
FPS-164 MAX[c]	10	Small 3-D fluid flow with heat transfer and with variable coefficients; virtually unlimited problems.
FPS-264	30	Fairly large 3-D fluid flow with heat transfer and with variable coefficients; virtually unlimited problems.
CYBER 205[c]	30	Moderately sized 3-D fluid flow and heat transfer with variable coefficients; virtually unlimited problems.
CRAY X-MP	40	Large 3-D fluid flow with heat transfer and variable coefficients; virtually unlimited problems.

[a] IBM AT operating at [illegible] speed
[b] IBM-AT equipped with an array processor board
[c] These machines are capable of [illegible] speeds, near 400 megaflops. However, the authors are not aware of any programs that make use of these capabilities
[d] Megaflop = million floating point operations per second—a good, but not exclusive measure of computational speed

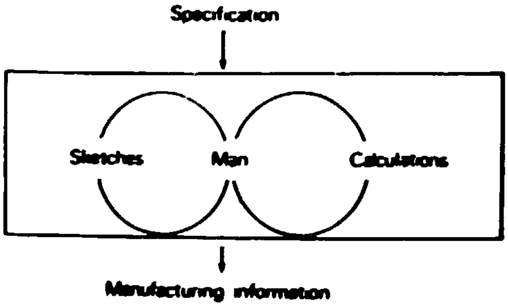


Fig. 1: The conventional design process.

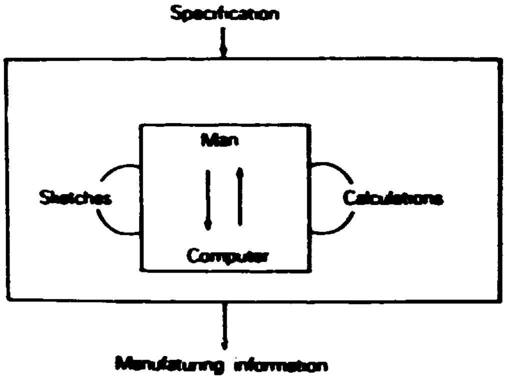


Fig. 2: Design process using CAD techniques.

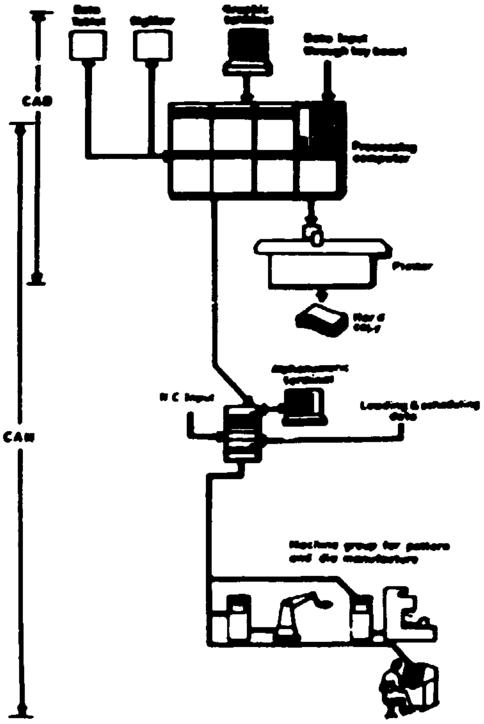


Fig. 3: A typical CAD/CAM system in a foundry.

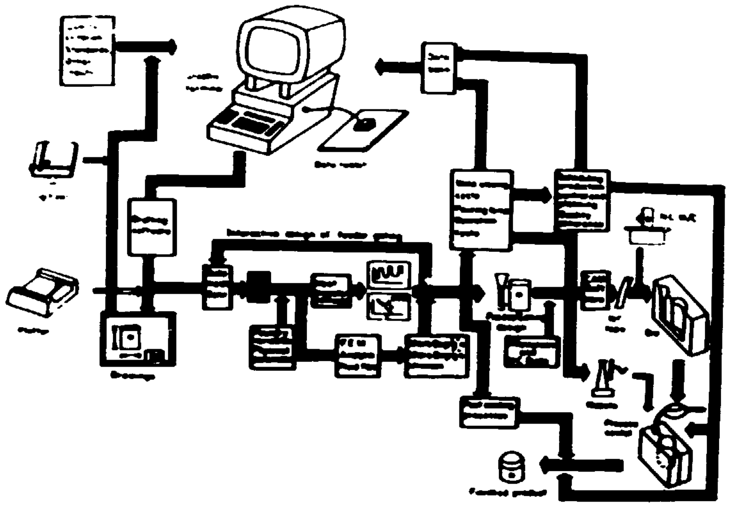


Fig. 4: Application of a CAD/CAM system in metal casting.

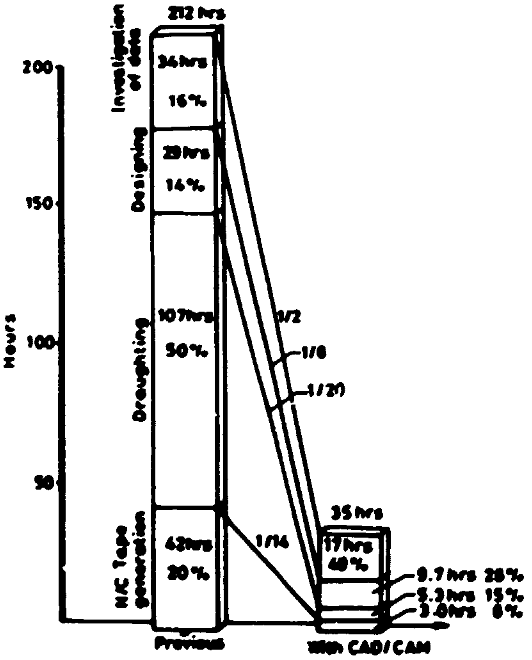


Fig. 5: An example of the benefits of introducing CAD/CAM system for computerised die manufacture.

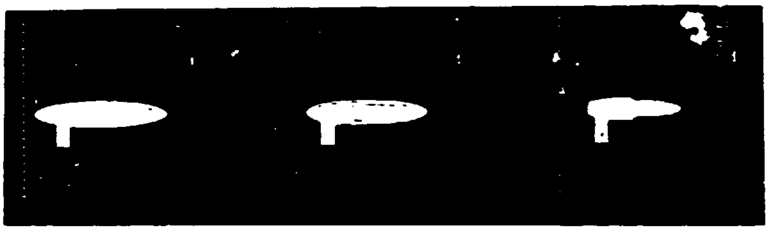


Fig. 6: Simulation of solidification and cooling in a turbine blade casting.

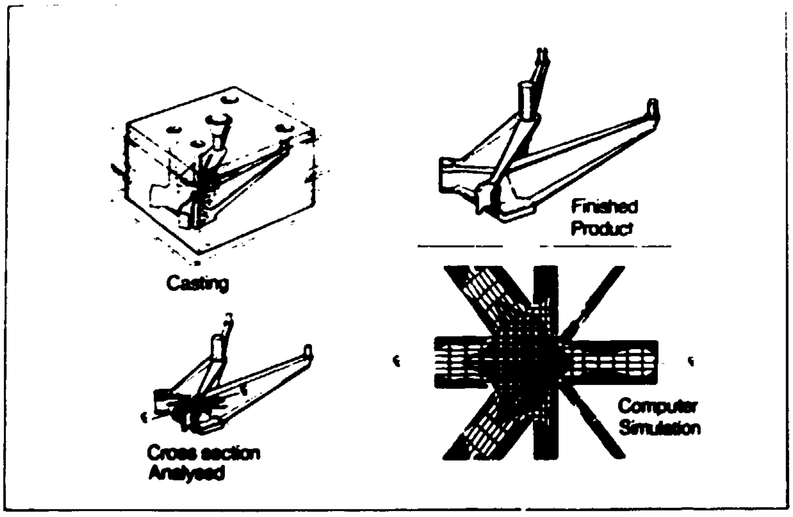


Fig. 7: Simulating the solidification process in a structural casting. The calculation tracks the progress of the solidification front.

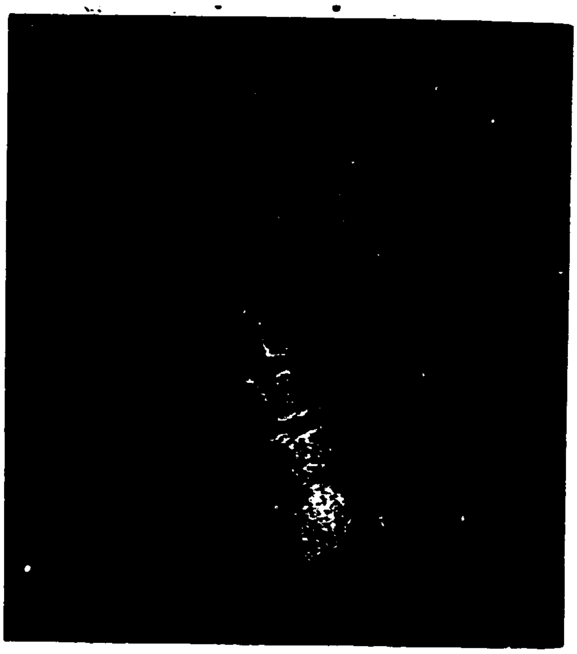


Fig. 8: Solid model of an aerospace burner nozzle.

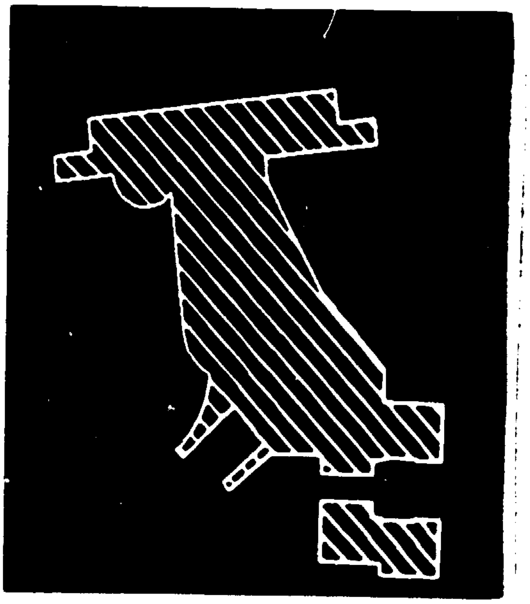


Fig. 9: Cross section through the aerospace burner nuzzle

Fig. 10: Solid modelling of a golf club head: a(top), rear view of the original head, b(centre), rear view of the redesigned head, c(bottom), front view of the redesigned head.

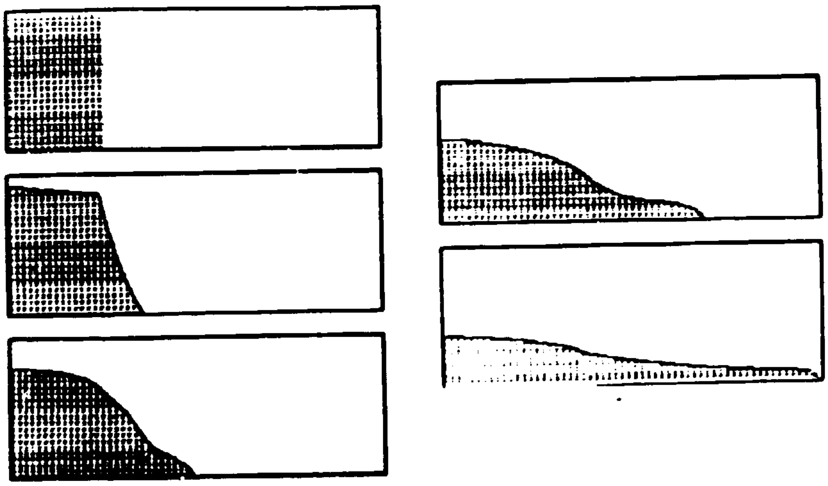


Fig. 11: The computed displacement pattern of a collapsing wall of fluid in a mould, taken at reference times of .6,.12,.18 and .24.

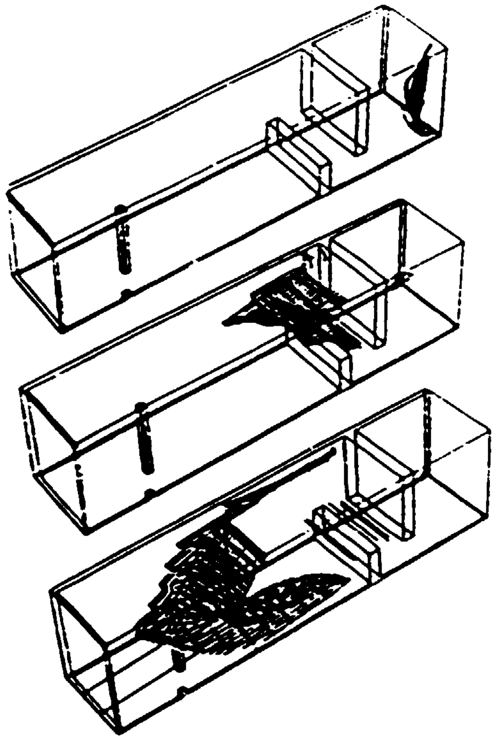


Fig. 12: The computed isotherms in a tundish: (a) 1595 °C (b) 1593 °C and (c) 1590 °C.

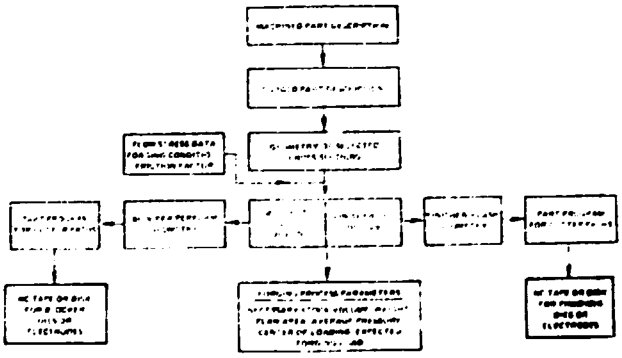


Fig. 13: Outline of an integrated CAD/CAM approach for hot forging.

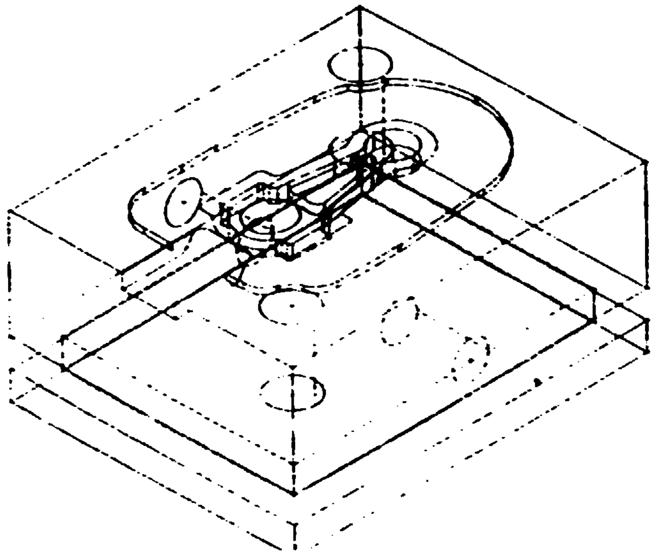


Fig. 14: Three-dimensional display of a connecting rod forging die prepared on a computervision CAD/CAM system.

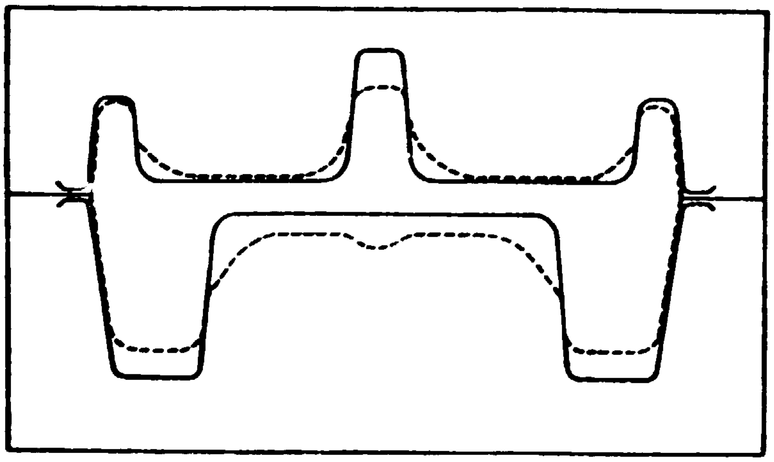


Fig. 15: A typical forging cross section and a possible blocker design displayed on a computer terminal.

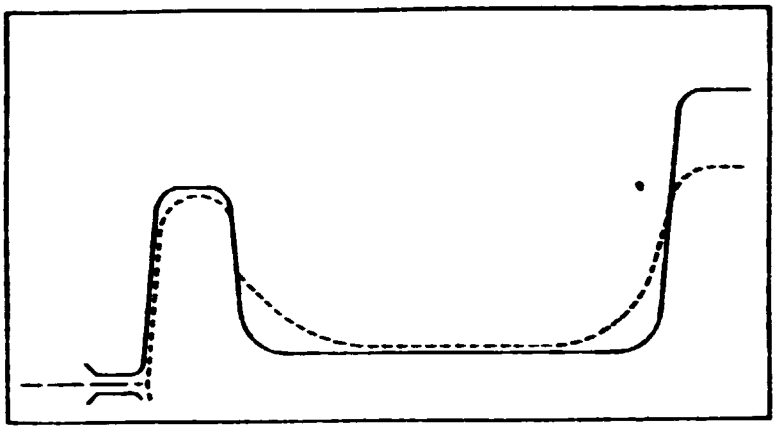


Fig. 16: Use of " zooming " to examine a small portion of the blocker/finisher cross sections in CAD.

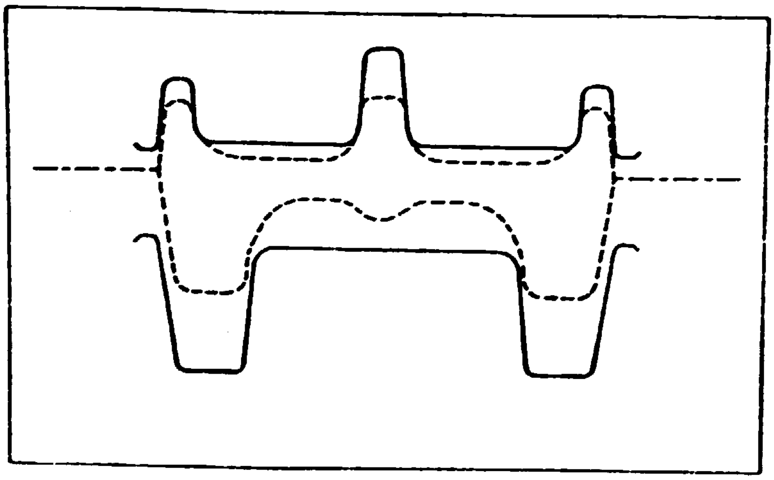


Fig. 17: Computer-designed blocker, shown with finisher dies in seperated position.

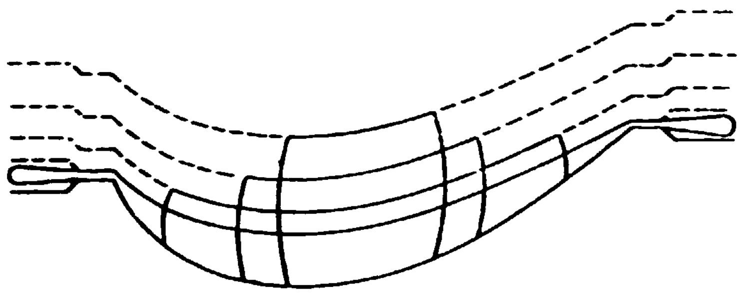


Fig. 18: Metal flow and die filling in a blade forging, as simulated by a computer programme.

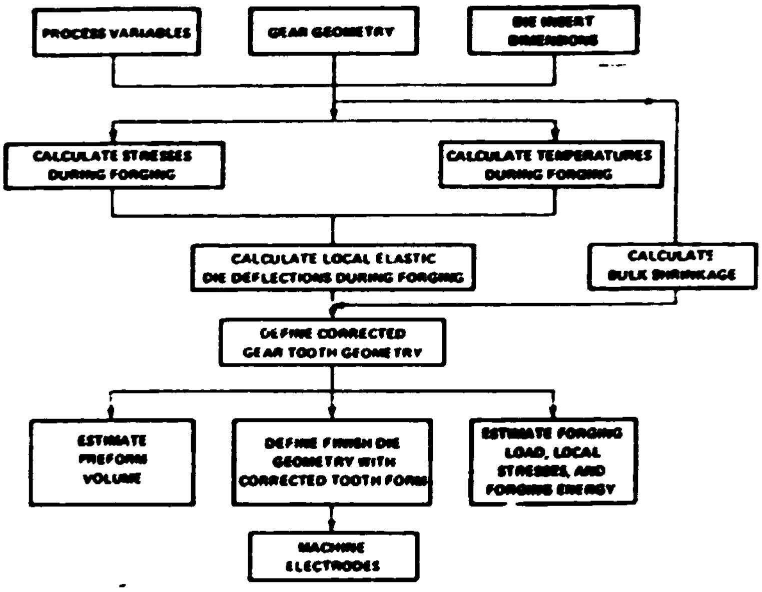


Fig. 19: Outline of a CAD procedure used for making forging dies used to produce spiral bevel gears.

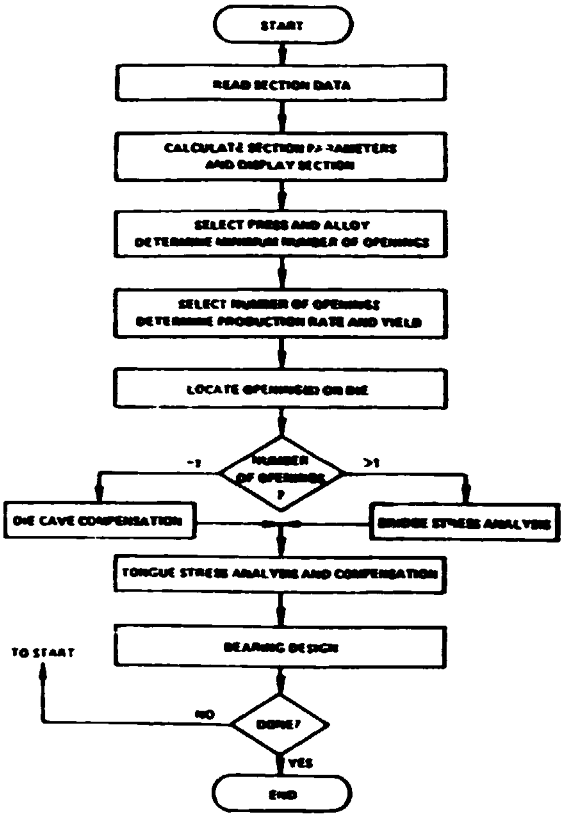


Fig. 20: General operation of ALEXTR

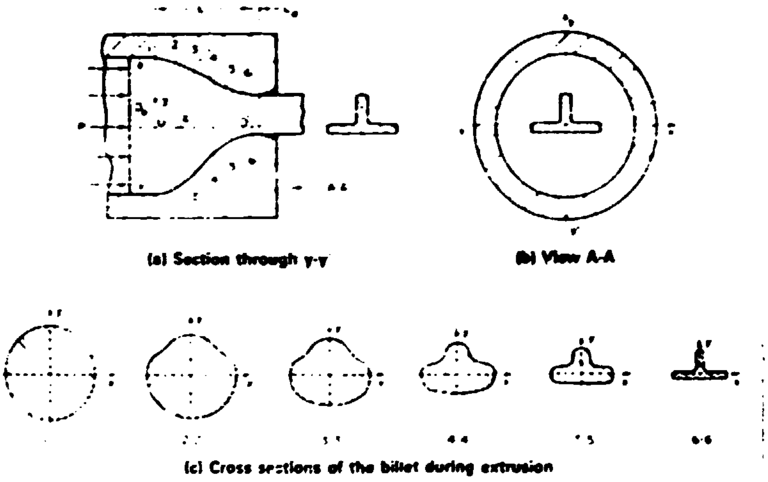


Fig. 21: Schematic illustration of a streamlined die for extrusion of a " T "-shape.

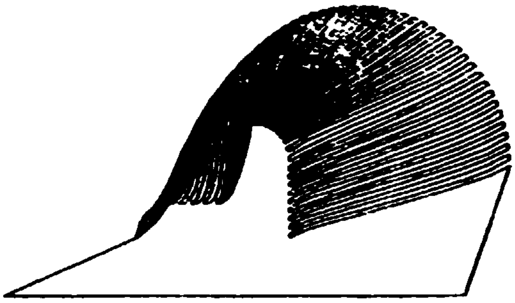


Fig. 22: Cutter path for NC machining of the EDM electrode for the streamlined " T "-shape die.

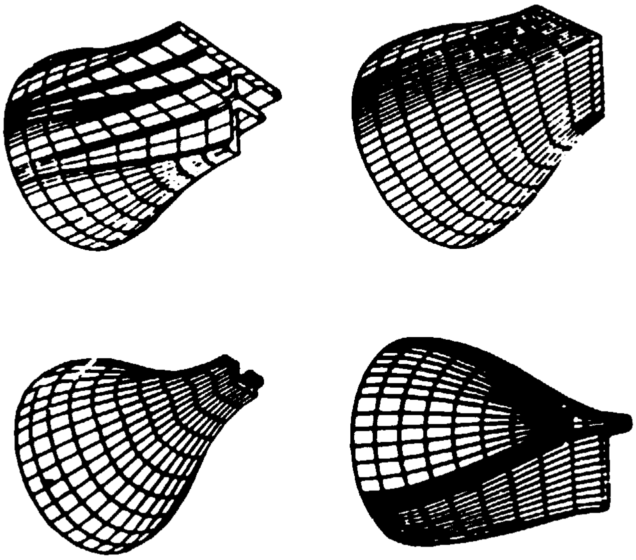


Fig. 23: Computer -designed streamlined die configaration for extrusion of complex shapes.

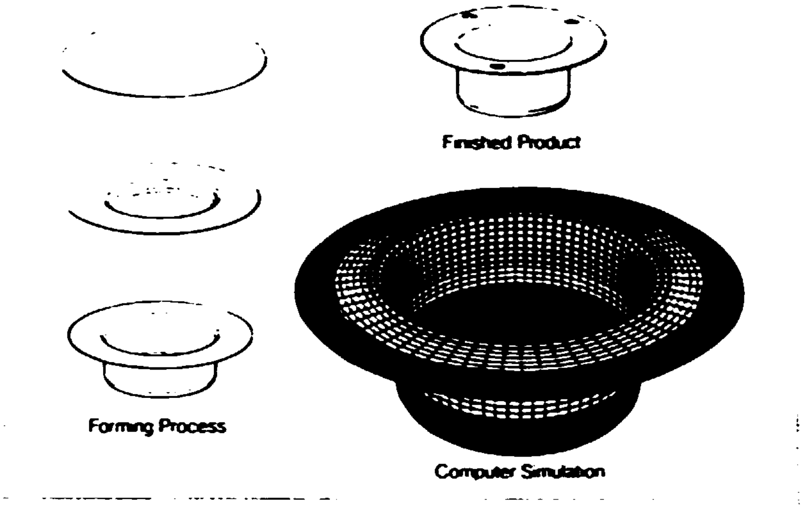


Fig. 24: Simulating the deep drawing of a sheet metal cup . The contours show different levels of strain in the finished part.

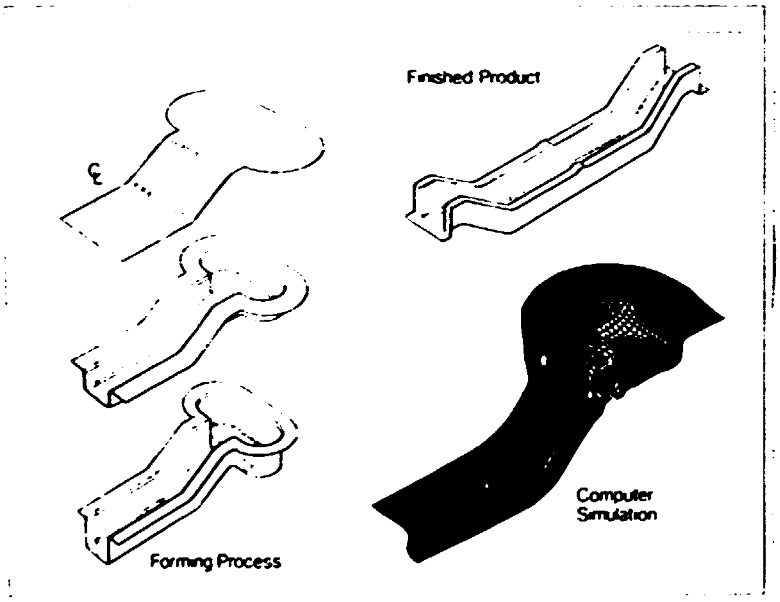


Fig. 25: Simulating the pressing of a sheet metal automotive component. Due to the symmetry, only one quarter of the component was modelled.

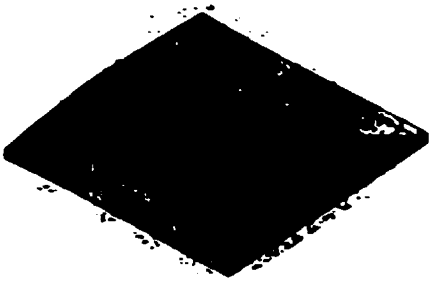


Fig. 26: The computed residual stress pattern of a thin aluminum strip showing the formation of a centre buckle which may occur in the cold rolling of aluminium.

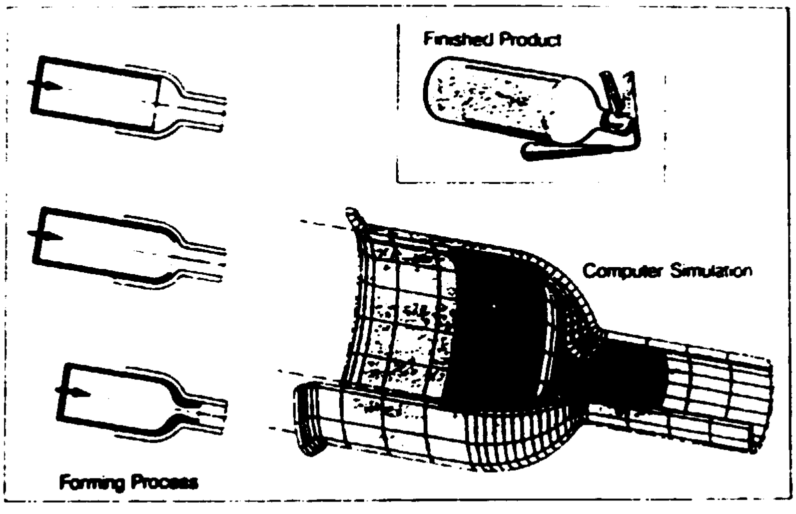


Fig. 27: Simulation of a nozzle forming operation. The contours show the strain rates that occour during the forming process.

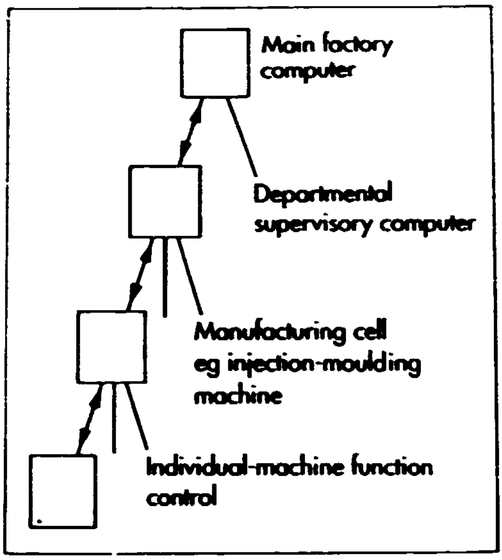


Fig. 28: Computer integrated manufacturing scheme.

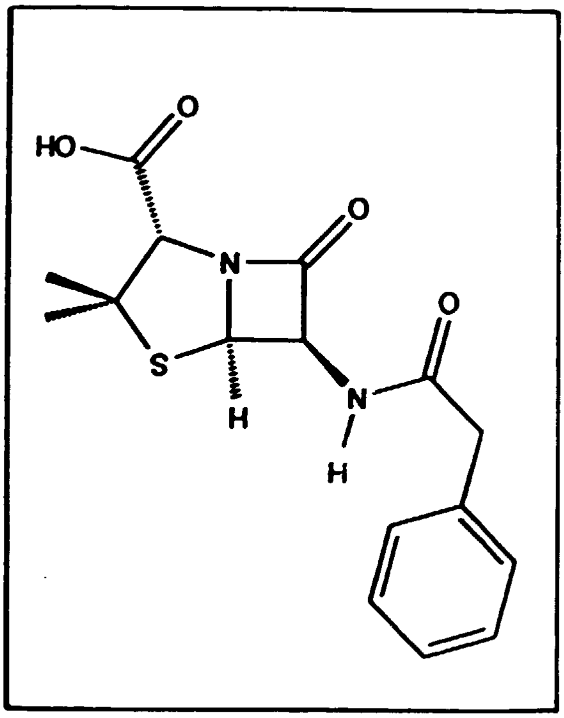


Fig. 29: The structure of penicillin G as normally drawn by a chemist.

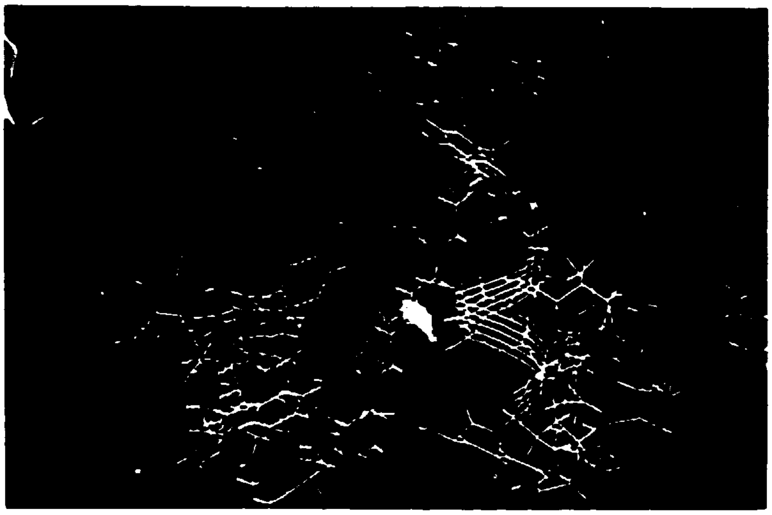


Fig. 30: Image of a protein molecule.

Fig. 31: A short segment of double-helical DNA, the molecule at the centre of the chemistry of life.

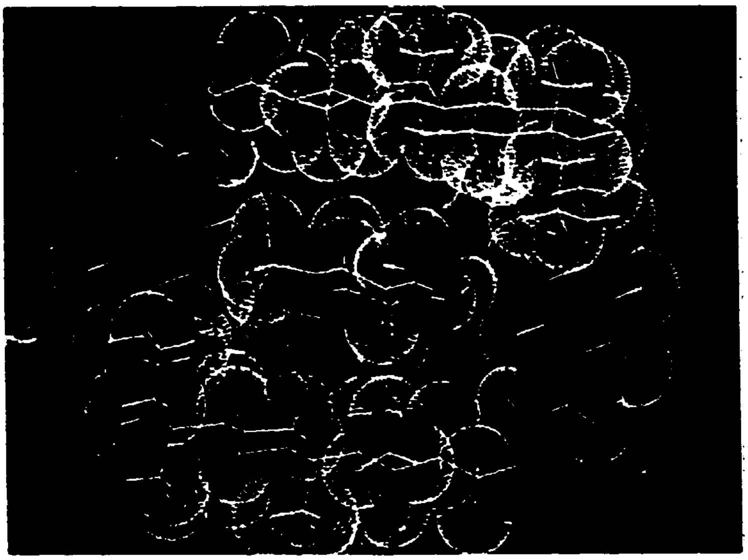


Fig. 32: Complex between a 'host' molecule and a 'guest' carbohydrate.

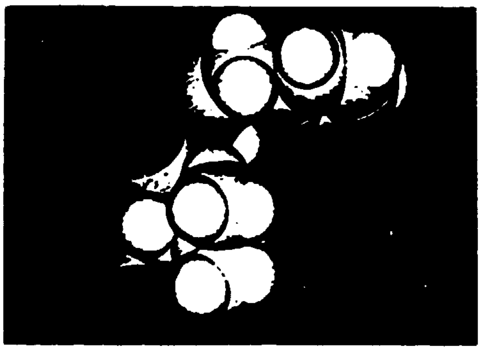


Fig. 33: Spacefilling representation of Penicillin G.