OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

UNITED NATIONS

INTERREGIONAL SYMPOSIUM ON THE APPLICATION OF MODERN TECHNICAL PRACTICES IN THE IRON AND STEEL INDUSTRY TO DEVELOPING COUNTRIES

11-26 NOVEMBER 1963

STEEL SYMP.1963/
Technical Paper/B.18
18 September 1963

Original: ENGLISH

D03590

THE CONTINUOUS CASTING OF ROUND SECTIONS

by

B. Tarmann and W. Poppmeier, Research Division
of Bohler Bros. & Co. Ltd., Austria

During the last ten years, the continuous casting of steel has been advanced from the trial stage to that of a full fledged production method. Today, it is a casting method which has achieved full equality to the conventional casting of ingots.

Sheets from continuously cast slabs and sections from square billets obtained by the continuous casting method are equal or superior in quality to the products processed from ingots. However, due to the more favourable economic aspects of the continuous casting process, their costs of production are lower.

For many applications, continuously cast round billets are especially useful. This applies to drop forged and pressed parts, to the manufacture of tubes by means of rotary piercing mills as well as to the manufacture of rings on tire mills, and especially to the new hot-working process of extruding.

For the above reasons, there was enough incentive to enquire into the special requirements for the continuous casting of round sections and to determine the conditions for large scale production. At the very beginning, it must be noted that round sections are more difficult to cast than square or even flat sections. The application of the round sections for the processes mentioned above, however, promised to entail so many advantages in respect to quality and economy that the costs for the investigation of the casting conditions had to be accepted.

While in other places more emphasis was placed on square and flat sections, the works at Kapfenberg, which by tradition spend large sums on research, decided to tackle the difficulties posed by the casting of round billets and to develop the process to routine perfection. The development work was greatly assisted by the comprehensive range of subsequent processes which were available at the works there.

It will now be endeavoured to discuss the various problems occurring at the casting of round billets and the further processing of the latter. At the same time the practical aspects of the casting procedure shall obtain proper treatment.

The Solidification of Round Billets

When the liquid metal comes into contact with the mould wall, a thin solid skin is formed quickly from which solidification continues radially towards the centre. In its lower part, the liquid core assumes the shape of a very slender cone. In the round billets, solidification, of course, follows the same laws as are applicable for ingots, but the individual crystals are smaller and finer as in the ingots. This is due to the faster rate of cooling and solidification which occur at least in small and medium sized sections. The case of fine globular crystals is followed by a more or less distinct columnar crystal zone while the centre again consists of equi-axed crystals. The depth of the various zones is dependent on the type of steel, and, for one type of steel is greatly influenced by the casting temperature. The case which forms at the level of the liquid metal shrinks quickly on further cooling and lifts from the mould wall. The lifting occurs in an irregular manner. In square sections, the edges are subject to increased cooling and preferred solidification whereby a rigid structure develops. In round sections no such preference can develop, and the places where lifting occurs and weaker cooling results, will vary not only from heat to heat but also within one heat. This is one of the main difficulties experienced in the casting of round sections. The premature and strongly irregular lifting of the case is accentuated by high pouring temperatures and low temperatures of the mould walls (chilling effect). For this reason, good results can be obtained with the lowest possible casting temperatures and high temperatures of the mould walls. Fig. 1 shows the increase of thickness of the case of a round billet 150mm (6 in.) dia., made visible by the bleeding of the billet. The billet was cast from plain carbon steel containing 0.25% carbon. The rate of casting was 1.50m (5 ft.) per minute and the casting temperature as measured in the tundish amounted to 1530°C (2786°F). The opposite diagram, using a distorted scale, indicates the rate of growth along the longitudinal section. The indicated values have been compiled from mean measurements. The cross section clearly indicates that the growth follows an irregular pattern along the circumference of the top portion. As mentioned before, the reason for this is to be found in the irregular lifting of the case from the mould. As can be seen from the sections which were taken further down the billet, the irregular growth can be equalised by proper control of the secondary cooling arrangement. The final solidification into a conical slag blanket can result in the formation of small secondary pipes in the centre. These, however, are not interconnected and thus pose no problem during subsequent processing operations if the casting was carried out properly. The rotary field inductor of JUNGHNAS - SCHAABER offers an additional means for the prevention of central pipes. By the use of this equipment, a primary structuro which lends itself readily to further processing operations can be obtained also from steels which tend to pronounced columnar solidification. Fig. 2 shows the effect of the rotary field on the solidification and porosity of the centre of an austenitic chrome-nickel steel. The figure also shows the influence of the mould wall temperature on the lifting behaviour of the case and the formation of the primary crystals. While a high mould wall temperature resulted in a uniform radial solidification, preferred lifting from and subsequent contacting of the mould wall were observed with the cold mould whereby the primary crystallisation deviated from its purely radial direction and took place in four distinct areas.

Casting Speed and Production Rate

The possible casting speed is dependent upon the heat transfer. The latter, again, is a function of the area to be cooled and the heat contents. Since a circle possesses the smallest circumference of a given area, it is plain that the heat transfer does not find as favourable conditions as with square or even flat sections. Since the ratio circumference : area of a circle corresponds to that of a circumscribed square, it was to be expected that the casting speed of round billets could be equalled to that square sections whose sides were equal to the diameter. By means of extensive trials, this was also proved experimentally. As the circumscribed circle has only 75% of the area of the corresponding square, the casting rate is necessarily smaller. Fig. 3 represents the possible casting speeds and the corresponding production rates for round and square sections. The break in the curve can be accounted for by the fact that a constant depth of the liquid core was assumed for sections of more than 150 mm (6 in.) side length or diameter. If an excessive length of the liquid core is permissible, the casting speed can be increased,of course. The casting speeds given in this connexion must be considered as upper limits according to the present state of technique and, of course, cannot be applied for all steel types. They are valid, for instance, for austenitic chrome-nickel steels which are very insusceptible to rapid cooling. The same applies to low carbon steels such as reinforcing bars and tonnage steel. By no means can they be applied to tool steels.

Moulds

As mentioned before, round sections require higher temperatures of the inner walls of the moulds than square or flat sections. With this in mind, it is possible to use materials having a smaller coefficient of thermal conductivity such as brass, bronze or iron for the construction of the moulds. For small round sections which permit relatively high casting speeds, the temperature of the mould walls can be held as low as for square sections so that the use of copper moulds is suggested. At any rate, the material must possess the highest possible yield point combined with a small thermal expansion. If these requirements are met, a long mould life can be expected. With a small coefficient of thermal conductivity and a low yield point, considerable stresses will occur in the mould at the level of the liquid metal if the coefficient of thermal conductivity is small. This will lead to a contraction of the mould in the vicinity of the level of the liquid metal. This behaviour of the mould wall is further accentuated by the frequent changes in the height of the level, so that many continuous casting machines are fitted with an automatic control of the steel level.

The contraction of the mould at the level of the liquid steel can be determined by taking careful measurements or are revealed by longitudinal cracks on the surface of the billets. Fig. 4 shows cracks caused by the above reason. If such cracks occur for the first time in the life of a mould, it is possible to eliminate them for the casting of the heat on hand by reducing the casting speed. After the casting operation, however, the mould should be removed and conditioned immediately.

The high casting speeds for round sections which were given above can be applied only when the moulds are provided with a taper. By means of the taper, the lifting of the billet from the mould is retarded and the solidification condition improved.

Instead of conical moulds finely undulated moulds can be used for the purpose of obtaining a higher casting speed if machining or flamescarfing precedes the hot working operation. The construction of round moulds is simple since seamless drawn tubes may be used for the purpose. Flanges can easily be mounted by means of screwed connections and the maintenance of the used moulds can be carried out repeatedly by grinding.

To conclude the discussion of moulds it must be stressed that the casting of round sections demands moulds that are absolutely free from any deficiency whatsoever.

Bending of Round Billets

Extensive investigations have shown that the bending also of round sections is possible without any adverse effects as to their quality. This applies not only to billets which have solidified completely prior to bending but also to those which have a liquid core left inside. Thus continuous casting machines having a small overall height can be built also for round sections. No matter whether the billets are cast in a tower-type machine and cut in the vertical position or whether they are bent into the horizontal position during solidification or whether they are cast in a bent mould where the billets are made to solidify followed by straightening in the horizontal position, it is important for any type of machine that a sufficiently long solidification range is provided since the billets are susceptible to excessive cooling.

The Processing of Continuously Cast Rounds

Continuously cast round billets can offer technological advantages during their further manufacture into finished products by hot-working. Such operations, for instance, may include drop forging and tire rolling. Round billets are also a prerequisite for piercing mills and extrusion plants. Since the continuously cast rounds can be considered as billets as far as their dimensions are concerned, it was desirable to have cast sections available for further processing by the methods mentioned above. Cast billets have already been used for large scale production and have proved their suitability. Their application has brought about all the expected advantages and no disadvantages at all were observed in respect to the quality of the products.

Fig. 5 shows a range of drop forged products that were manufactured directly from cast round stock. The products in question differ widely in regard to their shapes and their steel analyses. The use of cast rounds as starting material for drop forgings and stampings suggest an advantage in respect to quality when the workpiece is to be severely stressed in the transverse direction. The excellent applicability of cast rounds in the drop forging process has been proved for all kinds of operations. This holds true also for offhand upsetting in the direction of the axis of the billets as well as for indirect extrusion of shells. It must be mentioned that the cast billets must be absolutely free from surface defects and cracks.

For rotary piercing mills, round sections are indispensable as starting material. Since ingots must be converted into billets before they can be used as stock, continuously cast rounds offer special advantages as regards manufacturing costs. The demands placed on the cast stock again include a good surface, freedom from cracks and in addition to that, relative absence of secondary pipes in the centre. The latter applies especially to high carbon steels in which considerable secondary pipes may occur owing to the wide solidification range. Such pipes invariably result in flaws at the inside of the tubes during the rolling on a rotary piercing mill. Another demand which must be satisfied is the absence of slag inclusions in the steel. This demand must be fulfilled by the melting shop since no influence can be exerted by the casting practice. The considerable stresses occurring during the rolling process may lead to fractures which originate at the non-metallic inclusions. Fig. 6 shows such fractures which occurred in a ball bearing steel.

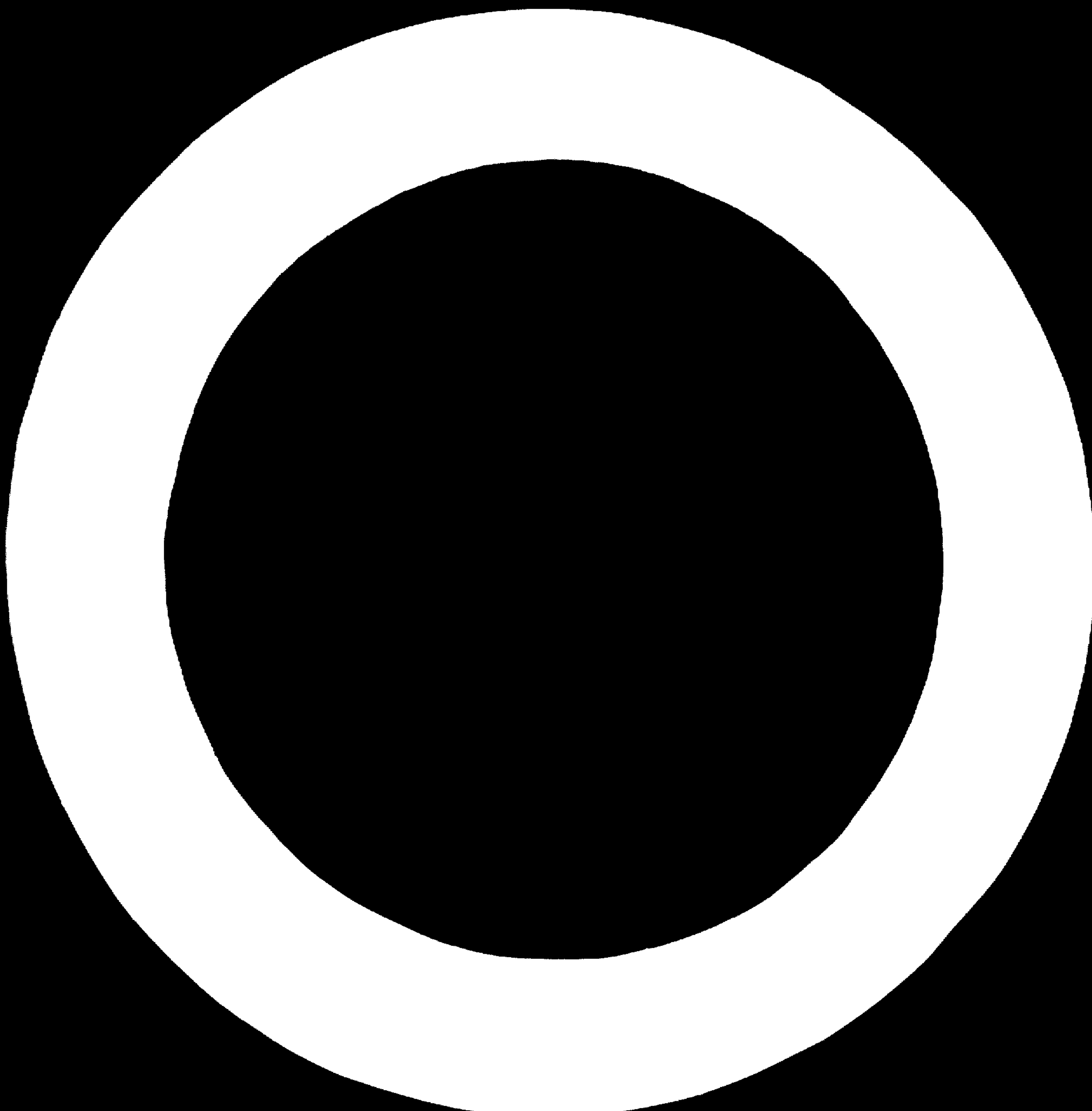
Perfect cast billets yield perfect tubes. They cannot be distinguished from tubes obtained from big ingots. This applies not only to the type and distribution of slag inclusions but also to the carbide distribution as can be seen from the ball bearing stock. Fig. 7 shows the outside and inside surface, the carbide distribution and cleanness of a tube which was rolled from a cast round 150 mm (6 in.) dia. The typical analysis of the steel was : carbon 1%, chromium 1.5%, manganese 0.35% and silicon 0.30%.

Tire rolling of round billets has also given good results. As an example, Fig. 8 shows a ring made from ball bearing steel. The ring has an OD of 245 mm (10 in.) and an ID of 190 mm ($7\frac{3}{4}$ in.). The stock used for the purpose was a cast billet of 150 mm (6 in.) dia. As can be seen from the photograph, the outside and inside surfaces of the ring as well as its structure and carbide distribution are perfect.

A new field of application for cast billets is offered by extrusion. Here again, the use of round stock is imperative. The use of billets obtained from ingots considerably increase the manufacturing costs of the finished products. Thus, cast rounds offer special economical aspects. The combination of the continuous casting process and the extrusion process seems to offer a great possibility for the future. Steel types which have been processed in this way include low and medium carbon steels, ball bearing steels as well as unstabilised and titanium stabilised austenitic chrome-nickel steels. The extrusion process was applied for tubes and various other sections of which Fig. 9 shows two examples.

In addition to the processes mentioned above, cast rounds will find additional application, especially in the field of quality steels. Thus, it has been established that the use of cast rounds instead of square billets can be of advantage for the surface quality of rolled stock. This is due to the fact that the mill scale falls off more readily from round stock during rolling in bar mills. However, round sections are more difficult to handle in reheating furnaces. Further advantages may be offered by round billets also when a surface conditioning operation must be introduced in order to give the desired quality. On the one hand round sections possess the smallest circumference for a given cross section, and, on the other hand, the conditioning can be carried out by means of simple and cheap lathes.

Altogether, it can be stated that the cast rounds offer such advantages in economical, technological and qualitative respects for a number of processing operations that their future application may be taken for granted, and, for all appearances, will be subject to a considerable increase.



FIGURES

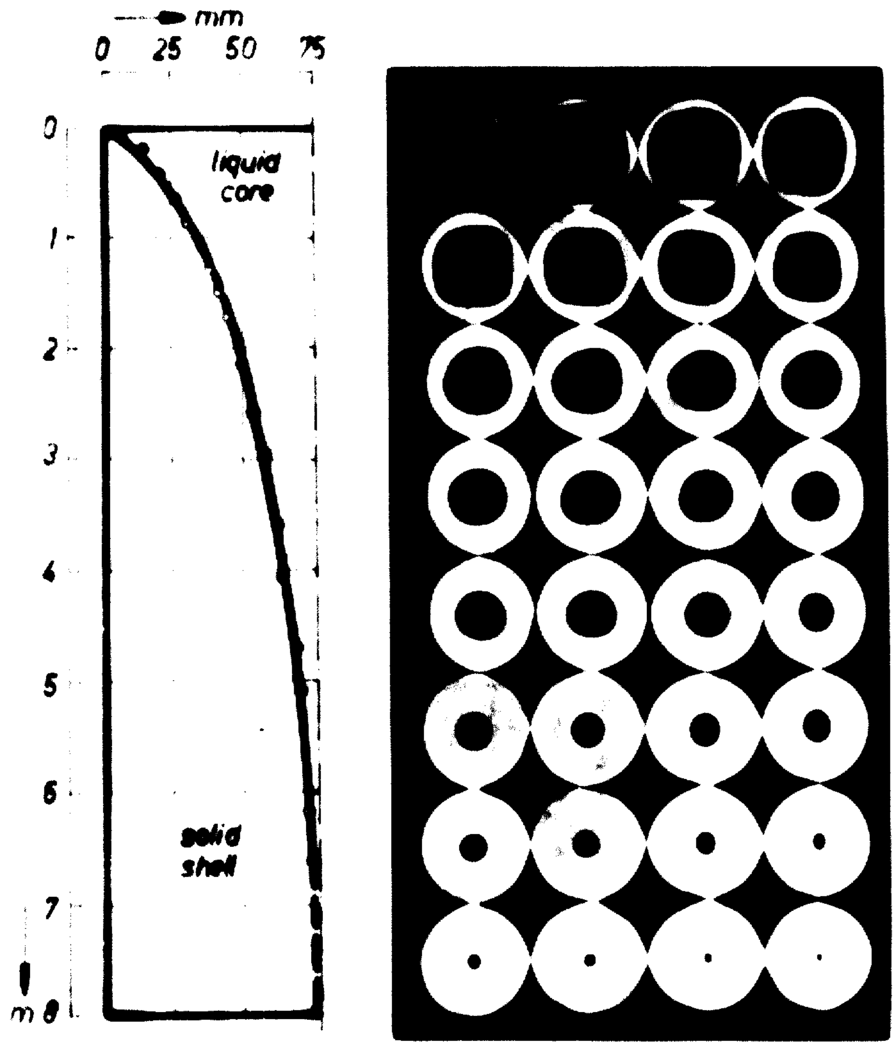


Fig. 1 solidification of a round billet

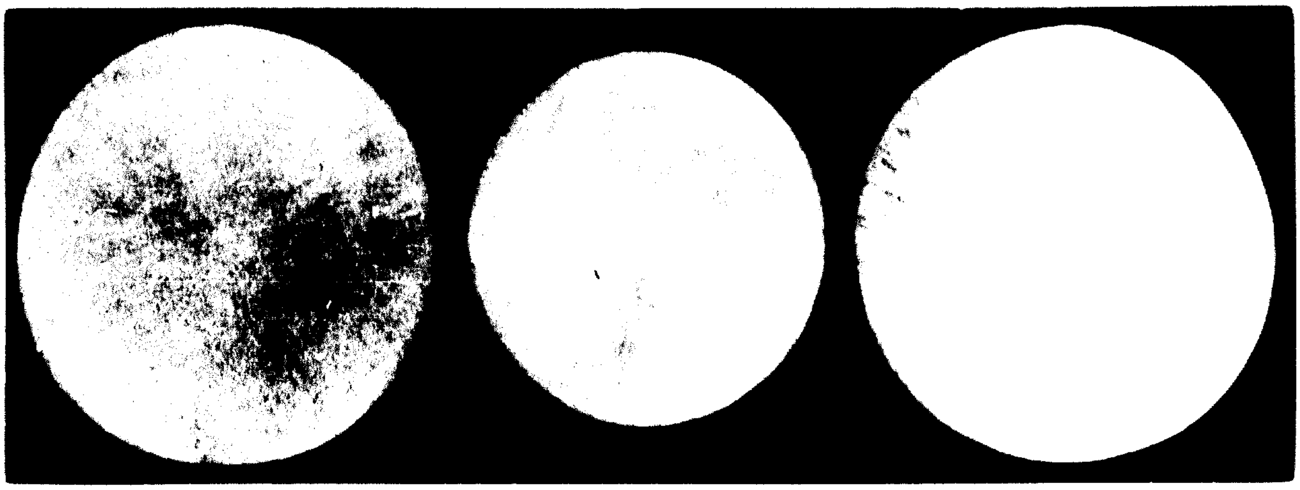
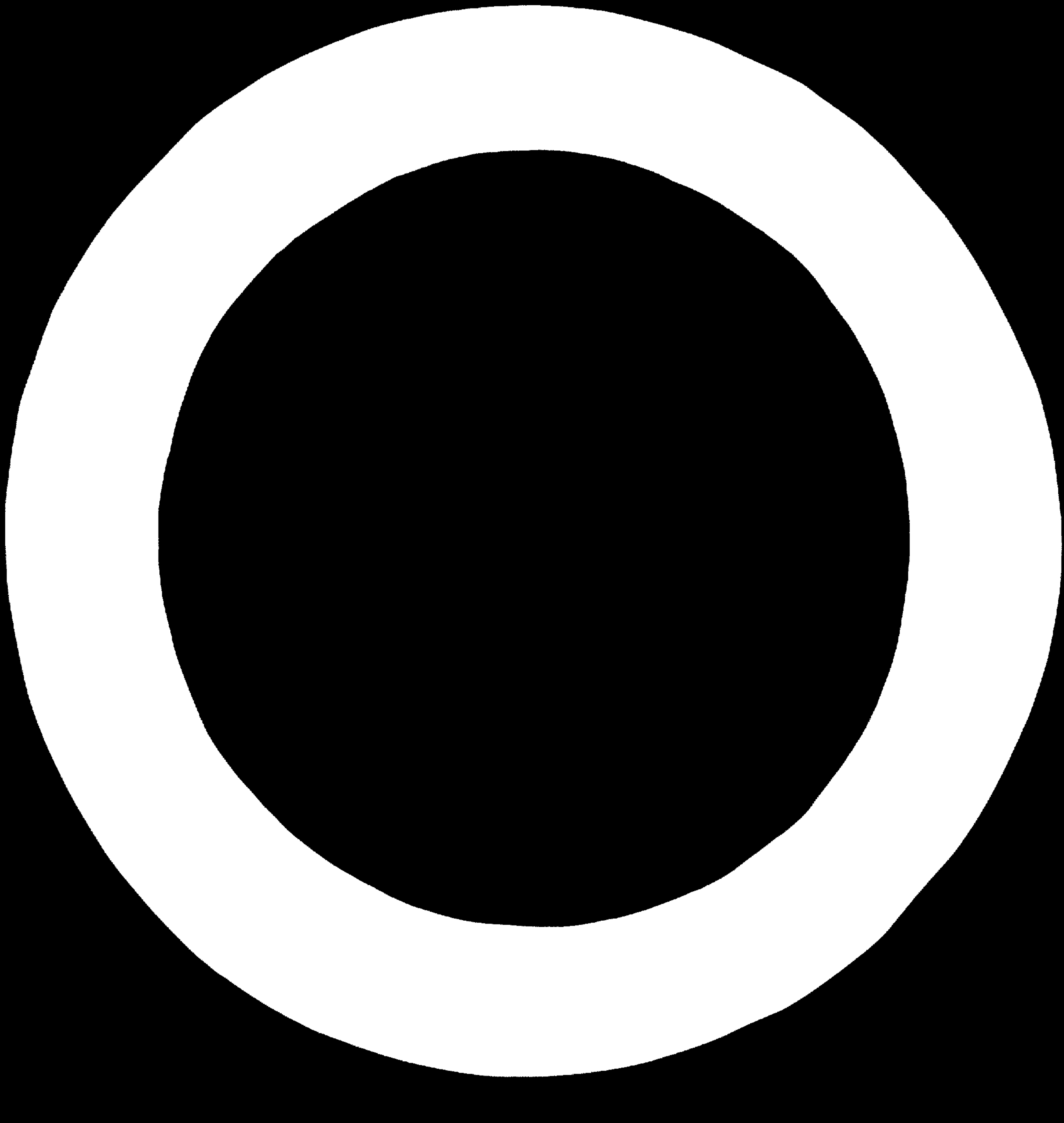


Fig. 2 growth of crystals; left influence of a rotary field, centre not stirred high mould wall temperature, right low mould wall temperature not stirred.



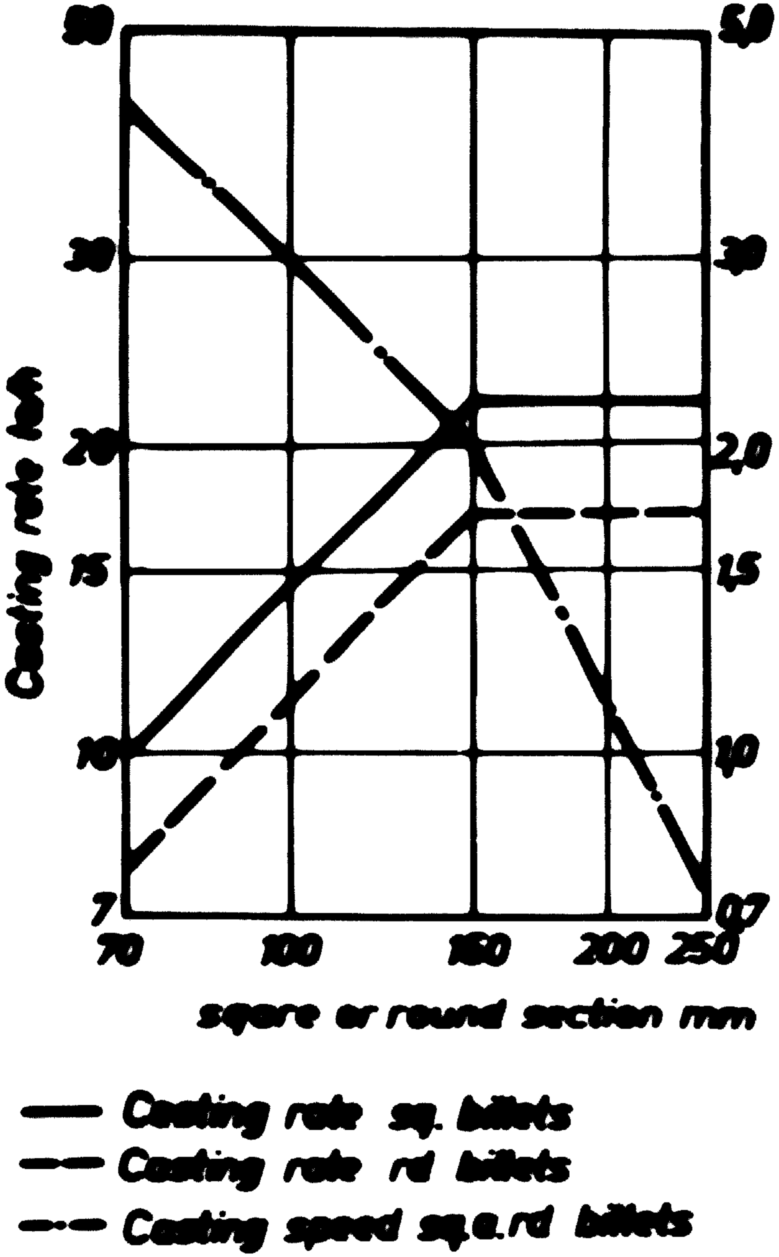
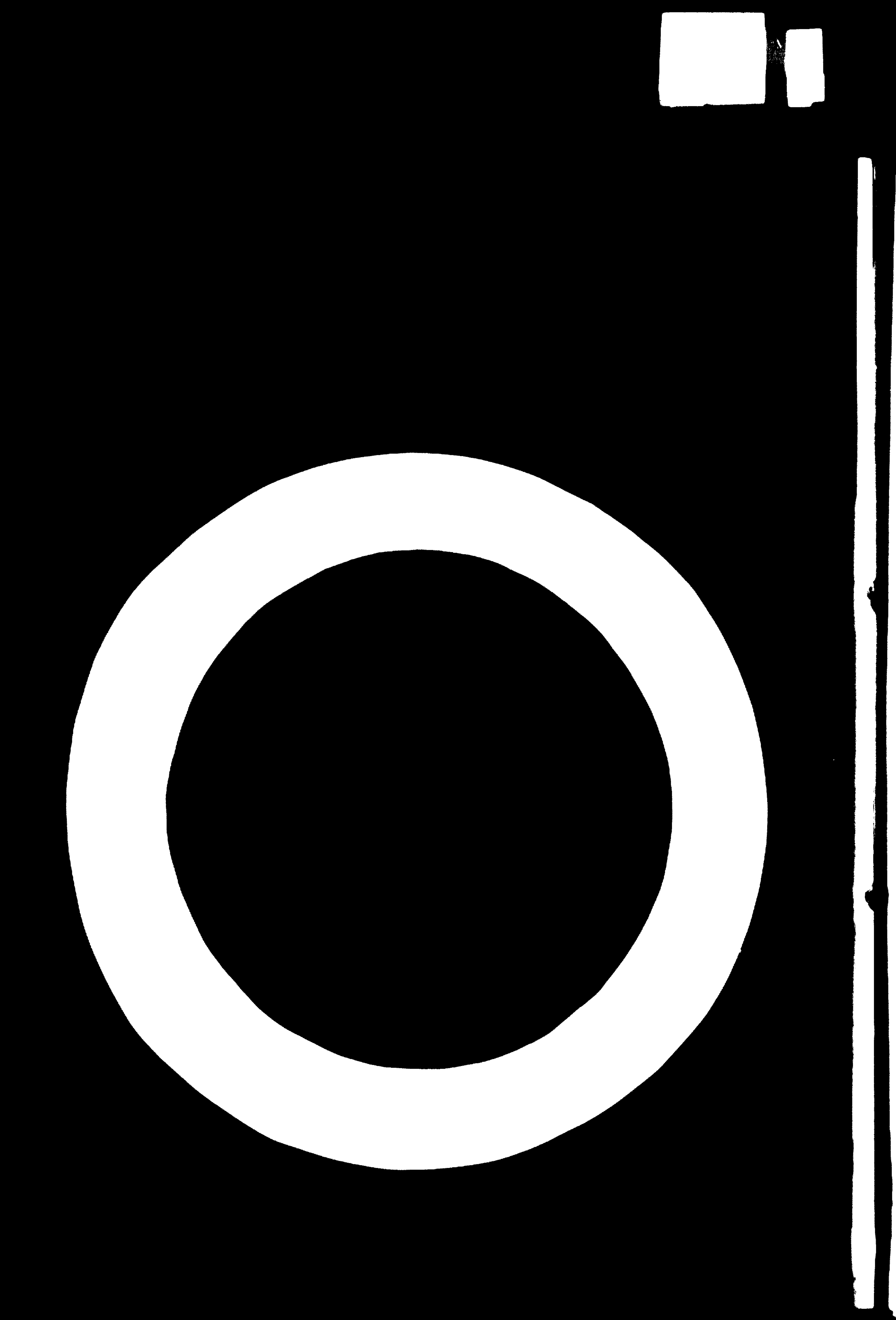


Fig. 3 casting speed and casting rate of round and square billets

Fig. 4 longitudinal crack



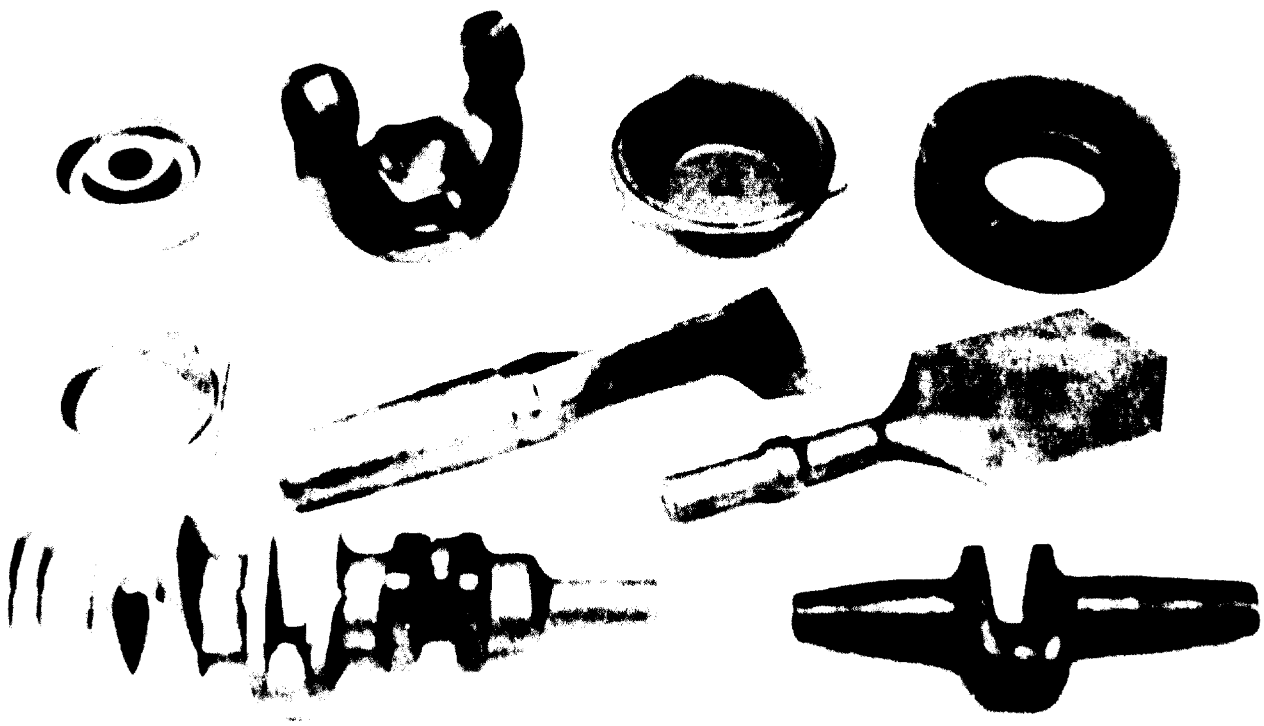
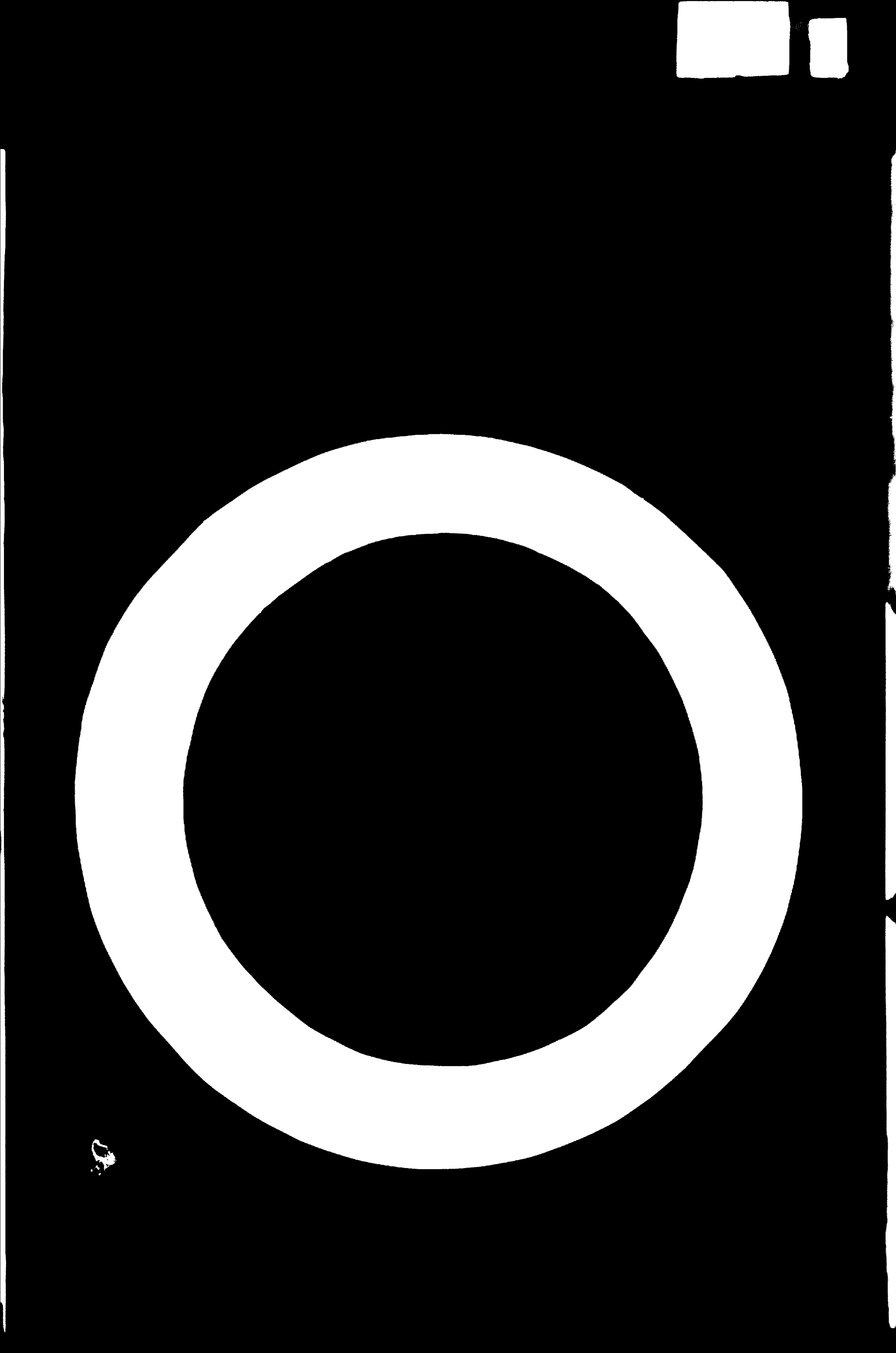


Fig.5 drop forged products

Fig. 6 fracture resulting from nonmetallic inclusion



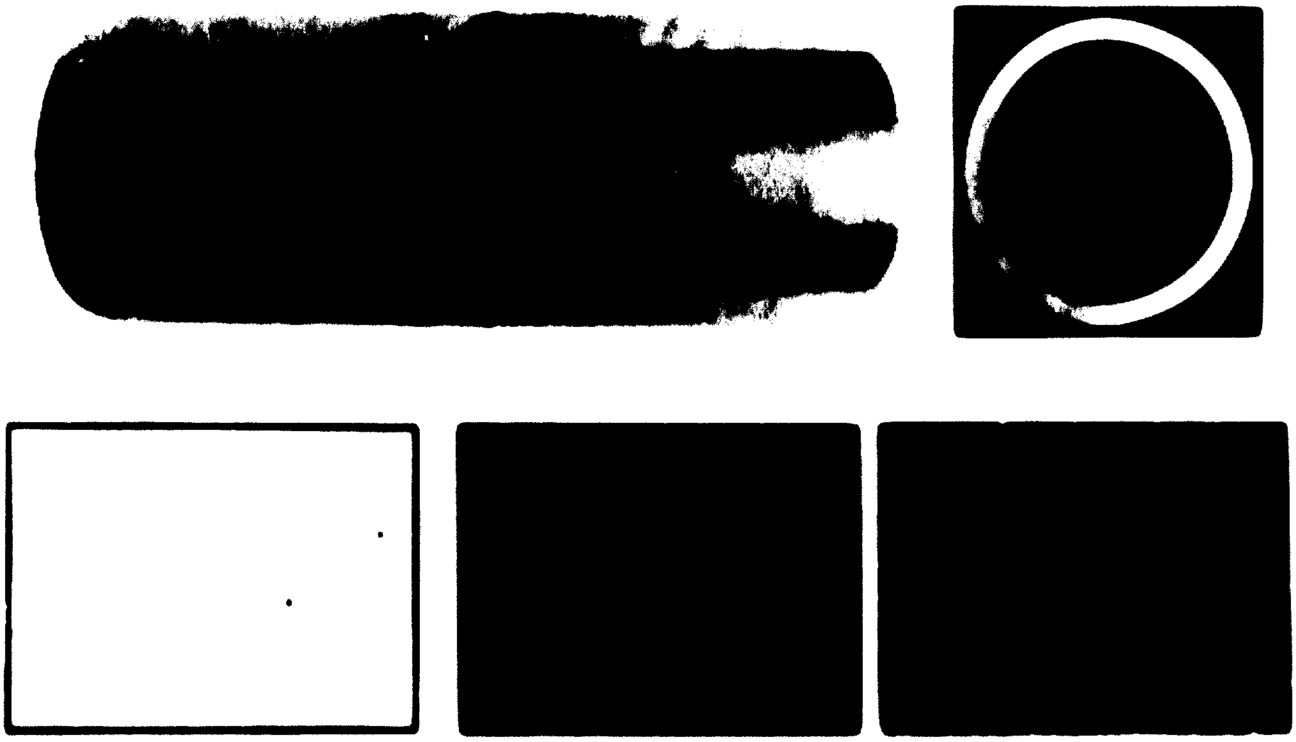
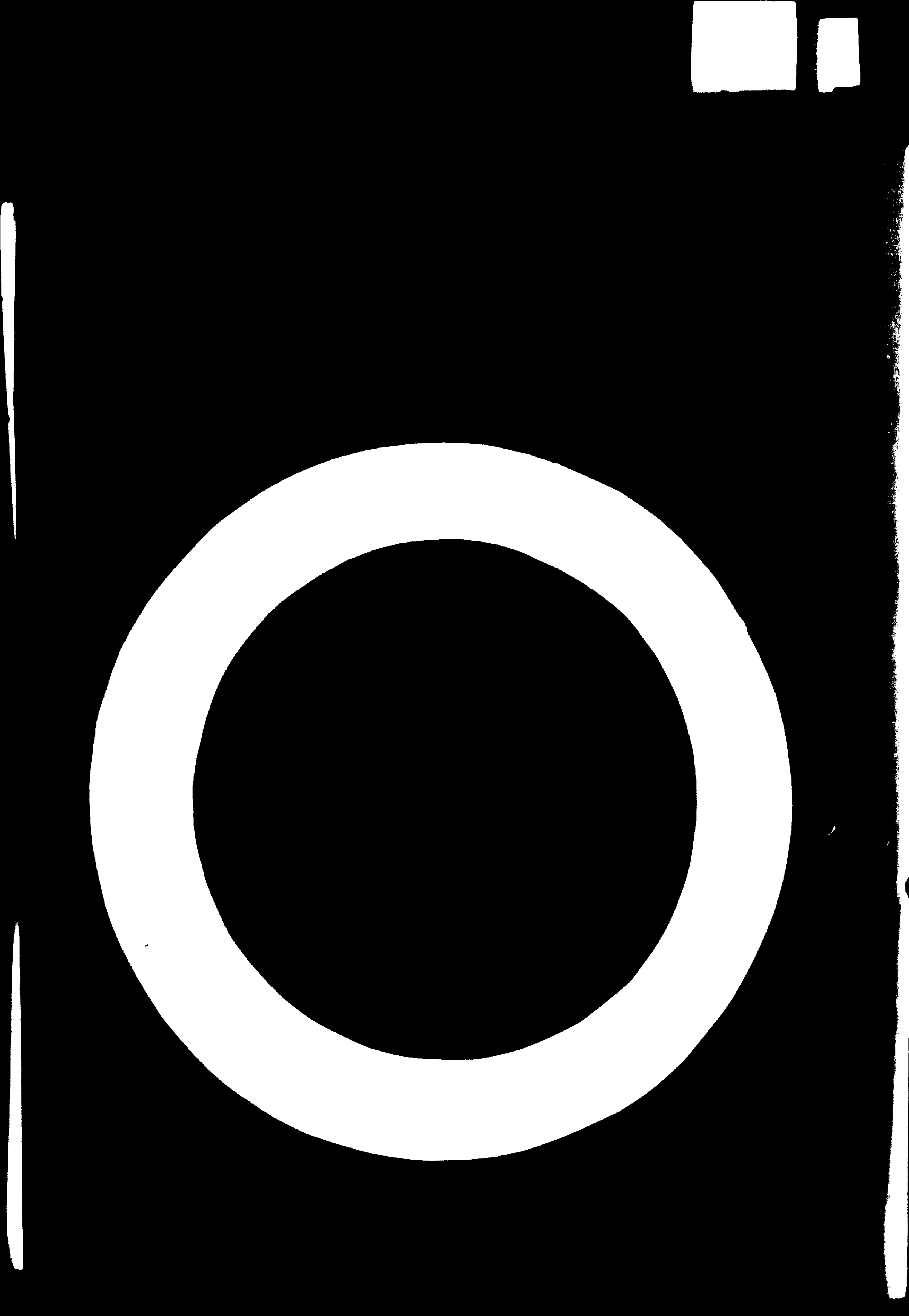


Fig. 7 surface, hotetched transverse section, cleanness and carbide distribution of a tube (ball bearing steel)

Fig. 8 ball bearing ring and structure of annealed material



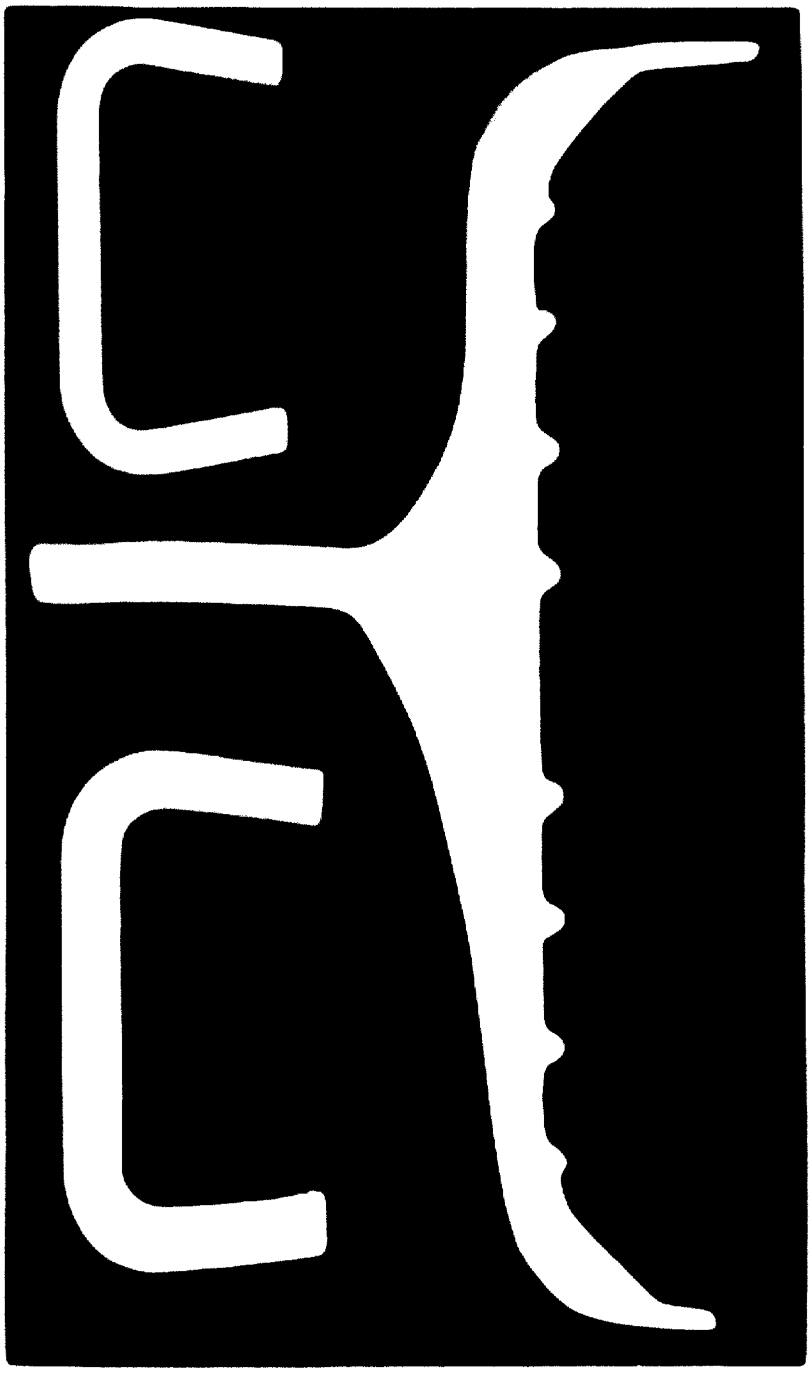


Fig. 9 sections made by extruding process
(etched with hot HCl)

22.3. 74