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32. For machines of the Concast group, Fig.2 shows typical mould tonnage rates for various square sections cast at several different plants, whilst Fig.3 shows the equivalent casting speeds and corresponding single-mould tonnage rates for square sections ranging 2 - 12 in. in size. These diagrams are described more fully elsewhere[2]; casting speed estimates for other simple section shapes may most easily be obtained by proportional comparison against inverse area/perimeter ratios, and tonnage estimates by direct proportionality to perimeters.

33. It remains to be noted that such estimates, although derived from vertical straight mould machine experience in the Concast group, are also directly applicable, in the first instance, to the Concast curved mould machines.

<u>Production Rate Matching</u>

34. Once the section size or sizes for a new production plant have been decided and mould tonnage rates determined, certain straightforward practical considerations can be combined to resolve the most suitable relationship between the number of machines required, number of strands per machine, ladle capacity, number and size of steelmaking furnaces and the anticipated annual output. A minimum initial investment cost compatible with minimised operating costs, reliability of operation under routine conditions and the production of good quality, are the criteria by which the possible combinations in any given case have to be judged.

35. The ladle may be of the bottom-pour or lip-pour type; the choice of which type to adopt is likely to remain somewhat controversial for years to come. Currently there is a marked tendency to prefer bottom-pour ladles, although lip-pour ladles have useful advantages, as described elsewhere[2] by the author. For any new project, both types of ladle should therefore be considered in context before taking a final decision. The limits of pouring time for design purposes are 45 mins. and 75 mins. for bottom- and lip-pour ladles respectively. Lip-pour ladles may allow the adoption of a machine with fewer strands for a given ladle or furnace capacity, or a larger machine throughput capacity for a relatively small multi-stranded section. Likewise, the casting of very small sections at high speeds is more advantageous from lip-pour ladles due mainly to greater flexibility and greater assurance of high yields. On the other hand, the actual pouring time might purposely be chosen relatively short - say, of the order of 30 mins., to fit in with frequently tapping L.D. vessels - and a bottom-pour ladle may well then be preferred. Likewise, for the casting of large sections and indeed wherever very large ladles are used, or where static ingots are also cast in the same shop, the bottom-pour design is more convenient.

36. The decision on the kind of ladle is best made in consultation with the machine suppliers, since many details of practice have to be checked, e.g. the time sequence of operations, and the occurrence of untoward delays and emergencies.

37. The number of strands or moulds installed to operate in parallel on a machine may be as many as 8, machines with 1, 2 or 4 strands being more common, although machines with 8, 6 or even 3 strands exist.

38. For a new machine, the number of strands has to be chosen to ensure that, with the casting rate per mould of the smallest section scheduled to be cast, the contents of the ladle are disposed of in a suitable time. The latter, whilst having upper limits as stipulated depending on the type of ladle adopted, has nevertheless also to be related to the tap-to-tap time of the steelmaking furnaces, or vessels. Machine reset time between casts, which may vary from less than 20 mins., as at Dillingen and Benteler, to about 1 hr., according to the type of plant and the facilities included, has to be taken into account in matching machine operations to the frequency of metal supply from the furnaces. In addition, if the production programme involves frequent size changes on the machines (moulds, roller aprons, sprays, dummy bars and control settings), extra precautions are needed.

39. When more than one furnace is involved, operations should be planned using time-base sequence charts, since "traffic" problems with ladles, tundishes and cranes, as well as delays at the machines and furnaces have to be eliminated as far as possible.

40. As a rule, for a given annual target tonnage, schemes based on the use of the smallest suitable number of furnaces and the smallest number of machine strands operating per cast consistent with obtaining reasonable time margins in the operations are usually the most economic. The use of only one large furnace tapping infrequently may not always be the best solution, since a machine with a large number of strands might then be needed and only be used at considerable intervals. Two smaller furnaces and one machine with half the number of strands might well be more economic for the same annual tonnage.

41. The foregoing considerations apply equally to curved mould machines.

42. It remains to be noted that the trend towards larger machine ladle capacities continues. Currently, the largest lip-pour ladles are employed at Appleby-Frodingham, (100 ton capacity); the largest bottom-pour ladles in use are 140 ton in capacity, at Donetsk, whilst 300 ton capacity bottom-pour ladles will be used on the 6-strand Concast Compact curved mould machine to be installed at National Steel's Weirton plant.

43. Likewise, the annual plant production levels also continue to increase, e.g. the Weirton plant has a definite target production of 1 mill.tons/annum, whilst plants elsewhere of 1½-mill.tons/annum, and still greater, are being planned. At the other end of the scale, plants with capacities as low as, say, 50,000 tons/annum of small billets are quite feasible, and even appreciably lower, depending on conditions.

GENERAL ADVANTAGES OF CONTINUOUS CASTING FOR STEEL

44. Continuous casting is commended to both established and about-to-be-developed steel plants by its advantages. These are mainly as follows:-

(a) Compared with ingot casting, the process is based on more standardized procedure and therefore allows improved control; being less of an art, it is more reliable for the production of good quality product on a routine basis.

(b) The average level of yield is high, e.g. typical Works Standard levels of about 96% are attained; generally the increase in average yield is of the order of 6 - 12% and this leads directly to reduced operating costs, reduced scrap re-cycling and reduced fuel consumption.

(c) Whilst large cross-sections can be cast, small sections down to 2 in.sq. can also be produced, eliminating or reducing the need for heavy primary rolling mill, or forging, operations and equipment.

(d) The quality of the cast material produced is uniform and good; often cast product can be transferred to the rolling mills with little or no surface dressing, whilst for stainless and other quality steels, where special degrees of surface finish are required in the ultimate product, the amount of surface dressing can be much reduced by the adoption of special procedures and equipment.

(e) The cast product is virtually free of macro-segregation and its non-metallic inclusion content is similar to that of good clean static ingot steel, and frequently tends to be lower.

(f) The cast product is eminently suitable to the direct application of severe deformation in rolling, forging and other hot-work operations, whilst its good regular shape and surface condition, and the uniformity of its "spread" in rolling, tend to result in smoother rolling operations and fewer "cobbles" at the mills.

(g) The capital investment for plants fully installed and ready to operate is relatively low.

(h) Process operating costs, when proper attention is given to design and planning, are also low, and thus make possible the installation of plant for much lower annual tonnages than can otherwise usually be justified, or result in major savings on higher tonnage plant.

(i) Machine operations can be automated.

(j) Because of the nature of the process, a scheduled furnace charge may well be tapped, cast and delivered through to the rolling mills in a relatively short period, thus appreciably reducing overall works production time and allowing faster product delivery times and reduced capital investment for materials being processed.

(k) Cast product can be delivered nearly hot enough for rolling and in a suitable manner for direct transfer to rolling mills or forges, allowing the possibility of additional savings to be achieved on reduced reheating prior to hot working.

(l) The process can be used for the production of almost all the ordinary steel qualities or their equivalents, but also lends itself to the production of the more difficult qualities, including steels which, produced as static ingots, are difficult to hot-work, and steels relatively high in alloy elements having a high affinity for oxygen; also to the production of new types of steel, e.g. those containing fugitive alloys.

(m) Where new steelmaking activity is planned, the process is well suited to the initial establishment of small tonnage plants, as well as large tonnage ones, and the capacity of new plants can be built up by the progressive installation of casting machines, or strands, as markets are established and the production requirement expands.

CONCAST CURVED MOULD MACHINES

45. The first installation of this type, Figs.4 and 5, was developed at A.G. der Von Moos'schen Eisenwerke of Lucerne, Switzerland, by Dr. E. Schneckenburger and Mr. C. Küng, and has been used since April 1963 mainly for the casting of 3 3/8 in.sq billets. Because of their important advantages, machines of this type - known as the Concast Model 'S' or Compact machines - are being built in preference to vertical straight mould/straight spray machines by Concast A.G. of Zurich, and Concast Inc. of New York. As indicated in Table 3, a wide range of section sizes is already being covered and operations are planned with ladle capacities up to 300 tons.

Principle

46. The method is based on the use of a water-cooled mould which, instead of being straight walled from top to bottom, is longitudinally curved, or radiused to one side, and is mounted on a lateral radius arm or on curved guides so that it is not only supported but can be reciprocated coincidentally with the path of its curvature. The curved mould is held in a near-vertical position and the cast section, during extraction from the mould cavity and emergence into the spray system, follows the curvature imposed on it during initial solidification of its 'skin' or 'wall' in the mould.

47. Below the mould the water sprays are grouped around a curved roller apron, or guide roller path of the same curvature, so that the emerging section is supported and made to follow this curvature through the whole curved length of the spray zone. The latter is arranged to approximate to a quadrant arc so that on emerging from the spray zone the section is travelling virtually in the horizontal direction and can be made to pass through a withdrawal roll group consisting of at least two roll pairs, preferably three pairs or more. The withdrawal roll group acts also as a straightening roll set and the section is discharged therefrom along a horizontal roller track to a cut-off station, where it can be cut to required lengths for further processing.

Control of Pouring

48. The arrangements for supplying liquid metal to the mould are essentially similar to those used on vertical straight mould machines. The metal can be teemed from a bottom- or lip-pour ladle via tundishes fitted with either stoppered or plain pouring nozzles positioned to discharge into the upper aperture of the curved mould. To control the metal supply to the mould, and to maintain the metal level within it, either of the techniques - stopper control or machine speed variation - can be used. Normal use is also made of mould lubricant oiling plates and of propane gas blankets for protection of the metal against oxidation.

49. The preferred teeming arrangements as adopted at Von Moos' are shown in Fig.6; a 5 ton capacity bottom-pour ladle supplies a non-stoppered tundish which discharges vertically into the $3^{3}/8$ in.sq. mould, manual speed control being used to maintain mould metal level.

Moulds

50. For small sections, up to about $4^{3}/4$ in.sq., tubular moulds are used, as at Von Moos', the mould tube being preformed to the required longitudinal curvature, as shown in Fig.7, and supported inside a likewise suitably curved mould casing. Mould tubes are about 32 ins. long and have $^{1}/4$ in. thick walls for tube sizes up to 4 in.sq. and $^{3}/8$ in. for larger sizes. Corner radii are typically $^{1}/4$ in., or $^{3}/8$ in. in the larger sizes.

51. For larger sections, the geometry of the curved mould cavity remains similar, but the preferred construction of the mould is the 4-plate design, wherein each wall consists of a copper plate bolted, or otherwise tied back, onto steel backing plates, the four walls being held tightly together to form the mould. For medium and large sections, certain designs of heavy solid block moulds could, and no doubt will, also be used, but the preference is likely to remain for the 4-plate design. For the medium/large sections, and particularly for the large/very large sections, the mould cavity, even though curved, is advantageously constructed with fairly normal amounts of mould taper so as to be smaller at its lower end by up to 1½ per cent per side, depending on the mould shape, its construction and the type of metal to be cast.

Radius of Curvature

52. The radius of curvature of the mould is related in a first approximation to the minimum thickness of the section, or more generally to its dimension in the radial direction of curvature. The radius of curvature, R, of the mould centreline and also of the spray zone for a machine specifically designed to cast one given square section of thickness, d, would probably be selected so that:-

$$\text{Degree of curvature} = \frac{d}{2} / R = 0.015,$$

where d and R are in the same units.

53. Similar to that of the Von Moos' machine, this degree of curvature is known to be reliable for practical operations, and is often quoted alternatively as an "eccentricity" of 1.5%. Its actual value could, however, be chosen over a range; clearly, smaller values are possible, down to zero, which corresponds to the case of vertically straight moulds, and larger values, already known to be possible, may eventually be adopted under certain conditions, e.g. 2.0% or even 4.0%. Most of the advantages, however, already pertain with 1.5% eccentricity.

54. In practice, a machine is usually required to cast a range of section sizes, and the machine is constructed to operate with a radius of curvature $R_{machine}$, to suit the 'radial' dimension of the largest section cast, say, to suit $d_{largest}$. In other words, the function:

$$\frac{d_{largest}}{2} / R_{machine} = 0.015, \text{ or } 1.5\%, \text{ say}$$

would apply. Furthermore, for all smaller section sizes cast on this machine, the required radius of curvature for the necessary moulds and sprays would also be $R_{machine}$.

55. This simple consideration led Concast to standardise the design and construction of the curved mould machine into at least three basic standard machine sizes, as follows:-

	Size Range mm. square	Machine Casting Radius m.
Type 1	65-120	4
Type 2	80-200	6
Type 3	Larger sizes, as specified	To suit maximum size

56. Whilst in no way discountenancing further development, nor alternative constructions of advantage for particular Works or site requirements, such standardisation has other obvious advantages, including minimising of initial machine cost and the cost of provision of spares, e.g. mould replacements.

Mould Reciprocation

57. Mould reciprocation arrangements differ from those for vertical straight mould machines only in that the actual movement of the mould is strictly held to the curved path corresponding to the machine radius of curvature. This curved reciprocative motion is mechanically more simple to achieve since there is no need to include lateral "lost motion" as in straight-line vertical reciprocation.

58. As on the Von Moos' machine, the mould may simply be supported at one end of a horizontal radius arm which is pivoted at its other end at top platform level substantially in line with the mould. By shaping it to pass below the top platform in the region between the pivot and the mould the radius arm can make contact with a double-acting type 3 : 1 ratio cam, or other form of reciprocation drive device, positioned on an auxiliary frame just below the top platform.

59. Stroke lengths are chosen, as for vertical straight mould practice, so as to obtain reciprocation frequencies of the order of 60-80 cycles/min. at the expected normal high casting speeds. Cam speeds are related to the driven withdrawal/straightening roll speeds so that each downward peripheral travel of the mould, curving with the section, is either synchronised to that of the section (i.e. no negative strip used), or, as is preferred, is made slightly faster, (i.e. ensuring negative strip). The latter condition makes possible the high casting speeds attainable on these Concast machines for small and medium section sizes.

60. Cams with other ratios, e.g. 2 : 1, and other devices such as eccentrics or crank mechanisms with ratios of approx. 1 : 1 are, of course, possible. These alternative styles of reciprocation will be adopted progressively, especially where still higher casting speeds are sought. Hydraulic reciprocation devices may of course also be used, whilst use of a radius arm to carry the mould may become rather cumbersome on machines casting very large or thick sections and alternative mould support equipment, including for example curved guides, can then be adopted.

Curved Sprays

61. The machine radius of curvature, $R_{machine}$, when defined by a given eccentricity, say 1.5%, for the largest section to be considered, almost completely determines the length of the curved spray zone below the mould. The main spray zone extends from immediately below the lower end of the mould to just ahead of the point of entry into the withdrawal/straightening roll group. Hence, the length of the spray zone is shorter than the quadrant arc length corresponding to the radius of curvature, namely $\frac{\pi}{2} \cdot R_{machine}$, or 1.57 x $R_{machine}$. The sprays are more typically 1.33 x $R_{machine}$ in length and the relationship, viz:

$$R_{machine} = \frac{1}{1.33} \text{ (spray length)} = 0.75 \text{ (spray length)},$$

indicates how the radius of curvature correlates to the spray zone length required.

62. The latter has normally to be constructed with increased length for the casting of thicker sections and/or for casting at higher speeds, and these considerations primarily determine the magnitude of the radius of curvature and the preferred eccentricity level for this type of machine.

63. The rollers forming the curved spray zone path are carried on support frames and may be located to maintain contact on all four sides or mainly on the upper and lower sides. For small sections, the rollers act mainly as guide rollers; for large sections, especially slabs, the rollers form an apron proper to maintain section shape as well as to provide support. Spray nozzles are arranged between the rollers to direct spray water onto the exposed surface of the moving section in a manner similar to that adopted on vertical straight spray machines. Fig.8 shows the roller guides and sprays during a cast on the Von Moos' machine.

64. The distribution of sprays at the sides, top and bottom of the curving section is such that solidification of the section to the centre is uniform on all sides and the centre of solidification of a square billet, say, is geometrically quite central.

Dummy Bar

65. To initiate casting of small sections, use is made of a dummy bar, which may be constructed as at Von Moos', of steel-reinforced rubber. Being flexible, it can be inserted prior to casting through the withdrawal/straightening roll group and threaded up through the curved spray zone to the mould. Its short headpiece is constructed of solid steel and can be pushed just into the bottom end of the mould. On withdrawal, the dummy bar emerges horizontally from the roll group and is disconnected, together with the initial discard portion of cast material, on making the first cut. A tendency for the reinforced rubber dummy bar to slip in the withdrawal rolls is reliably eliminated by attaching a light wire rope to its leading end and tensioning with an auxiliary winch. Other dummy bar constructions are also available which have advantages in machines casting large sections.

Withdrawal/Straightening Rolls

66. The withdrawal/straightening roll group performs the dual function of maintaining withdrawal and straightening prior to discharge. On the Von Moos' machine, four driven roll pairs are housed, as seen in Fig. 9, in two rectangular frames - a lower frame carrying four lower rolls grouped in a near horizontal line, and a similar upper frame four upper rolls. During casting, the frame with the four upper rolls, pivoting about the axis of its leading roll, is pressed down by a spring loaded saddle attached

to its discharge end whilst the frame with the four lower rolls, fulcruming on the axis of its discharge end roll, is likewise pressed upwards by a spring loaded saddle positioned at its leading end. Using mechanised screw down gear, or, as at Von Moos', manual equipment, these saddled springs can be loaded so as to bring the upper and lower line-groups of rolls to bear on the section opposite each other and so discharge a straightened product. The drive to both the upper and lower rolls is from a single input shaft, through distribution gears along both sides, or, as at Von Moos', one side. The rolls may be internally water-cooled or perhaps more effectively, as preferred at Von Moos', externally cooled by suitably positioned water jets.

67. Other kinds of withdrawal roll assemblies to perform the same duty are of course possible; the Von Moos' design, however, has the considerable advantages of compactness, relative simplicity and high rigidity for minimum weight.

Main Drive Equipment

68. The main drive equipment on curved mould machines is greatly simplified whether based on the use of A.C. or D.C. motors, mainly due to the disposition of the machine parts and because only two main drives are required - that to the withdrawal/straightening roll group and that to the reciprocating device. Two suitably synchronised D.C. motors could be used, but the relative positions of the driven units below the top platform conveniently facilitate a simple mechanical interconnection, as seen in Fig.4, and this is much preferred since only one main drive motor need then be installed. With the two drives mechanically interconnected, a single main drive A.C. motor coupled with infinitely variable gear boxes, as is done at Von Moos', is as effective and considerably less costly than the use of a D.C. motor.

69. The main drive units are mounted on an auxiliary platform, seen in Fig.5, below the top platform of the machine and in line with the reciprocation mechanism on its attached supporting frame. From the distribution gear box, a horizontal shaft drives the reciprocation equipment whilst a vertical shaft descends to the driving side and interconnecting gears of the withdrawal/straightening roll group.

Straightening and Discharge

70. The grouped withdrawal/straightening rolls allow straightening of small/medium cast sections at higher and more precisely controlled temperatures than on conventional machines with discharge by bending - which is advantageous with certain high alloy steels. The horizontal discharge facilities either manual or mechanised cutting to length of the product and its collection on hot banks, or direct despatch to heat-soaking furnaces and hot rolling mills.

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CONTINUOUS CASTING FOR STEEL: NEW SIGNIFICANCE AND DEVELOPMENT

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1. Not only for established steel industries, but also for localities where new steelmaking activity is being developed for the first time, three points are salient and important:

(a) Continuous casting, rather than ingot casting, is greatly to be recommended as a result of its development in recent years and on account of its inherent advantages.

(b) The new curved mould casting process, developed by the Concast group and dating only from April of this year (1963), brings further practical advantages which are immediately available by way of greatly reduced initial costs, greater facility of application and increased flexibility to production, thus enhancing the previous point.

(c) Other current development work, which is almost all still equally applicable to the new method, and the expanding use of the latter, will undoubtedly lead to further valuable advances in the near future, and thus reinforce the above views.

2. Activity in the field of continuous casting for steel has lately been centred largely on a broadening application of the vertical straight mould process. The method, as developed and practised at present, is concerned with the direct conversion of the liquid metal by solidification to long continuous lengths of billet, bloom, or slab sections. The process of solidification is generally maintained in a vertical straight-walled mould and by a vertical zone of secondary cooling water sprays below the mould. The new Concast method, based on casting with a curved mould and with a curved secondary cooling zone, can also produce similar cast sections and also uses many of the other techniques of the straight mould method, but the reduced machine height, indicated in Fig.1, and the resultant greater convenience and advantages give increased industrial potential to the process. Hence, it is not surprising that, although so recently introduced, the installation of curved mould machines is already making rapid progress, in many cases in preference to vertical straight mould machines.

Multi-Strand Machines

71. Multi-strand machines conveniently have the moulds, apron rollers and sprays of each strand installed side by side, together with their individual reciprocating and withdrawal/straightening roll units and drives. Other 'plan forms', e.g. back-to-back, square, or staggered-square arrangements, could be used, but the side-by-side or 'in-line' layout is generally preferred.

Machine Dimensions

72. Top platform areas and the disposition of ladle, tundishes, moulds and control equipment hardly differ from those currently adopted for straight mould machines with the same duty.

73. Curved mould machines, however, allow great savings in machine height. Below the top platform the main support structure of the machine can be built, as indicated in Figs.4 and 1, as a relatively simple frame of almost square, or rectangular, construction in the plane of curvature. The height of the top platform is only a little more than the radius of curvature of the machine, depending mainly on the height of the withdrawal/straightening roll group above ground level.

74. Compared with similar duty vertical straight mould machines, e.g. in Fig.1, the support tower and/or excavated pit of which contains three or more platforms, the Concast 'S' type/Compact curved mould machines avoid the need to provide great crane heights and expensive buildings or, alternatively, deep pits and expensive discharge machinery. In practice, the top platform height of a curved mould machine equates to about 75 per cent - theoretically about 64 per cent - of the spray length height of the equivalent vertical straight mould machine. Allowing for the height of the ladle and tundish, etc., the total saving in height is still very considerable and the machines can generally be easily sited in existing shops.

Manning

75. The reduced height and the elimination of individual withdrawal, bending and straightening equipment make the operation of these machines considerably easier than that of the more conventional easy-to-operate vertical machines fitted with discharge by bending.

76. Under similar production conditions, the manning requirements for machines with 1, 2 or 4 strands, however, is likely to remain essentially similar to the requirement on vertical machines, although in certain cases one less man may be possible in crews which range 4 - 12 in number, according to the number of strands, the degree of mechanization and inclusive of the foreman, or shift manager, in charge of the machine.

ADDED ADVANTAGES OF CURVED MOULD CASTING MACHINES

77. Without doubt, Concast curved mould casting machines provide important additional advantages over those of the more conventional vertical straight mould machines of similar duty. These added advantages are as follows: -

a. Under production conditions, the average yield is likely to prove a little higher in most cases because of the greater general simplicity of the machines.

b. Because of greatly reduced height, the machines are more convenient to install in existing melting shops and beneath existing cranes; also, on new sites the expenditure on buildings and foundations is considerably reduced.

c. Certain mechanical features are greatly simplified, e.g. the requirements for mould reciprocation, the combination of withdrawal and straightening rolls, and the reduced number of main drives, thus minimising maintenance.

d. The horizontal delivery of large blooms and slab sections is greatly facilitated by casting on a radius, since the use of heavy bending equipment below the withdrawal rolls and the resultant heavy reaction stresses as in vertical straight mould machines are eliminated.

e. The essentially horizontal discharge and the more precisely controlled high temperature are ideal for the direct transfer of product to subsequent processes, and facilitate the discharge of certain high alloy steels.

f. Because of the reduced height, and mechanical simplifications, the initial cost of machines is greatly reduced - by as much as 18 to 28 per cent - and the total cost of a machine erected and ready to operate, i.e. with buildings and services on a green field site, may be reduced by

f. contd. almost as much; much greater savings, up to about 50 per cent., occur where these machines can be mounted in existing melting shops, and where new buildings or pits essential for vertical type machines need not be provided.

g. Reduced operating costs are likely mainly from reduced depreciation relative to the lower investment cost and from reduced maintenance requirements.

h. The lower initial cost and easy installation allow greater flexibility of plant operations and further savings in operating costs if advantage is taken by installing extra machines equipped to cast alternative sizes; the same points greatly assist the progressive build-up of new steelmaking activity as the markets are developed.

i. The metallurgical quality of material cast on curved mould machines is in all respects equally as good as that produced from vertical straight mould machines.

j. Automation is simplified to the provision of mainly automatic mould metal level control and mechanised cutting of product to length, both of which are available and can lead to savings in man power.

k. There are strong indications that appreciably higher casting speeds and hence greater production rates per mould may be facilitated.

l. Machines of this type are equally suited to the adoption of other future developments envisaged for vertical straight mould machines.

THE APPROACH TO NEW STEEL PRODUCTION ACTIVITY

78. Where new steel production activity is contemplated for the first time, continuous casting by the curved mould process is to be particularly advocated as a more attractive and reliable process than the adoption of static casting of orthodox ingots. This argument is based on the general advantages of continuous casting and the extra gains afforded by Concast-type curved mould machines, together with the metallurgical features of the cast product (indicated in Appendix 1).

79. A decision to take up steel production and include continuous casting on any site must rest, of course, on the economic and practical feasibility of the overall scheme. Continuous casting does allow a Works to operate at lower tonnage levels than with static ingot casting, or become economic at higher tonnage levels, mainly because of the inherently higher average yield and the uniform good quality of product, coupled with the elimination of intermediate operations such as ingot mould stripping, ingot reheating and heavy primary rolling. These features result in major savings on initial investment and reduced operating costs.

80. Moreover, certain other "immediate" advantages are also afforded. Projected performances at the casting machines are likely to be attained at an earlier date and to a more reliable routine, provided proper conditions and good plant design based on experience of the process pertain. Operators can be trained to run machines in 2 - 3 weeks and soon become experienced in the operation of their own particular plant. Initial commissioning periods for new machines are not long and good quality product is frequently made from the very first cast. Teething troubles, of course, occur, but for the most part are not serious, and high average yields and good machine performance are usually attainable within a fairly short time. The attainment of initial production targets may well be more dependent upon the performance of the associated newly installed steelmaking units or rolling mills.

81. Whilst such short-term aspects are important, certain long-term considerations should not be overlooked. Assuming proper feasibility studies have been made in regard to markets, plant location, raw materials, communications, etc., and the practicability of instigating development or expanding has been confirmed, then the kind of production and ultimate tonnages expected, including any intermediate stages of tonnage expansion, are used to clarify as far as possible the ultimate scheme and/or its later stages at the time of planning the initial stage. In this way the character and capacity of the initially installed equipment will not be severely at variance with the later installations. This briefing of progressive expansion of capacity is valuable in ensuring the most suitable decisions are taken in respect of the steelmaking furnaces and rolling mills, as well as the casting machines, and often saves investment on plant which later becomes less suitable and shows how expansion may be financed out of earnings as progress is made. Judiciously applied, this can lead to savings in foreign exchange, where pertinent. Where the potential production is appreciable, but difficult to define in the years ahead, such briefing is indeed still worthwhile.

82. Even although casting machines, especially curved mould machines, are low in cost and economic to operate at relatively low output levels, the central connecting-link position of the process between steelmaking and, say, hot rolling to semi-finished products, demands sensible matching of operations between the three processes for each stage of development. Matching for optimum results has already been described, but summarises in the main as follows:-

a. select one, or a few section sizes which allow adequate hot work reductions in area according to the size and duty classifications of the final products;

b. estimate the most practicable number of machine strands casting the smallest chosen section to suit possible ladle capacities of either type;

c. determine the capacity and smallest practicable number of steelmaking units to yield the required annual tonnages, yet also match the throughput tonnage rate at one or more machines;

d. check operational sequences on time-base charts for both main equipment and auxiliaries, and ensure standby capacity if necessary.

Flexibility

83. If plans are prepared on these lines, it is then usually quite evident that continuous casting can afford ample flexibility under production conditions at each stage of development.

84. Frequently, in the larger schemes, greater flexibility can be obtained by installing an extra machine which can be brought into operation at any time and gives extra standby capacity should a major stoppage or emergency occur on the other machine or machines. The extra machine is often desirable in itself since it can facilitate planned maintenance and the scheduling of size changes against production programmes, although it is not essential to the making of planned changes, nor needed for routine maintenance arrangements. It may well transpire that the total number of strands, including the extra machine, is still no greater than the total number required perhaps by other arrangements, because of greater general availability.

Diversification

85. The inefficiency of excessive diversification, which may arise from a desire to produce a wide variety of section sizes from a given machine, should of course be avoided. Machines can be made to cast a large number of section shapes and sizes, but it is usually preferable to install a number of machines each equipped to produce limited ranges of sections. A wider degree of plant diversification in respect of section sizes and their tonnages can, where necessary, then be obtained (again due to improved machine availability), together with much greater flexibility in programming production. Better matching between furnaces and machines is then clearly possible and delays for size changes are largely avoided.

86. Where wide ranges of section sizes are envisaged, such considerations suggest the establishment of operations classified according to more limited ranges of section sizes cast. Thus, Works or sections of Works may with advantage be centred on the casting of particular ranges of size and for a growing new industry this aspect can lead to gains if considered on an area, regional or even national basis. The actual delineation of size ranges can of course vary considerably and even overlap. Greater continuity of production and a fuller utilisation of machines would be the aim; the correlation of furnace and machine operations can clearly be improved and so also will machine production fit more closely into the rolling mill programmes.

87. Due to their lower initial cost and ease of installation, Concast type curved mould machines simplify planning on the lines indicated, and allow still greater efficiency under practical production conditions.

FURTHER DEVELOPMENTS

88. Although continuous casting is a well fledged production process with considerable advantages, several further advances are imminent, if not indeed already in use. Some of these are mentioned below. A main point is that all these advances can be equally made use of with Concast-type curved mould machines and undoubtedly the rate of application of such new possibilities will be accelerated by the increasingly wider adoption of these machines.

Higher Tonnage Throughputs

89. Apart from the trend towards larger ladles, the casting of larger sections and improved machine construction allowing reductions in reset times between casts, higher casting speeds to increase mould output rate are likely to be adopted in cases where larger ladles, or outputs per cast, are sought. The production of small sections in melting shops having large capacity furnaces has renewed this interest and outputs up to 50 per cent greater than normally specified have recently been show at Barrow to be feasible in the casting of, for example, 3 in.sq. billets.

Casting of Special Shapes

90. The casting of special shapes to reduce the hot work load at rolling mills and even in forging has not been given much attention and the casting of hollow sections has not been generally developed. Work in Russia and elsewhere, and advances in mould design, suggest however, that specially shaped sections can be produced, and progress with the casting of hollow sections from vertical machines is being made at least at one plant.

91 Suggestions that curved mould machines will not be suitable for the production of these sections appear to be unfounded although, as yet, no evidence can be quoted.

92. The installation of a Concast 'S'/Compact type machine fitted with a Weybridge type mould to cast 'corrugated' sections for later slitting or cutting to square billet shapes is doubtless also feasible, and would be one possible method of simultaneously producing several strands of billets which require to be separated. The main difficulties with the method are likely to remain; as for a vertical machine of this type, heavy and costly slitting roll equipment is required and, more important, the edges of the billets are likely to be less perfect.

Automatic Controls

93. The main automatic controls required for curved mould machines are concerned with mould metal level control and mechanised cutting to length. Equipment for the latter is available in different forms at various plants whilst, for the former, a gamma-ray scintillation counter equipment including self-start circuits, has been in use for several years at Barrow, both on the pilot and production plants.

94. There is no doubt that the use of automatic controls will in time become standard equipment on most production plants and that, in addition, more sophisticated arrangements will be introduced. For example, automatic spray and other controls are being tried out. Whilst the use of automatic controls may in certain cases allow reductions in the manning of the machines, these are unlikely to be considerable for some time to come. The main advantage of such controls lies in the more precise operation of the plant and in minimising the fatigue of the operators, thus also leading to greater reliability.

<u>Direct Rolling</u>

95. The horizontal delivery of product from curved mould machines undoubtedly will lead to further interest in the transfer of product direct to the rolling mill. Whilst reduced handling and reduced stocking space accrue, the main gain lies in the considerable conservation of heat. The material delivered from the machines being almost at rolling temperature can be passed direct to heat-soaking furnaces, which may require to reheat the material, but at most only to the extent of 50 per cent of normal reheat requirements. Already an installation of this type exists at Bentoler, where slabs are continuously cast and discharged direct to a Sendzimir mill through a tunnel furnace.

96. Various types of rolling mill, other than just continuous ones of the Morgan or Sendzimir type, could be operated to work in tandem in this way. The main problems in such installations concern integration of machine output and mill intake rates and the practical issues which inevitably arise under production conditions when delays occur. The provision of some hot stocking capacity between machines and mill is clearly an advantage. Another practical approach to conserving heat in this manner on part of the tonnage output will also be made at Shelton.

97. Where necessary, in special cases, continuous dressing of the section can also be introduced before the material is finally rolled.

<u>Thin Slabs</u>

98. As was pointed out several years ago[3/], almost as high tonnage rates can be obtained casting thin slabs as thick ones; in addition, since casting speeds are generally higher, these sections tend to have smoother surfaces. Another aspect is that machine dimensions can be reduced as compared with similar tonnages on thicker sections. The casting of thin slabs of the order of 3 - 4 ins. thick will, it seems, gradually become more common, especially where direct rolling by continuous mills is contemplated.

99. In this connexion, as also for the multi-stranding of other small sections, use may well be made of electro-magnetic stream guiding devices to ensure clean entry of the metal into the mould during teeming. Equipment of this type, developed by Schloemann, has been in use at Benteler for some time.

Continuous Casting

100. Short of the development of continuous steelmaking, the urge is indeed considerable to arrange for almost non-stop production through a casting machine with ladles supplying metal to it, one after another. The gains are clearly almost complete elimination of machine reset time and further savings in yield by elimination of end discards. Machine designs are available, allowing a sequence of ladles to be handled in turn without interruptions in pouring and, although some practical problems may arise with refractories for certain steels for long runs, the method is awaiting adoption for production purposes.

101. The main problem on a production plant of this type would be the maintenance of a regular tapping cycle at the steelmaking units; L.D. and arc furnace units, however, could conveniently and without difficulty meet the scheduling requirements.

102. It is to be noted that two 140 ton capacity ladles have been teemed consecutively at Donetsk in Russia, and runs with up to 3 ladles have been made at Benteler.

Vacuum Degassing

103. There is currently great interest in the possibility of combining continuous casting with vacuum degassing processes. For the most part the interest lies in casting metal degassed by one of the known methods prior to its transfer to the casting machine. Operations on these lines are reported from Russia (Novo Lipetsk), Benteler, and Atlas Steels. Methods of continuously degassing metal have from time to time been also advocated and this procedure is reported to be under trial in Russia.

104. Whilst the former "off the machine" degassing methods are fairly straightforward to apply, provided degassing plant and casting machines exist on the same site, the latter "on the machine" degassing methods undoubtedly will require pilot plant development. The objectives of such work are essentially the further improvement of cast product quality, and there is no doubt that in time both these methods, combined possibly with other techniques, will lead not only to improved product quality but also to the production of new kinds of steel.

CONCLUSION

105. With or without the extra gains of these further development, the continuous casting method for steel has become - with the advent of the curved mould machine - an easily installed, low cost, high performance process, and, as a result, both flexible and easily diversified. For large sections or small, for large production outputs or small tonnages, for common steels or 'super' ones, the process is certain by its improved economy and greater reliability to become the key operation in the line of steel manufacture and will increasingly exert a profound influence on the future character of most steel plants, both established and to come.

106. It is therefore a considerable privilege to be able to draw the early attention of those concerned in developing new steel industries in new localities to this inherently advantageous, almost unavoidable and, indeed, rather thrilling process.

3. The use of curved mould machines, it seems, will largely supplant the adoption of vertical straight mould machines over a wide range of applications. It is a little early yet to pronounce how far in fact this far-reaching change will encompass; the two methods are essentially complementary and the vertical straight mould process will probably not disappear, but rather find its special role.

4. The experience and lessons learnt with the straight mould vertical machines will, of course, remain - as also the majority of the existing plants. By their existence and performance these straight mould plants formulate no mean achievement and indeed form the starting point in considering the application of continuous casting in any locality even where curved mould casting is likely to be adopted.

5. This paper deals firstly, therefore, mainly with the straight mould vertical process, before examining the curved mould process in some detail and considering the applicability of continuous casting to new steel production projects.

EXTENT OF PRESENT APPLICATION

6. The background of development of continuous casting for steel, as indicated in previous reviews in 1960[1] and 1961[2], lies in the pilot plant work undertaken almost entirely since World War II and for the most part within the last 10 years. The main organizations associated with these pilot plants and centres of development activity, e.g. the Russian group, the Bühler/Mannesmann/Demag group, the BISRA group, and the Rossi/Concast group, still continue in active and leading positions with further development and expanding the industrial application of the process in new production plants. In addition, certain new machine builders deriving much of their initial experience from the major groups, have entered the field as separate concerns, notably: The Koppers Company, the Olsson/Motala combination, and the new organizations in Poland, Czechoslovakia, etc.

7. On the whole, the last 2 - 3 years appear mainly to have been a period of consolidation with work directed towards process development tending to give way to greater emphasis on the installation of new production plants. Nevertheless, whilst development and refinement of techniques at the pilot plants has continued, each new production plant has in its turn contributed much to the further broadening of experience. The increase in number of new production plants has been remarkable - to be matched in importance only by the advent of curved mould casting, and perhaps also by another notable change, namely, the quite widely preferred use of reciprocating moulds, not only in almost all the new production plants but even on some of the older established units.

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LIST OF FIGURE CAPTIONS

Fig. 1: Comparison of Concast conventional vertical straight mould/straight spray machine with discharge by bending and Concast Compact/'S' type casting machine with curved mould and curved sprays.

Fig. 2: Typical mould tonnage rates for various square sections cast at different plants of the Concast group, showing apparent and equivalent tonnage rate relationships. (Mainly carbon steels.)

Fig. 3: Equivalent casting speeds and single mould tonnage rates for square sections ranging 2 - 12 ins. in size. (Based on the Barrow standard for 2 in. square billets.)

Fig. 4: Side view of 'S' type curved mould/curved spray machine at A.G. der Von Moos'schen Eisenwerke, Lucerne, in operation during a cast.

Fig. 5: Discharge end view of 'S' type casting machine at Von Moos', in operation during a cast.

Fig. 6: Bottom-pour ladle and tundish teeming into mould on top platform of Von Moos' 'S' type machine.

Fig. 7: Curved copper mould tube used for casting 3 3/8in. square billets on the Von Moos' 'S' type machine.

Fig. 8: Side view of curved roller guide path and water cooling sprays during a cast on the Von Moos' 'S' type machine.

Fig. 9: View looking down onto withdrawal/straightening roll group in operation and discharging 3 3/8in. square billet horizontally during a cast on the Von Moos' 'S' type curved mould/curved spray casting machine.

TABLE 1.

WORLD SURVEY: CONTINUOUS CASTING PRODUCTION PLANTS FOR STEEL

(As known 30th June, 1963)

Plant (Name in Brief)	Date Started	Ladle Capacity tons	No. of Strands	Type of Plant	Typical Sizes Cast: Rounds ins.	Typical Sizes Cast: Squares ins.	Typical Sizes Cast: Slabs ins.	Production Rate (As quoted)	Steel Qualities Cast
AUSTRALIA:									
K.M. Steel	1962	12 & 18	2	Concast/ Schloemann/ Distington.	-	2,3,4½	7 x 4½	Aim 60,000 t/a.	Medium carbon and low alloy steels. Also steels for forging.
AUSTRIA:									
Böhler Bros.	1952	½ to 10	2	Böhler	4 - 8[illegible]	2 - 5[illegible]	6[illegible] x 2 13 x 4 14[illegible] x 6[illegible] 18[illegible] x 5[illegible] 19[illegible] x 4[illegible] 40[illegible] x 4[illegible] 40[illegible] x 6[illegible]	800 t/m.	Carbon and alloy steels including stainless and special high alloy steels. Also high speed tool steel.
Breitenfeld A.	1953	4,10 & 15	2	Böhler	-	-	7[illegible] x 2	3,000 t/m. (A. and B.)	Carbon and low alloy steels.
B.	1962	15	3	Böhler	-	3[illegible]	9[illegible] x 2[illegible] -		
Schoeller-Bleckmann	1957	12,18 & 20	1	Concast/ Schloemann.	-	4[illegible],4[illegible]	20[illegible] x 7[illegible]	1,000 t/m.	Stainless and titanium stabilised stainless steels. Also carbon and other high alloy steels.
Schmidt-stahl.	1961	7	1	Concast/ Innocenti.	-	4	-	Up to 1,000 t/m.	Carbon, low alloy and some stainless steel.

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BRAZIL:									
Rio Grandense	1961	10	2	Böhler	-	3½,4	-	2,500t/m.	Unalloyed low carbon steels
CANADA:									
Atlas I	1954	30& 50	1 or 2	Rossi/ Koppers.	-	6 - 8½	17 x 2½ 19 x 4 24½ x 6½	Up to 450 t/d.	Carbon, low alloy, high alloy, stainless and special steels.
Atlas II	Under Constr.	75	1	Concast 'S' machine.	-	-	39 x 5 42 x 5 52 x 6		Mainly stainless steels.
Atlas III	Under Constr.	40	4	Concast 'S' machine.	-	5 - 7¼	-		Mainly stainless steels.
Premier Steel	1962	21	2	Rossi/ Koppers.	-	3 5/8, 5¼	-	300 t/d.	Carbon and low alloy steels.
W. Canada Steel	Under Constr.	30	2 or 1	Continuous Casting Co.	-	3½(3 ply) 5½(3 ply)	-		Killed carbon steels.
CHINA:									
Dalien	1958	6	1	Granat (Inclined mould)	-	4	-		Carbon steels.
Chungking Third	1958			(Unknown vertical type)	-	3½,4	7 1/8 x 3 9½ x 6¼		Carbon and spring steels. Rail steels.
CZECHOSLOVAKIA:									
Kladno	1960	10 & 50		(Not known)					Carbon and alloy steels.
Podbrezova	1961	50	2	U.S.S.R./ Czech.	-	-	2 5/8 x 5 7/8	120,000 t/a.	Carbon steels.

FRANCE:									
Unieux	1953	1½	1 or 2	[illegible]	Ovals 3¼ x 2⅞ 4⅛ x 3⅛	-	14 x 1⅝	Up to 25 t/d.	Stainless, high speed and special high alloy steels.
[illegible]	1954	35	4	Mannesmann	-	6¼, 9¼	-	3,900-4,000t/m.	Carbon and alloy steels, particularly silicon transformer steels.
Allevard (A)	1955	12	1	Concast/ C.A.F.L.	-	3, 4⅛	4¼ x 3¼	) Abt) 25,000 t/a.	Mainly silico-manganese spring steel. Some chromium cutlery steels.
(B)	1963	12	2	Concast/ C.A.F.L.	-	2⅝, 3⅝, 4⅝, 4⅝	-	)	
S.A.F.E.	1960	30/36	4 Later 8	Demag	-	4¾, 7⅞	-	5,500 t/a.	Carbon and alloy structural steels for automobile construction.
FINLAND:									
Rautaruukki	Under Constr.	50	3 m/cs.at 1 cpr.each	(Unknown)	-	-			Carbon steels.
E. GERMANY:									
Freital	1957	15	3	E.German (Semi-continuous)	-	-	8⅝ x 7⅞ 9 x 7⅞ 12⅝ x 9¼ 14⅝ x 7⅞		Killed and rimming carbon steels.
W. GERMANY:									
Mannesmann	1950	30/40	4	Mannesmann	10¼-11⅞	13	9¼ x 7⅞	Now mainly experi-mental.	Tube and structural steels.

W.GERMANY (Cont'd.)									
Benteler-Paderborn	1958	20	2	Concast/Schoemann.	-	4½ - 6¼	17⅞x2¼	6,000 t/m.	Carbon tube steels
Dillingen	1961	30	1	Concast/Schoemann.	-	-	40'x7¼ 40'x7⅞ 40'x8⅞ 59 x7⅞	Up to 500 t/d.	Killed and rimming carbon steels.
F.Meyer	1962	20	3/2	Demag	-	4 - 5½	19⅞x4	Aim 5,500 t/m.	Structural and tube steels.
Grillo-Funke	1962	60 & 85	2 m/cs.at 4/2 str. each.	Demag	-	11	15 x5½ 39 x8 59 x8	Aim 12,000 t/m	Killed and unkilled carbon steels including silicon transformer steels.
Neunkirchen	Under Constr.			Mannesmann/Demag.	-	-	Up to 84 in.wide		Carbon steels.
HUNGARY:									
Diosgyör	Date Unknown	3	1	(Not known)	-	7⅛	8⅛x7⅛	Semi-production.	
INDIA:									
Camara	Under Constr.	7	1	Concast/Distington.	-	3⅛	-	Aim 7,200 t/a.	Killed carbon and low alloy steels.
ITALY:									
Elettro-Terni	1958	30 & 75	4/8	Demag	-	5⅛	-	10,000-12,000 t/m.	Reinforcing bars and small sections; also low alloy steels for forgings.
Riva	Under Constr.	20	3	Interconst	-	4-5⅛	-		Carbon steels.

JAPAN:									
Sumitomo	1955	30	2	Concast/ Sumitomo.	-	5½ - 10	-	3,000 t/m.	Carbon steels, low alloy and spring steels.
Yawata	1961	[illegible]	1	Concast/ Sumitomo.	7,8	8½, 10	30¼ x 5¼ 36⅛ x 4⅛ 41 x 4⅜ 49½ x 4	Up to 200 t/d.	Carbon and low alloy steels, including ball bearing steels. Also stainless steels.
Hachinoe	Under Constr.	15/20	2/1	Demag.	-	4-6½	31⅛ x 6⅞	Up to 4,500 t/m.	Carbon and low alloy steel. Later stainless steel.
MEXICO:									
Chihuahua	1961	8 Later 15	2 m/cs.at 1 str.each Later 2 m/cs.at 2 str.each	Rossi/ Koppers.	-	2½,6 Later 3,4	-	Up to 2,100 t/m.	Carbon steels. Later rimming steel.
Ecatepec	Under Constr.	11	2 m/cs.at 1 str.each	Concast/ C.A.F.L.	-	3	Slab	75,000 t/a.	Carbon and low alloy steels.
NORWAY:									
Stavanger	1959	12	1	Concast/ Nyby.	-	6½	-	6,000-10,000 t/a.	Carbon, low alloy, stainless and other high alloy steels.
PERU:									
Chimbote	Under Constr.	28	4	Concast/ Schloemann.	-	3½-6⅞	-	Aim 90,000 t/a.	Carbon steels.

POLAND:									
Katowice	1962			(Not known)					
Jednosc	1962	56	4	U.S.S.R./ Polish	-	5/8	-	Aim 100,000t/a.	(Prototype, perhaps production later.) Carbon tube steels.
Zawiercie	Under Constr.			(Not known)					
Pierwszy Maja	Under Constr.			(Not known)					
Kosciuszko	Under Constr.			(Not known)					
SOUTH AFRICA:									
Scaw Metals	Under Constr.	12	2	Concast/ Distington.	-	3½ - 4	-	50,400 t/a.	Carbon and low alloy steels.
SPAIN:									
Del Bosco	1960	15	1	Concast/ Schloemann.	-	3½	-	2,000 t/m.	Carbon steels.
Cerrajera	Under Constr.	25	2	Olsson.	-	5/8	16½x3¾	Aim 90,000 t/a.	Carbon and stainless steels.
Santander	Under Constr.	80	4	Demag.	-	5/8	-		Medium carbon steels.
SWEDEN:									
Nyby Bruk	1954	15	1	Concast/ Nyby.	-	-	30 x 2½	-	Mainly stainless steels. Some carbon and alloy steels.
Metals	1962	60	1	Olsson.	-	4 (2½-4½)	-	36,000 t/a.	Carbon steels.

[illegible] (Cont'd)									
Halmstads	Under Constr.	45	4 Later 6	Olsson.	-	5¼	-	Aim 140,000 t/a.	Carbon and low alloy steels.
SWITZERLAND:									
Von Moos' (A)	1959	15	1	Concast/ Schloemann.	-	3⅜	-	About 3,600 t/m.	Carbon steels.
(m)	1963	5	1	Von Moos'/ Concast 'S' machine.	-	3⅜	-		Carbon steels.
[illegible]:									
Metals Izmir	Under Constr.	18	2	Concast 'S' machine.	-	3–4	-		Carbon steels.
U.K.:									
Low Moor	1946	2½	1 or 2	Low Moor.	5½	3½–5	16 x 2⅞ 12 x 3 13 x 2 14 x 3		Stainless steels mainly
Distington I (A)	1952/ 1958	7½	2	Barrow/ Round.	-	2–4	4½ x 2 6 x 2 7 x 3	Mainly experimental but some production	Carbon, silico-manganese and other low alloy steels. Special high alloy and stainless steels.
(B)	1959		1 or 2	Barrow.	-	9	36 x 5½	Mainly experimental.	Carbon and low alloy steels. Stainless including titanium stabilised steels. Also rimming steels.

U.K. (Cont'd)									
Barrow II	1961	20	2 m/cs.at 2 str.each	Barrow/ Concast.	-	2 - 4	4¼ x 2 6 x 2	36,000 t/a.	Carbon steels and low alloy steels, including silico-manganese.
R.T.B./ Panteg	1962	15 Later 35	1	Concast/ Distington.	-	-	34 x 4⅝ 38 x 4⅞ Later 41¼ x 4¼ 50 x 6 60 x 5	Mainly experimental but some production.	Stainless steels and later rimming steels.
Appleby-Frodingham	1962	90-105	4	Distington/ Concast.	-	9	-	250,000 t/a.	Killed and rimming carbon steels.
Steel Co. of Wales	1963	60	2	B.I.S.R.A./ Continuous Casting Co.	-	-	33 x 7 up to 48 x 8	Aim 200,000 t/a.	Rimming steels, mainly low carbon.
Shelton	Under Constr.	55	4 m/cs. with 11 strands. Possibly 13 strands later.	Concast/ Distington.	-	5½,7	9½ x 9 12 x 5 14 x 8 16¼ x 9 18 x 14 24 x 17 42 x 8	7,000 t/w. overall.	Carbon steels and some low alloy steels. Rimming steels in case of 42x8 in. slabs.
T.I./ Round Oak	Under Constr.	8	1	Concast/ Distington.	-	4	-	Experimental, perhaps production later.	
Baker Bessemer	Under Constr.	7 Later 15	1	Baker Bessemer/ B.I.S.R.A.	-	3 - 8 5(3ply)	-	Indeterminate.	Carbon and low alloy steels.

8. In fact, the vertical straight mould process, so widely used at present, has during the last two years or so become considerably more stereotyped. The differences distinguishing the pilot and early production plants built by the different groups have largely disappeared, particularly those relating to mould operation and the main control technique[1,2] of the process. Gone almost entirely is the use of rigidly mounted vertical moulds in which successful and continued extraction of the initially solidified section depended mainly on mould face lubrication; likewise, moulds mounted on springs which could yield if sticking of the section in the mould occurred are no longer favoured, and the 'pause and pull' method of casting with rigidly mounted moulds has also virtually been abandoned. The majority of casting machines now in operation make use of vertical reciprocation of the moulds, either by the Junghans method, in which the mould descent speed is synchronised to that of the section being cast, or according to the Barrow process in which the mould is vertically reciprocated with negative strip, i.e. made to descend at a slightly faster speed than the section during the downstroke so as to overtake the section by a small amount, which is called the negative strip[3].

9. On the other hand individual machines still vary considerably according to local site conditions and production requirements, and still retain many of the individual features, mainly constructional features, preferred as aids to smoother operation by the different machine builders. Such design details are of as vital importance as ever to routine production operations and, of course, depend almost entirely on the accumulated experience and "know how" of those responsible for the design.

Existing Production Plants

10. The extent of World development of the process and some appreciation of the rate of advancement in applying continuous casting to steel production can most rapidly be obtained from a World survey of existing and intended production plants. The principal data of continuous casting production plants known to exist or be under construction contracts throughout the World, as at 30th June, 1963, is listed in Table 1. The total list amounts to at least 99 machines at 80 different plants or sites; of these, there are 61 machines in operation and at least 38 under construction, and these machines include minimum totals of about 119 and 75 strands respectively.

[illegible]:									
Roanoke	1962	22	2	Babcock & Wilcox.	-	4½	-	6,000 t/m.	Plain carbon steel
McLouth	Under Constr.	60	1	Concast/ Schloemann.	-	-	36 x 8 50 x 5½ Later 66 x 10		Rimming and stainless steels.
Armco (Sand Springs)	Under Constr.	90	4	Demag.	-	2½,3,4½	-	15,000 t/m.	Killed and unkilled carbon steels.
Roblin-Seaway	Under Constr.	25	2	Koppers.	-	2 - 6	-	Aim 400 t/d.	Carbon and low alloy steels.
Connors Steel	Under Constr.	18	2m/ea.at 2 str.each	Koppers.	-	2½-6	-	Aim 650 t/d.	Carbon and low all y steels.
National (Weirton)	Under Constr.	300	6	Concast/ Schloemann 'S' machine.	-	-	31½x5½ -50 x9	Aim 1,000,000 t/a.	Killed and rimming steel.
[illegible]:									
Beshitskii	1950 (1938 at Kuznetsk; 1941 at Serp-i-Molot.)	25	1	Goldobin (Conveyer type)	-	5½	12 x6½	About 24,000 t/a.	Carbon steels.
Krasny Oktyabr (Red October)	1951	10	1m/e.at 2 str. 1m/e.at 4 str.	TsNIIChermet (Semi-continuous)	-	-	11½x6½ [illegible] [illegible] 31½x7½	Aim 36,000 t/a.	Stainless steel, including titanium stabilised. Other alloy steels.

U.S.S.R. (Cont'd.)

Novo Tula	1953	10	1 or 2	T.H.I.Chemist/ Stalprecht.	–	7 7/8	19 3/8 x 5 7/8 24 [illegible] x 5 [illegible] 24 [illegible] x [illegible] 25 [illegible] x 7 [illegible]	About 15,000 t/a.	Killed and rimming carbon steels; also low alloy steels, including silico-manganese and silicon transformer steels
Krasnaya Sormovo (A) (B)	1955) 1960)	50	2 m/co.at 2 str.each	T.H.I.Chemist	–	–	16 1/4 x 6 7/8 21 [illegible] x 5 [illegible]	Aim up to 200,000 t/a.	Killed and rimming carbon steels.
Kalinin (First of May Works)	1956	1 [illegible]	1	T.H.I.Chemist	1 to 2 [illegible]	–	–	Spasmodic use	Medium carbon steels.
Novo Lipetsk (A) (B)	1959) 1960)	90	2 m/co.at 2 str.each	T.H.I.Chemist/ Stalprecht.	–	–	24 [illegible] x 5 7/8 30 [illegible] x 5 [illegible] 40 [illegible] x 6 [illegible]	About 250,000 t/a.	Transformer steel; also killed carbon and rimming steels.
Donetsk (Stalino)	1960	140	4	Dniepropetal	–	–	23 [illegible] x 5 7/8 27 [illegible] x 6 [illegible] 31 [illegible] x 7 [illegible] 39 [illegible] x 7 [illegible] Later 47 [illegible] x 7 [illegible]	Aim 350,000 t/a.	Killed and rimming carbon steels and low alloy steels.
Zoodn	1960								
Gorki	1962	15 & 50	2	UIChemist	–	–	9 x 5 [illegible]		Rimming steel.
				Stalprecht	–	8 [illegible] (3 hole)	15 [illegible] x 9 7/8 21 [illegible] x 7 [illegible]	Aim up to 130,000 t/a.	Carbon tool steels and titanium stabilised stainless steel
Ushgoil	1962	80	4	Stalprecht	–	7 7/8	–	Aim up to 200,000 t/a.	Carbon steels

[illegible] (Cont'd.)

[illegible]	Under Constr.		2m/ea.at 1 str.each	[illegible]/ [illegible] (Conveyor type)	-	5[illegible]	-	Carbon steels.
Zarch	Under Constr.			[illegible].				

[illegible]:

[illegible]	Under Constr.	[illegible]/20	2m/ea.at 2 str.each	Concast 'S' machine.	-	3[illegible] - 4[illegible]	-	Carbon steels.

TABLE 2.

Summary of Numbers of Casting Machines and Strands in Operation and Under Construction by Activity Groups (As at 30th June, 1963.)

Group	Plants in operation: No. of Machines	Plants in operation: No. of Strands	Plants under construction: No. of Machines	Plants under construction: No. of Strands	TOTALS: No. of Machines	TOTALS: No. of Strands
Russian and Russian Sphere	18	37	6	6+	24	43+
Mannesmann/Böhler/Demag	11	35	4	10	15	45
Rossi/Concast	24	35	17	39	41	74
Others	8	12	11	20	19	32
TOTALS	61	119	38	75+	99	194+

TABLE 3.

Continuous Casting Production Plants based on Curved Mould Machines of the Concast Model 'S'/Concast Type (As known 31st July, 1963).

Plant (Name in Brief)	Date Started	Ladle Capacity tons	No. of Strands	Typical Sizes Cast: Rounds ins.	Typical Sizes Cast: Squares ins.	Typical Sizes Cast: Slabs ins.	Production Rate (As quoted)	Steel Qualities Cast
BELGIUM:								
Le Creyere	Under Constr.	25	2 m/cs.at 2 str.each	-	3[illegible] - 6[illegible]	-		Carbon and alloy steels
CANADA:								
Atlas II	Under Constr.	75	1	-	-	39 x 5 42 x 5 52 x 6		Mainly stainless steels
Atlas III	Under Constr.	40	4	-	5 - 7[illegible]	-		Mainly stainless steels
W. GERMANY:								
Dillingen II	Under Constr.	80/85	1	-	-	49½ x 9[illegible] 61 x 9[illegible]		Carbon steels
[illegible]:								
(Name withheld).	Under Constr.	7	1	-	3[illegible] - 4[illegible]	-		Carbon steels
SWITZERLAND:								
Von Moos'(B)	1963	5	1	-	3[illegible]	-		Carbon steels

TUNISIA:								
Elfouladh	Under Constr.	12	2 m/cast 2 str.each	-	2 - 4¾	-		Carbon steels.
TURKEY								
Metals Izmir	Under Constr.	18	2	-	3 - 4	-		Carbon steels.
U.S.A.:								
National (Weirton)	Under Constr.	3[illegible]	6				in 1,000,000 t/c.	Killed and rimming steels.
VENEZUELA:								
Sivensa	Under Constr.	8/20	2 m/cast 2 str.each	-	3½ - 4¾	-		Carbon steels.

TABLE 4

Numerical Summary of Different Kinds of Casting Machines in Operation and under Construction for Production Purposes.
(as at 31 July 1962)

Type of Machine (Classification by Main Features)	Machines In Operation		Machines Under Construction		TOTAL	
Inclined Mould (Continuous) Machines:						
Inclined Conveyor type Mould	1		2		3	
Inclined Straight Mould	1		–		1	
Vertical Straight Mould/Straight Spray Machines:						
Non-Reciprocating Mould (All types)	3		–		3	
Reciprocating Mould - Semi-Continuous type	3	53	–	24	3	77
- Vertical Cut-off	32		6		38	
- Bending Discharge	14		14		28	
- Discharge Unknown	4		4		8	
Other Machines (Details Unknown)	2		5		7	
Vertical Straight Mould/Curved Spray Machines:	–		1		1	
Curved Mould/Curved Spray Machines:	1		12		13	
TOTALS	61		44		105	

TABLE [illegible]

Summary of Section Shapes and Sizes Cast : Numbers of Machines in Operation and Under Construction counted according to Section Cast (where known 30th June, 1963.)

Section Cast (or to be cast)	Machines in operation	Machines under construction	All Known Machines
Rounds	5	–	5
Ovals	1	–	1
Squares:			
2 to 4 in. incl.	20	12	32
Over 4 to 7 in. incl.	19	19	38
Over 7 to 10 in. incl.	12	3	15
Over 10 in.	3	–	3
Rectangles (width/thickness ratio > 2 : 1) :			
Small (Thickness up to 4 in.)	1	2	3
Large (Thickness over 4 in.)	7	4	11
Slabs (width/thickness ratio > 2 : 1) :			
Thin (Thickness up to 4 in.)	12	–	12
Thick (Thickness over 4 in.)	21	10	31

NOTES :

a. Counts based on cast sizes quoted in Table 1.

b. Some machines cast several shapes and sizes; hence, more than one entry made for each of these cases.

c. Where information on sizes cast is not known, the cases have perforce been omitted.

APPENDIX 1

Metallurgical Aspects

The main metallurgical characteristics of continuous cast material produced on vertical straight reciprocating mould machines are summarised for normal shapes and qualities. The summary applies also to material produced by Concast curved mould/curved spray casting machines of the 'S' or Compact type:-

(a) Essential Feature

Continuous cast sections are billets, blooms or slabs produced as advantageous alternatives to static-cast ingots; being cast material, the sections require to be hot-worked by rolling, forging or other means, to break down the as-cast structure to that required for engineering or other applications.

(b) Structure

(i) Killed carbon steels consist typically of a very thin sub-microcrystalline surface layer inside which columnar crystals occur with a central zone of equiaxed crystals. The depth of the columnar zone varies from about two-thirds to one-fifth of the surface-centre distance, depending mainly on carbon content; the columnar crystals are relatively short for the higher carbon steels and of finer texture, whilst the equiaxed crystal zone is correspondingly larger and also of finer grain size.

(ii) Alloy steels show their own characteristic variations on this structure in a similar manner as in orthodox ingots. Thus, low carbon 18/8 Cr.Ni. stainless steel, being austenitic (single-phase), consists of columnar crystals reaching almost to the centre and meeting along the partition lines; on the other hand, Si.Mn. spring steel consists largely of a fine grained central zone of equiaxed crystals.

(c) Grain Size

As in statically cast ingots, elements which coarsen the grain, e.g. molybdenum, produce relatively coarser crystal structures in continuous cast material. In addition, fine grained steels can also be produced where necessary by feeding aluminium wire to the mould during casting at rates of up to 6 oz./ton of metal cast.

(d) Hot Work Requirement

(i) The amount of hot work reduction in area required depends largely on the stress duty which the final product has to meet. Area reductions for killed steels of at least 8 : 1 are normally needed for high duty purposes, and preferably 10 : 1 for specially high duties. Reductions of about 6 : 1 are feasible for medium duties and for certain low stress applications above at least 4 : 1 may suffice. The kind of duty expected of the final products, whether rolled or forged, always forms the starting point in determining, against these hot reduction requirements, the minimum sizes of section which may be cast in any new continuous casting project.

(ii) Stress duty considerations for forging are often appreciably more complicated, especially when the shape of the final product and its operational function are complex. Analysis of the different working stresses within a forged shape can then be of advantage.

(e) Central Porosity

Associated with the internal as-cast structure of killed steels is a definite tendency to slight central porosity. The amount depends to some extent on the kind of steel cast, but can usually be reduced to a remnant central looseness hardly or just discernible to the eye by proper attention to casting conditions, particularly minimisation of metal casting temperature and spray cooling. This looseness or porosity usually welds up in the early stages of rolling but, with some high alloy steels, the higher reductions in area mentioned previously are necessary. Such central unsoundness is least evident in as-cast slab sections, and more accentuated in square and particularly in round sections; it often tends to appear more severe in larger square sections than in small ones, but in general is probably a smaller proportion of the sectional area. Central porosity is discontinuous along the length of the sections.

(f) Surface Pinholes

(i) Many killed steels, e.g. plain carbon and low alloy steels, show a marked tendency to the formation of small and/or minute surface pinholes, which do not appear to reduce the mechanical properties of the final forged or rolled product, but which do affect the appearance or 'brightness' of bright-finished bar qualities, since they result in dark or discoloured streak marks.

(ii) It has been found possible at Barrow by special techniques on a routine basis to eliminate or to reduce to negligible proportions the occurrence of pinholes in these steels, e.g. for carbon steels, from pickled sample counts ranging 30 - 80 pinholes per sq.ft. and even higher, to counts of 0 - 2 per sq.ft., but mainly zero. The routine feeding of aluminium wire to the mould throughout a cast at approx. 4 oz./ton achieves this condition, but other techniques have also been developed which appear to more consistently maintain a zero count level. Different mould lubricants and rates of lubricant usage appear to have only a minor marginal effect on the incidence of pinholes.

11. When grouped according to origin, the total list of 99 machines can be summarized as follows: the Russian group, inclusive of countries within the Soviet sphere, comprises 18 machines in operation and at least 6 under construction, the Mannesmann/Bühler/Demag group totals 11 operating and at least 4 constructing, whilst the Rossi/Concast group have 24 and 17 machines in operation and under construction, respectively - all at 30th June, 1963. In addition, attributable to the others, namely: Koppers, Olsson/Motala, BISRA and associates, etc., taken together as a group there are 8 machines in operation and 11 machines under construction. These figures are shown in tabular form in Table 2, which also lists the corresponding total numbers of strands installed or under construction. The figures of Table 2 are correct, as far as is known, for the date of the survey, namely: 30th June, 1963.

12. Compared with previous surveys made almost exactly 2 and 3½ years ago[2,1], the total number of recorded machines has been rising at a steady rate. Over the last 2 years the reported World total has increased by about 43 machines or at an average rate of about 1 3/4 machines per month; the total for machines in operation has risen by about 26, or 1 machine per month. This record of expansion is notable.

13. As in previous surveys, however, some uncertainty always remains as to what additional plants may have been brought into operation, or may be under construction, but as yet have not been reported. The point is perhaps more pertinent than usual to the present survey in respect of, for example, progress in China, which is obscure. Also, with regard to Russian plants which may be under construction, it did not seem justifiable to include in the present list any count relating to the Russian announcement made early this year[4] of their intention "to proceed with the design and construction of further units for installation at six other works in 1964". Nevertheless, such plans are doubtless in hand, as witness a further recent Soviet announcement to the same effect (August 1963)[5] which also states that by 1967 the total annual capacity of continuous casting is expected to reach 22 mill.tons.

14. Furthermore, within the last year or so there have been negotiations between V/O Licensingtorg of Moscow and certain companies, notably in France[6], the U.K.[7,8] and the USA[9], with the aim of extending the use of Soviet continuous casting systems. It was announced[6] that a plant would be built in conjunction with Schneider-Delattre-Levivier of France at the Sidmar Works in Belgium, consisting of 4 casting machines each to produce 500,000 tons/annum of sheet bar, the capacity of which would later be extended to 6 mill.tons/annum. No confirmation of this, however, was available and no reference to it was therefore included in Table 1.

(g) **Balanced Steels**

Balanced steels are not able to be continuously cast because blowholes form too closely beneath the surface of the section. In general, a killed steel quality can usually be found as a metallurgical substitute and there is no detriment to product yield, which is often the main consideration in producing these steels in static-ingot practice. Alternatively, if the section cast is large enough, a rimming quality steel can be substituted.

(h) **Rimming Steels**

(i) Effervescing steel can be continuously cast in mould sizes preferably above 7 in.sq. The resultant product is different from normal ingot cast material in that, although formed with a sound rim and suitable blowhole structure inside it, the rim does not consist of low carbon material, e.g. mainly ferrite as might be expected. The carbon and manganese contents of the rim are in fact little or no different from those of the central blown structure. Control of effervescence at the mould during casting is usually effected by controlled rates of addition of aluminium rod or wire, but the preferred method developed at Barrow consists of ensuring correct metal condition at the furnace and casting without aluminium additions at the mould, a lower mould metal level being adopted to avoid metal splash over the top of the mould due to the quite vigorous effervescing reaction effects. Under these conditions the thickness of the rim is usually related proportionally to the minimum dimension of the section[2]. Its thickness seems largely independent of casting speed and, although only affected to a minor degree by carbon content above 0.10% C., seems to increase with decrease in carbon, particularly below 0.06% C.

(ii) The importance of the uniformity of carbon and manganese contents across the rim and core of continuous cast rim steel sections, combined with the major feature of the virtual absence of silicon and aluminium in the metal resulting from the production method described have still to be fully assessed.

(iii) Another production control method has been developed at Barrow for the casting of rimming steels in small sections, e.g. 7 x 3 in. slab sections. The process is, however, of a special type and its application should not be considered except in particular circumstances.

(iv) Where rimming steel sections of the type described can not be accepted, fully solid killed sections, e.g. of low carbon steel with only traces of silicon, can be produced.

(i) <u>Ripple Marks</u>

The as-cast surface shows light "ripple" marks or undulations corresponding to each reciprocation movement of the mould, and these marks characterise material produced through reciprocating moulds. Frequently, the marks are so light as to be hardly discernible except for changes of surface texture associated with mould upstrokes and downstrokes. The marks may, however, become heavy or excessive if the movement of the mould and its associated driving link system acquires much backlash or looseness due to wear at pin-joints and bearings. The ripple marks, however, even when fairly heavy, roll out completely in the initial stages of rolling.

(j) <u>Uniformity</u>

Section shape and metallurgical structure are generally uniform throughout the whole length of any particular cast and from cast to cast for the same steel quality. In addition, the maintenance of uniformity of chemical analysis within a cast is invariably assured and requires no attention.

(k) <u>Segregation</u>

In contrast to ingot steel, a most desirable feature inherent to continuous cast material is a notable freedom from segregation which pertains for almost all elements, both transversely across the section and longitudinally.

(l) <u>Internal Cleanliness</u>

(i) Non-metallic inclusions, present usually in no greater amounts than in static-ingot cast steel, are generally smaller in size and fairly uniformly dispersed.

(ii) Methods of casting have recently been developed at Barrow which promise to allow still cleaner steel to be produced. Quantitative measurements indicate that Fox Inclusion Count levels of 36 – 56 and possibly even lower may well be obtainable on a routine basis as compared with the more normal levels of 56 – 76.

(m) <u>Occluded Gas Separation</u>

There is reason to believe that occluded gases contribute in some degree to the occurrence of central porosity and, to this extent, some separation of a gaseous phase can occur. Separation and entrapment of carbon monoxide clearly occurs in continuous cast rimming steel sections.

(n) <u>Surface Dressing</u>

In many cases little or no dressing of continuous cast sections is required prior to rolling; with stainless and other special steels, however, some dressing is usually practised in amounts varying up to about 7%.

(o) <u>Suitability for Rolling</u>

Continuous cast material is usually preferred at the rolling and/or rerolling mills, because of its regularity of shape and structure. Greater continuity of rolling mill operations is generally experienced due mainly to the more consistent character of its 'spread' in rolling, and the reduced incidence of defects. The as-cast sections can withstand heavy initial reductions at the rolling mills.

(p) <u>Suitability for Forging</u>

Continuous cast material is particularly capable of being severely forged direct from the as-cast condition.

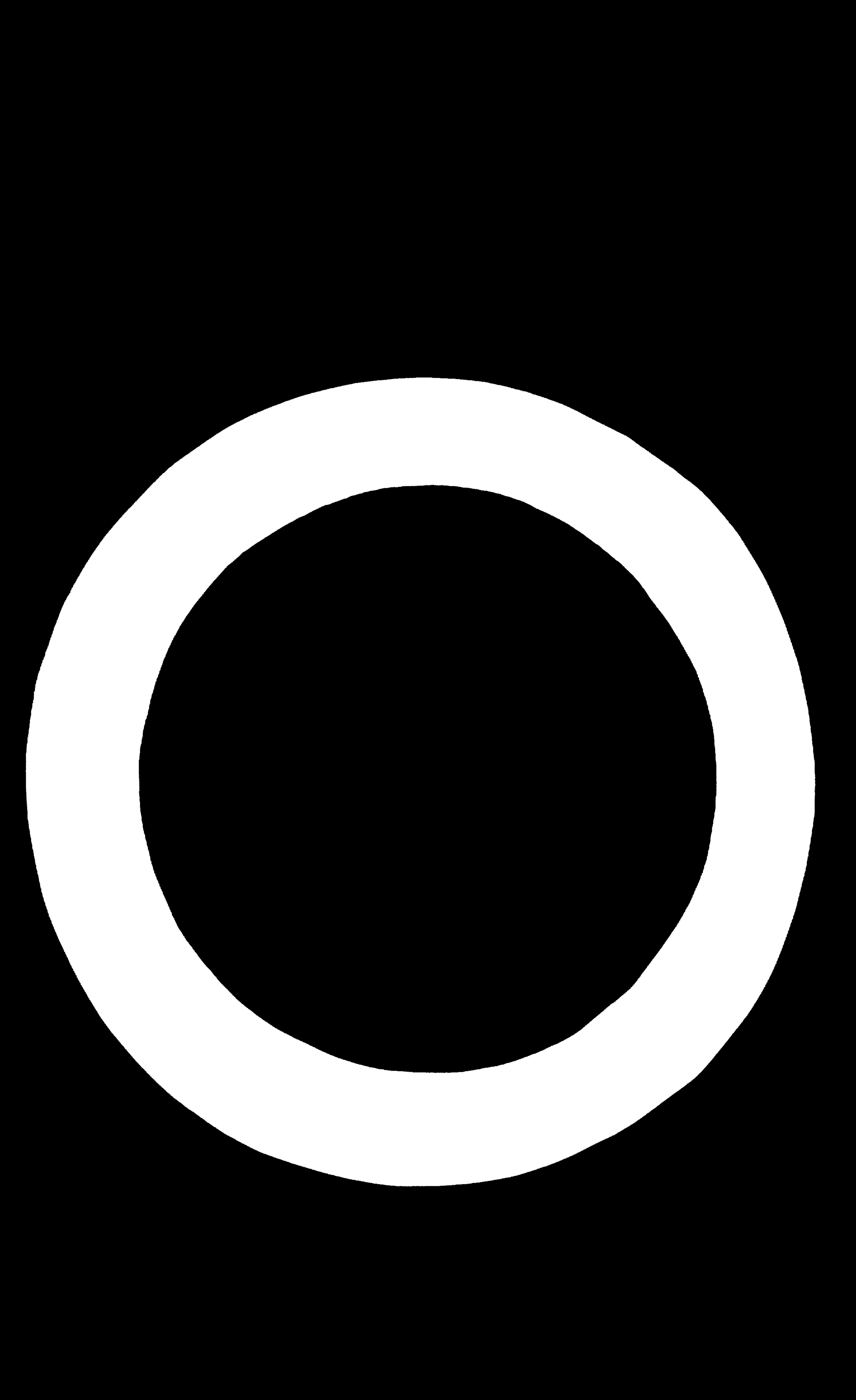
(q) <u>Defects</u>

Under routine production conditions, defects inevitably arise from time to time in the product. Some examples are: rhomboid, dimpled or bulging shapes, longitudinal or transverse cracks, surface pinholes, inclusions or surface slag patches, internal cracks and subcutaneous blowholes. A full correlated classification of such defects, including their identification and a tabulation of the irregularities in practice causing them has been reported elsewhere[2]. It is necessary to stress, however, that with experience and normal attention to detail the occasional occurrence of such defects can certainly be minimised and in most cases virtually eliminated.

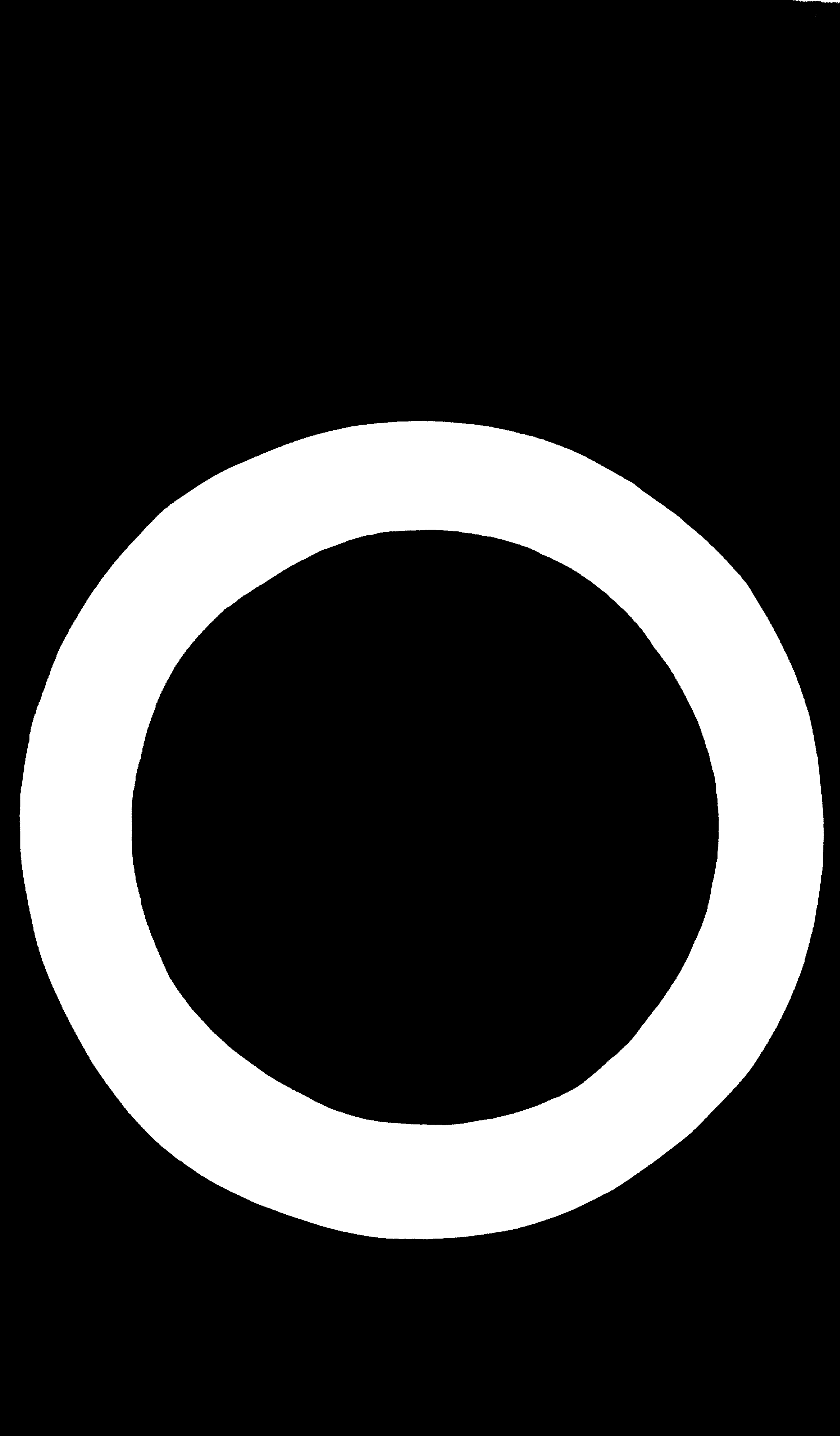
(r) <u>Properties of Rolled or Forged Product</u>

(i) The quality of continuous cast material is essentially good, and frequently very good. Likewise, the physical and mechanical properties of product derived by rolling or forging from cast billets, blooms or slabs have been found to be generally satisfactory and not distinguishable from those of good quality similar product produced from orthodox ingots.

(ii) In some cases, the properties of material derived from continuous cast sections have indeed been found to be superior to corresponding material derived from ingots, and, whilst this claim is not normally emphasized, there is indeed factual evidence in support of it.



FIGURES



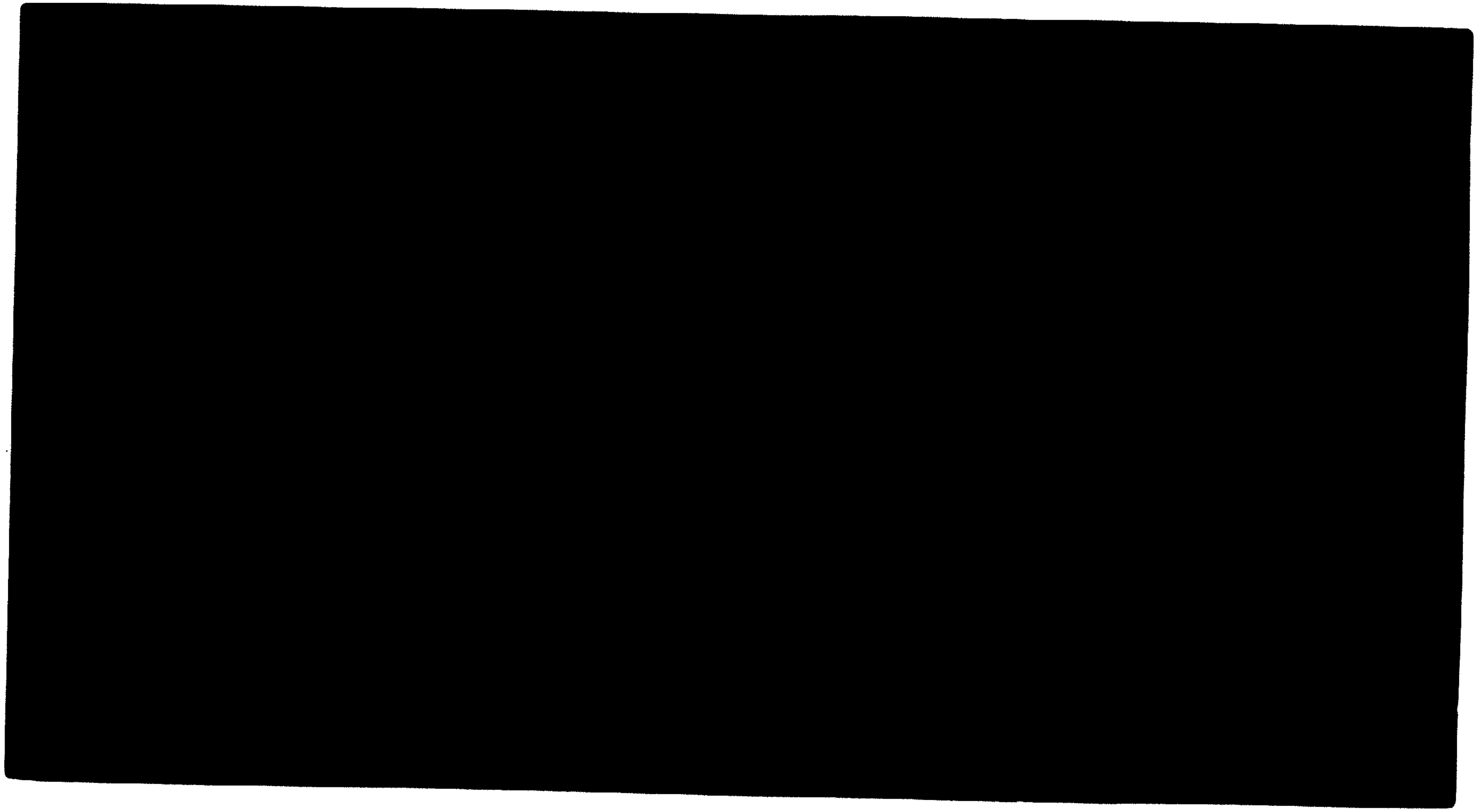


Fig. 1: Comparison of Concast conventional vertical straight mould/straight spray machine with discharge by bending and Concast Compact/'S' type casting machine with curved mould and curved sprays.

22. 3. 74

15. On the other hand, the recent introduction of curved mould casting at the Von Moos' Steelworks, Lucerne, and the attractive advantages of added reliability, lower price and greater convenience afforded by this type of machine have led to a marked surge of decisions to adopt the new method for steel production. New contracts for curved mould casting machines concluded by the Concast group were continuing to increase rapidly at the time of the survey, and to this extent the survey data of Tables 1 and 2 are rendered out of date almost as soon as completed. Thus, one month later, by 31st July, 1963, the total number of curved mould machines - called Concast 'S' type machines in Europe, or Concast 'Compact' machines in America - had risen to a total of 13 machines in operation or under construction contract at 10 different sites involving the use of 28 strands. An auxiliary tabulation of data on these production machines is given in Table 3.

16. With these further Concast Model 'S'/Compact type machines, the number of known machines at 31st July, 1963, increases to a total of 105, of which 61 are in operation and 44 under construction.

Different Kinds of Machines

17. An analysis of these machines into different types, as distinguished by their main features, namely: character of mould, sprays, and of discharge arrangement, is given in Table 4.

18. The now relatively old Goldobin machine with its inclined conveyor type pallet mould is still in operation in Russia at Bezhitzii, and two further machines of this type are reported under construction (Omutninsk), the main interest being apparently to provide continuous cast material at suitably high tonnage rates for direct supply into a rolling mill and immediate conversion to rolled product. Another inclined mould machine originally of Russian design, a Granat 30° inclined straight fixed mould machine, is reported to be in operation in China at Dalien. The vast majority of the machines, however, are of the vertical straight mould type with a vertical straight spray cooling zone below the mould. As seen in Table 4, only 3 such machines exist with fixed or non-reciprocating moulds, and none are under construction; in contrast, 77 machines - 53 in operation and 24 under construction - employ reciprocating moulds. Of this group almost half the machines have, or will have, vertical cut-off equipment prior to discharge (38 machines), whilst almost as many (28 machines) are, or will be, fitted with discharge by bending facilities.

19. The two remaining types of machine in Table 4 are of very recent advent: firstly, the group comprising the Von Moos' and other Concast curved mould/curved spray machines, listed in Table 3, and, secondly, the type of machine under construction at the Riva Works, Milan, the operation of which is based on the use of a vertical straight mould and a curved spray zone path beneath it. Details of the new machine at Riva, beyond those given in Table 1, are not known; the plant, although intended at least ultimately to be used as a production unit, has yet to be proved in performance and this will be of considerable interest, particularly in regard to product quality, since the basic principle has long been a subject of widespread technical discussion. Meanwhile, the development of curved mould casting by the Concast group is already being widely established as shown by Table 3; in addition, Mannesmann A.G.[10] are reported to have an experimental unit operating on the curved mould principle.

MAIN PRODUCTION PLANT PARAMETERS

20. The plant data quoted in Tables 1 and 3, although at first perhaps rather bewildering, illustrates the extent to which casting machines are being used to suit production requirements. Most of the production plant practice, and the experience gained, with vertical straight mould machines is directly applicable to the use of curved mould casting machines. The main features are therefore summarized which form the background to the subject and to the possible adoption of continuous casting in the planning of new steel plants, or in the reshaping of established works. Needless to say, much detail has to be omitted.

Metallurgical Quality of Material Cast

21. Steel prepared in any of the normal steelmaking furnaces, or vessels, can be continuously cast; the most convenient steelmaking methods are those having a regular tapping-time cycle, but this in no way precludes the use of less regular processes.

22. Whatever the steelmaking unit, almost all plain carbon and alloy killed steels can be cast with advantage, and also rimming steels, if certain reservations on their metallurgical streture are accepted: balanced or semi-killed steels can not be produced. However, the latter restriction and the limitations in regard to rimming steel are not seriously detrimental, since the continuous casting yield for killed steels is high and killed metallurgical substitutes are in most cases available.

23. The metallurgical aspects of continuous cast material have been summarised in some detail in Appendix 1, because of their importance and because quality considerations indeed form the starting point when considering the adoption of continuous casting. Briefly, continuous cast material is generally of uniform, good quality, notably free of segregation and usually relatively clean in regard to non-metallics. The cast sections, for the most part regular in shape, usually show surface reciprocation or 'ripple' marks and also some central porosity. Surface dressing in most cases is small and frequently can be eliminated. Although various defects inevitably occur under production conditions, these do not preponderate and in fact can be eliminated with attention to detail as indicated elsewhere[2].

24. The summary of metallurgical aspects given in Appendix 1 also applies to material produced by Concast 'S'/Compact type curved mould machines.

Section Sizes Cast

25. In Table 5 a summary of section shapes and sizes cast is given by counts of the number of machines in operation or under construction, as known at 30th June, 1963, i.e. corresponding to Table 1 survey date. The more popular sections cast are, almost to the same degree, small- and medium-sized billets in the ranges 2 - 4 and 4 - 7 in.sq., and medium/large slabs over 4 in. thick. Blooms 7 - 10 in.sq., rectangles thicker than 4 in. and thin slabs, i.e. up to 4 in. thick, are also quite commonly produced. Relatively few machines cast round and oval sections, large blooms, i.e. over 10 in.sq., and small rectangles - the demand for these production-wise being more limited.

26. For both thick and thin slabs, width to thickness ratios extend up to just over 12: 1. The larger slabs have widths ranging up to 59 in. as cast at Dillingen and 84 in. as proposed for the new Huckingen plant. The smallest dimension preferred in practice for squares, slabs and other shapes is usually not less than 2 in., because for smaller or thinner sections continuous operation of the process becomes increasingly difficult. The known thickest section, 24 x 17 in., is scheduled to be produced at Shelton.

27. There exists indeed a trend towards the casting of larger sections, encouraged by the demand of the larger capacity steel plants for higher production rates to match the larger steelmaking units and heavy rolling mills. Nevertheless, one of the facilities provided by the continuous casting process still pertains, namely, that it allows smaller sections to be produced economically, which is particularly advantageous where the installation, or use, of a large primary mill can be eliminated.

28. The casting of special shapes, and of hollow sections for tubes, are as yet relatively undeveloped, except perhaps in China and Russia (shapes) and in Germany (hollows). On the other hand, the range of solid shapes and sizes which can be produced is extensive and already allows a wide scope of application. In all cases the section size cast has to be adequately large at least to allow the requisite reduction in area at rolling or forging. Frequently, larger sections are selected to meet other conditions, e.g. mill dimensions for cross rolling and/or final product weight, or the desire to standardize on a few cast section sizes, or only one.

29. The most important point to note, however, is that all continuous cast sections require to be hot-worked to break down the as-cast crystal structure. The hot work reductions in area either by rolling or forging or other means, may range from at least 4 : 1 to 10 : 1, increasing with the severity of the engineering duty expected of the finished product. The area reductions can of course be greater, but the stipulated minimum usually results in physical and mechanical properties in the finished product which are generally not distinguishable from those of corresponding product derived from orthodox ingots.

30. The reduction in area ratios clearly determine the minimum section sizes which have to be cast on any new machine so as to satisfactorily produce the finished products. For each final product category the anticipated largest size usually sets the size of section to be cast, after allowing for the necessary reduction in area. To suit mill requirements, of course, more than one cast section size may be adopted so long as adequate area reductions are maintained.

Casting Rates

31. Different machine suppliers with their differing backgrounds of experience, design preferences, and the all-important "know how", do differ to some extent in the levels of casting speed which they would recommend or can obtain with different section sizes. They tend to agree fairly closely however on the relative speeds at which different sizes of section of the same metal quality can be cast. This is because the solidification times of different section sizes are largely dependent on their area/perimeter ratios and, as described elsewhere[2], if the physical conditions affecting solidification are likewise appropriately modified to be equivalent for the different sizes of section, their casting speeds, and therefore mould tonnage rates, are then related in a fairly simple manner. This, however, may not be true on an existing machine when a section size outside the range for which the machine was originally designed is tried, since one of the equivalent conditions is then likely to be unfulfilled.

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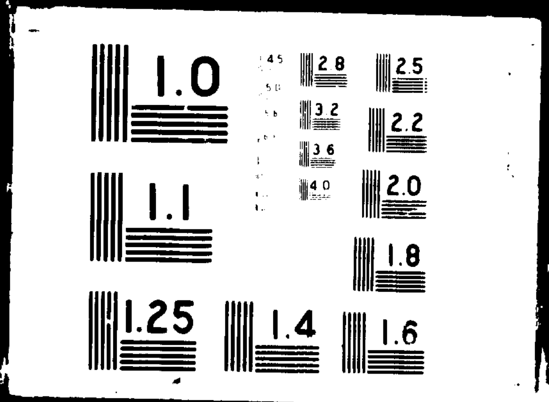
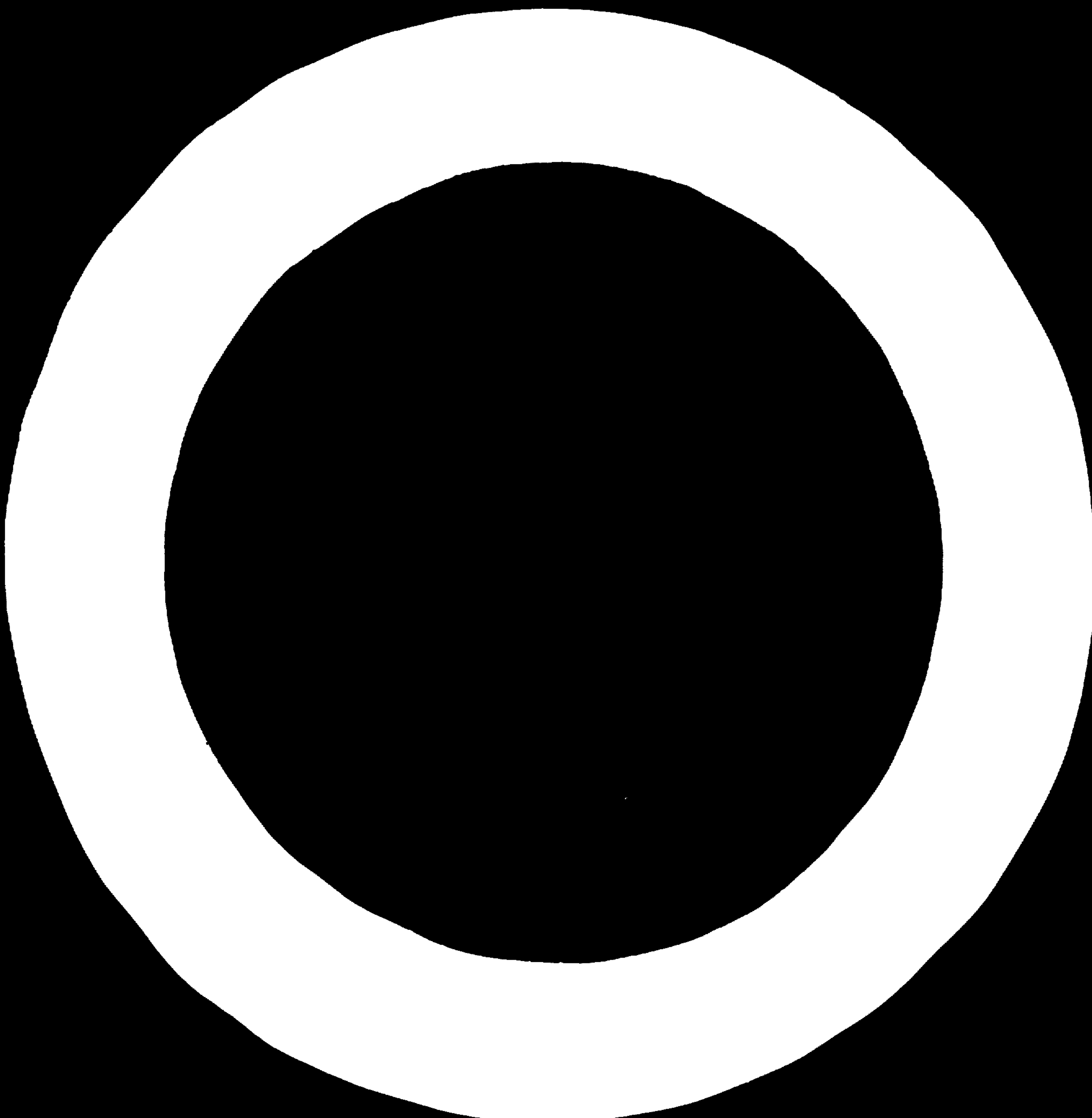




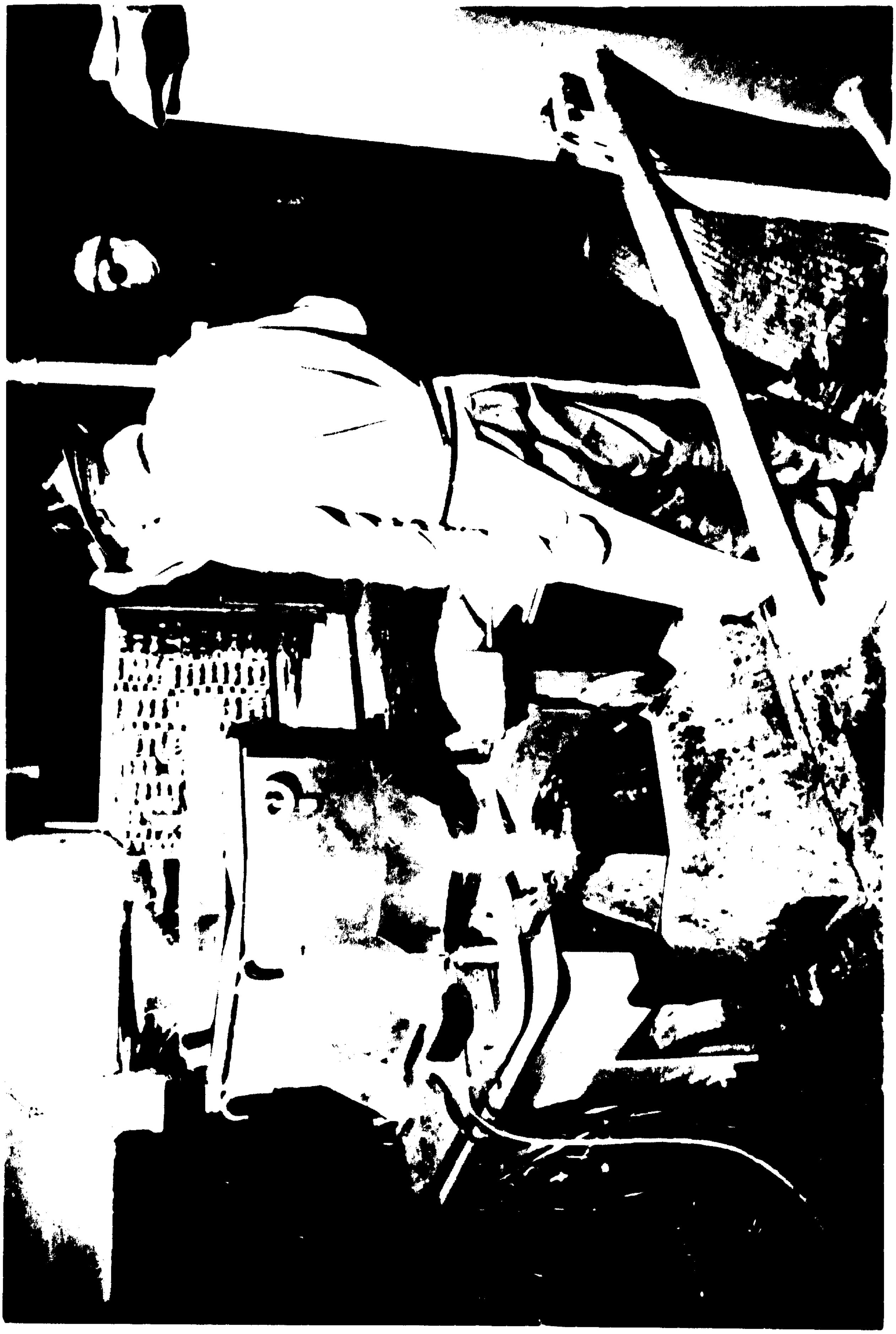
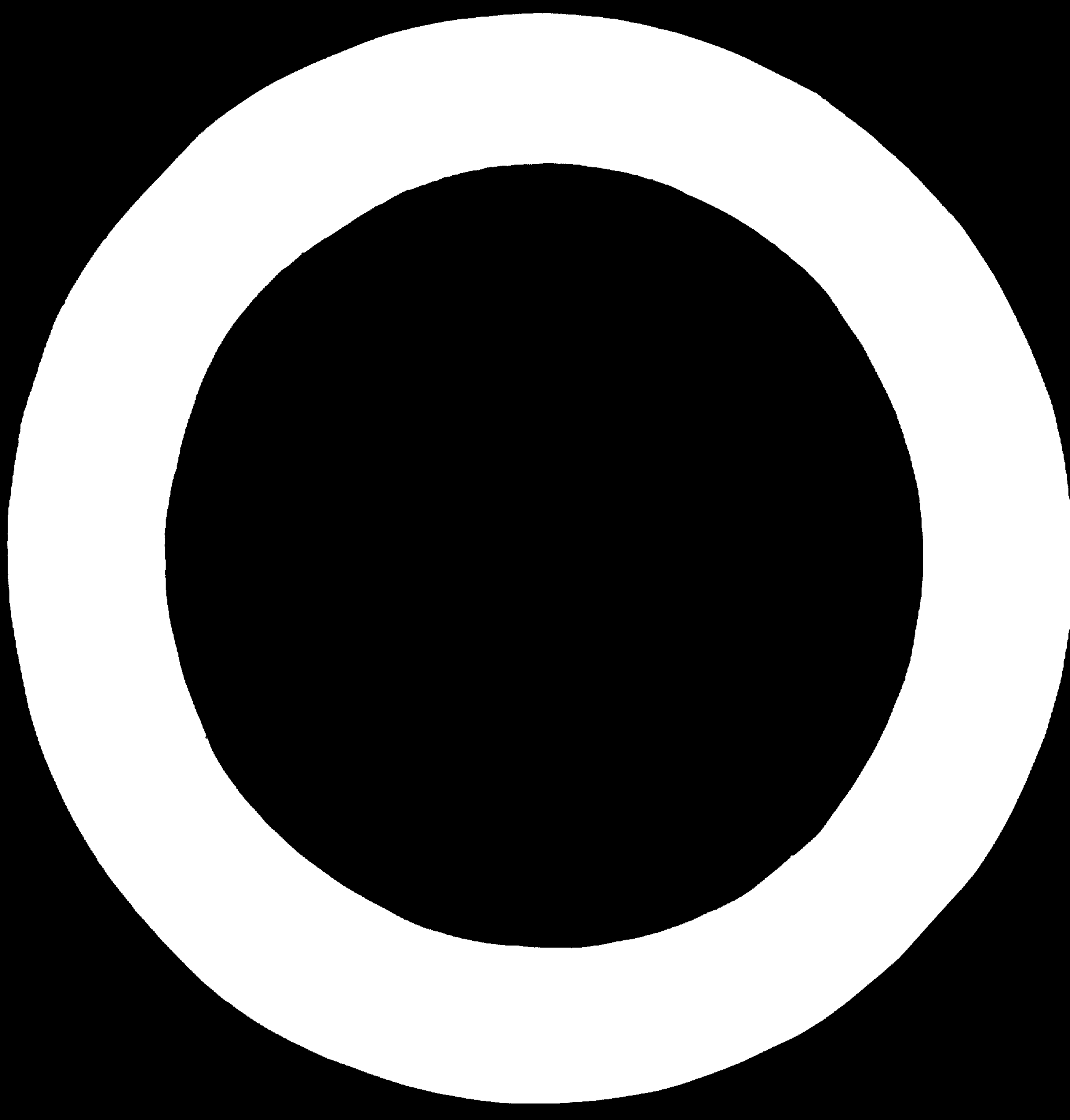


Fig. 6:



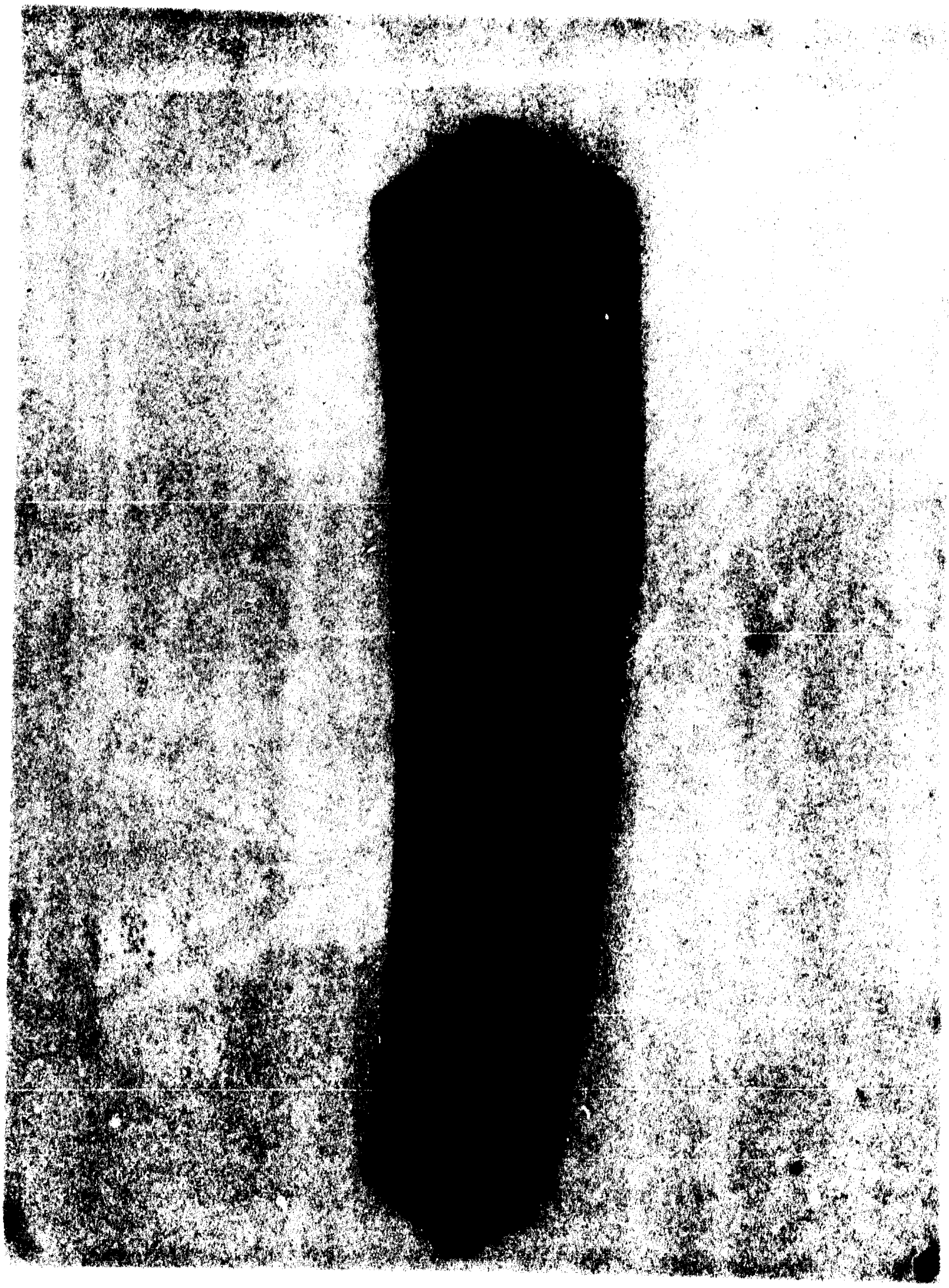


Fig. 7: Curved copper mould tube used for casting $3\frac{3}{8}$ in. square billets on the Von Moos' 'S' type machine.

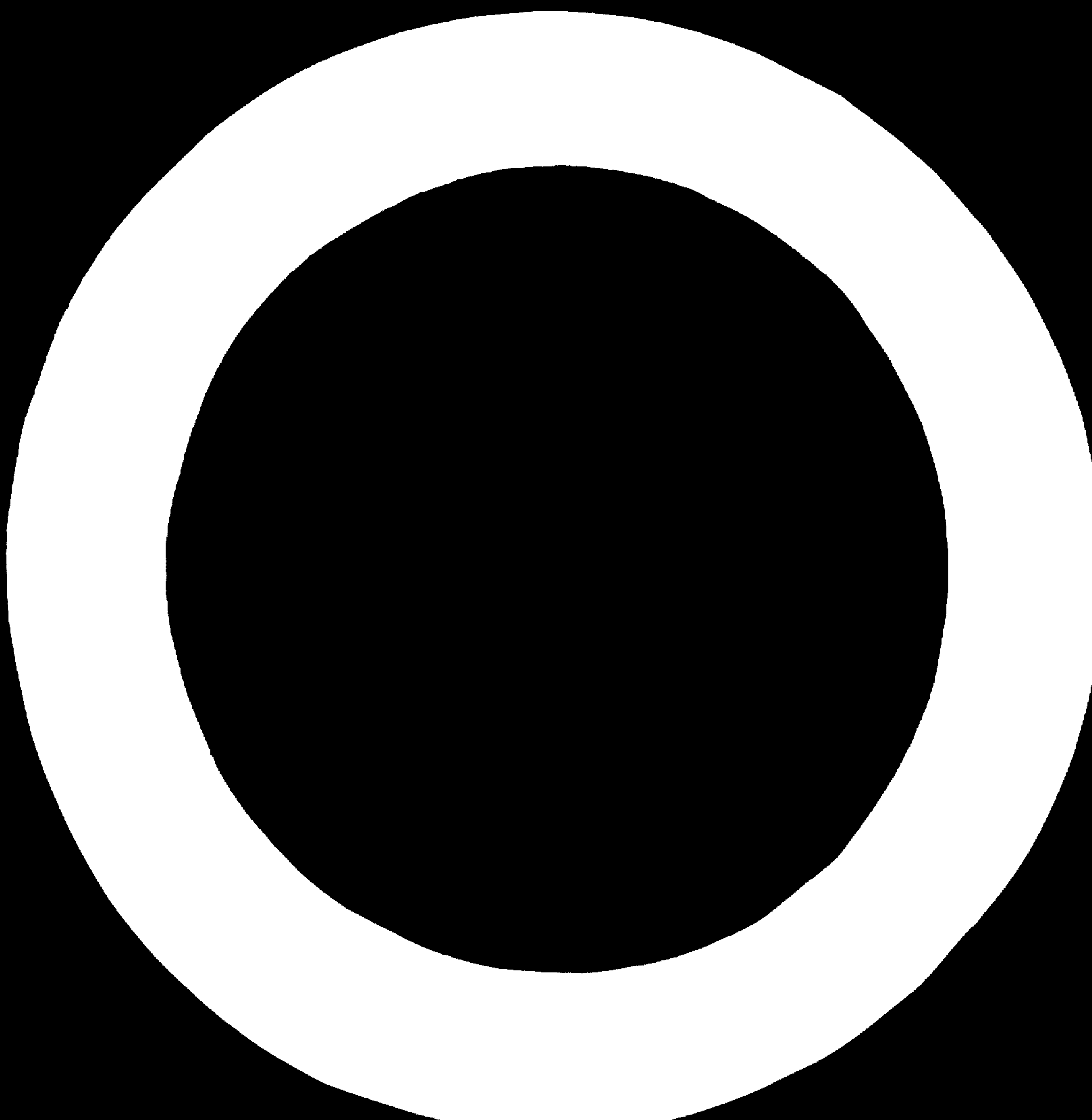


Fig. 8: Side view of curved roller guide path and water cooling sprays during a cast on the Von Moos' 'S' type machine.

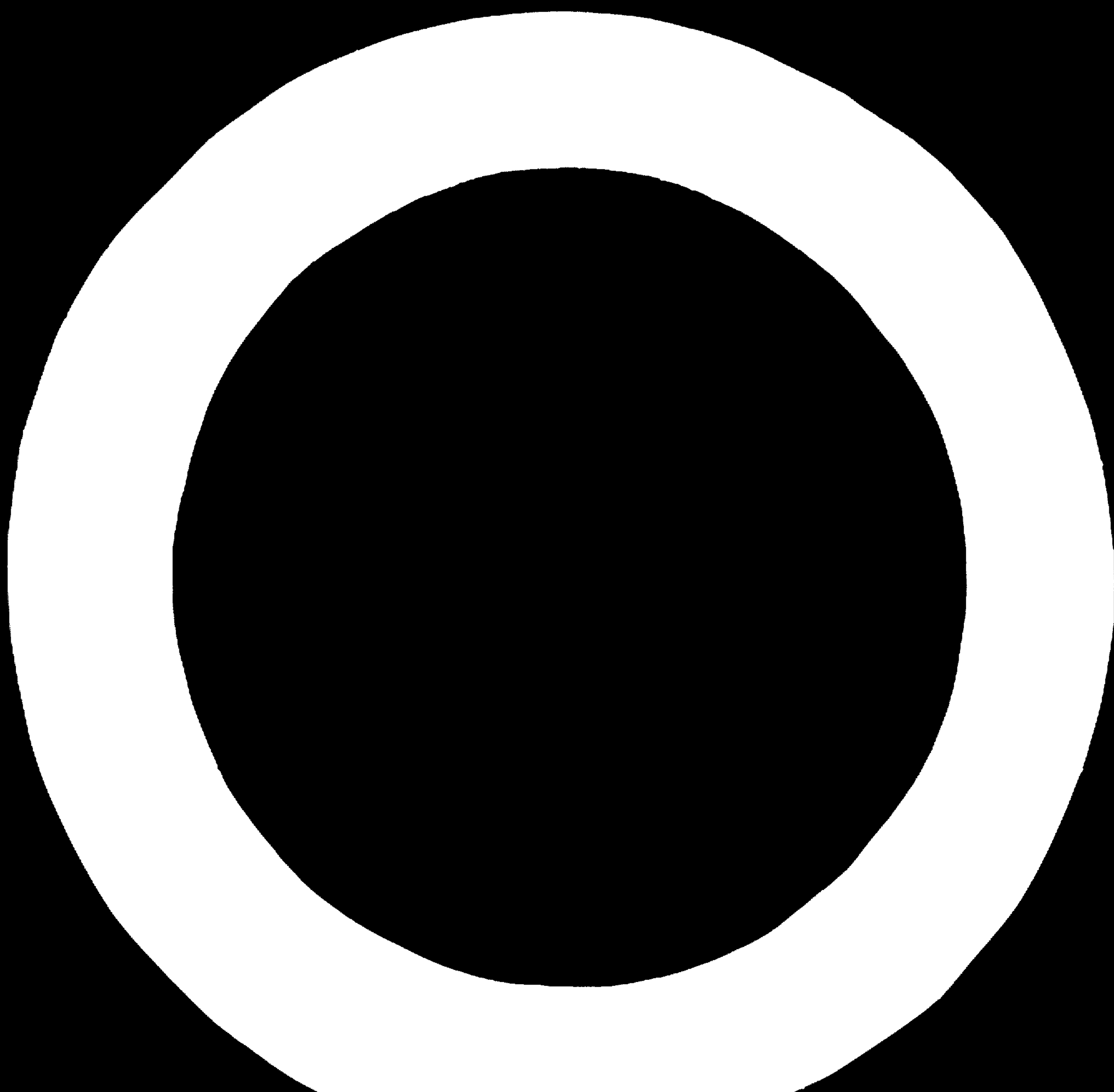


Fig. 9: View looking down onto withdrawal/straightening roll group in operation and discharging $3\frac{3}{8}$ in. square billet horizontally during a cast on the Von Moos' 'S' type curved mould/curved spray casting machine.

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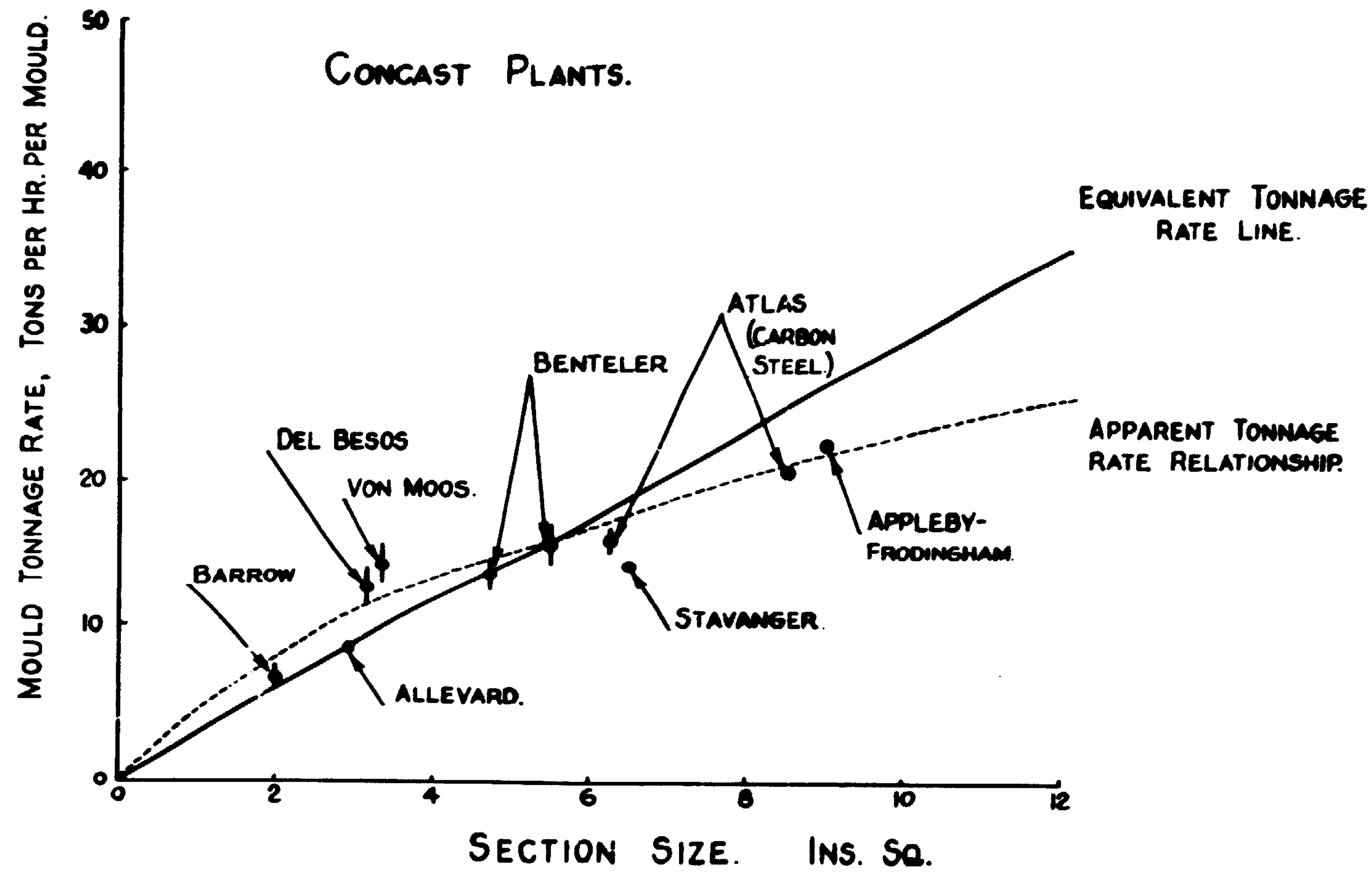
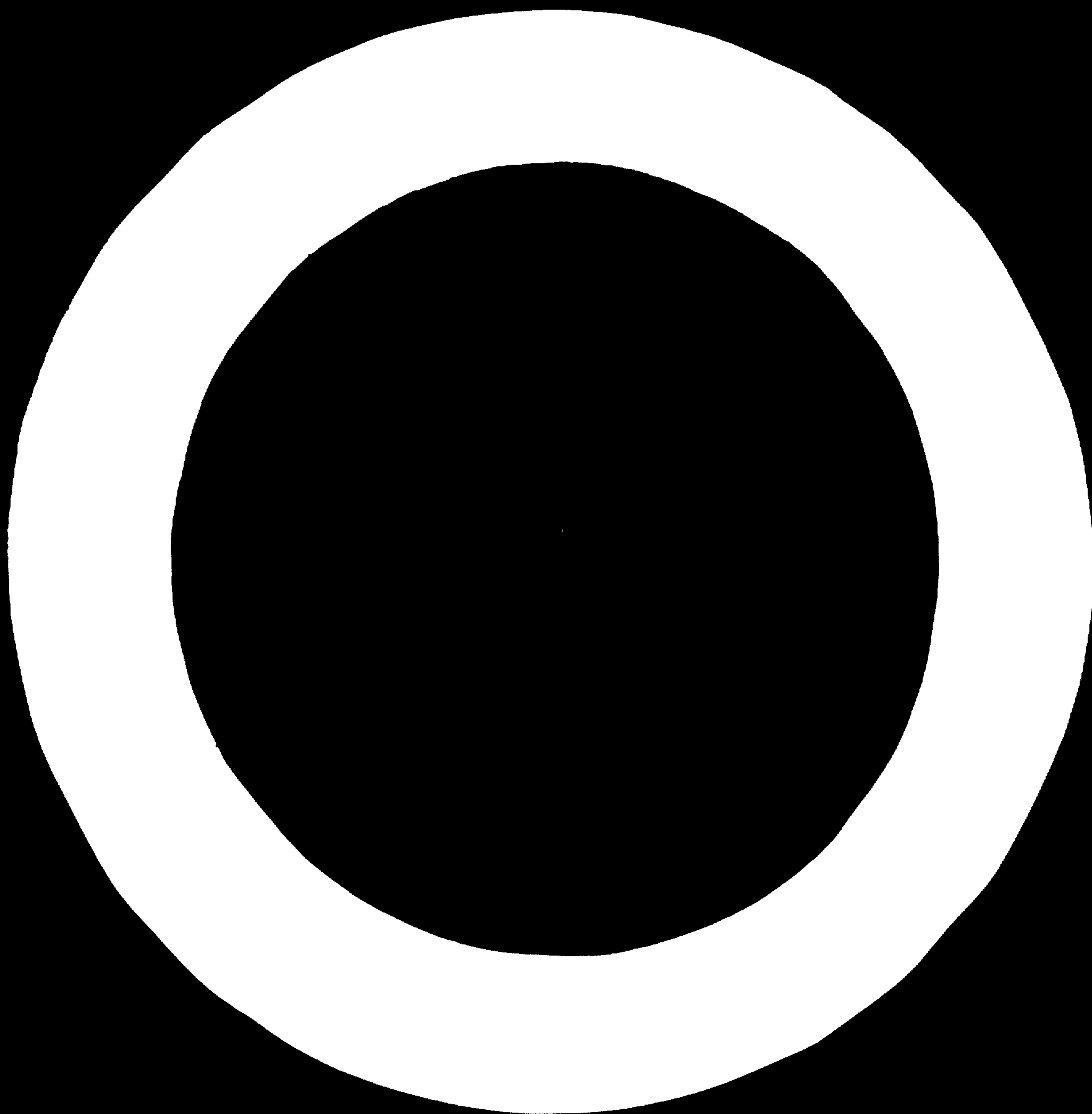


Fig. 2: Typical mould tonnage rates for various square sections cast at different plants of the Concast group, showing apparent and equivalent tonnage rate relationships. (Mainly carbon steels.)



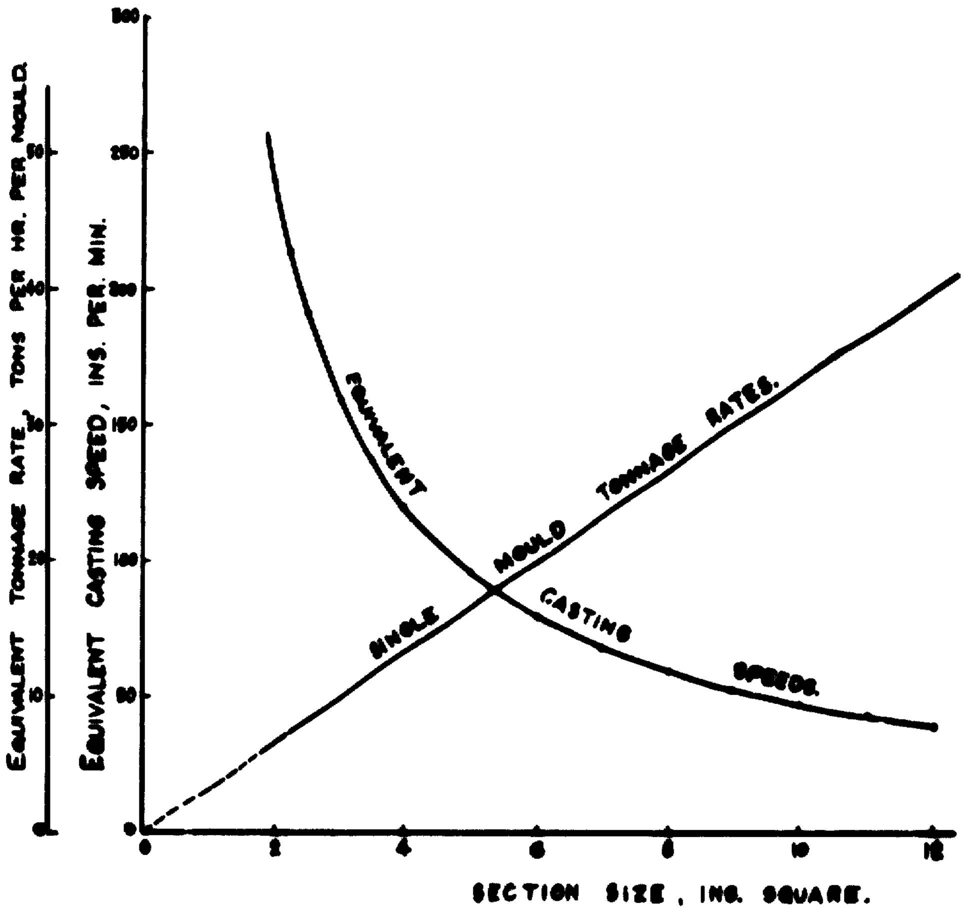
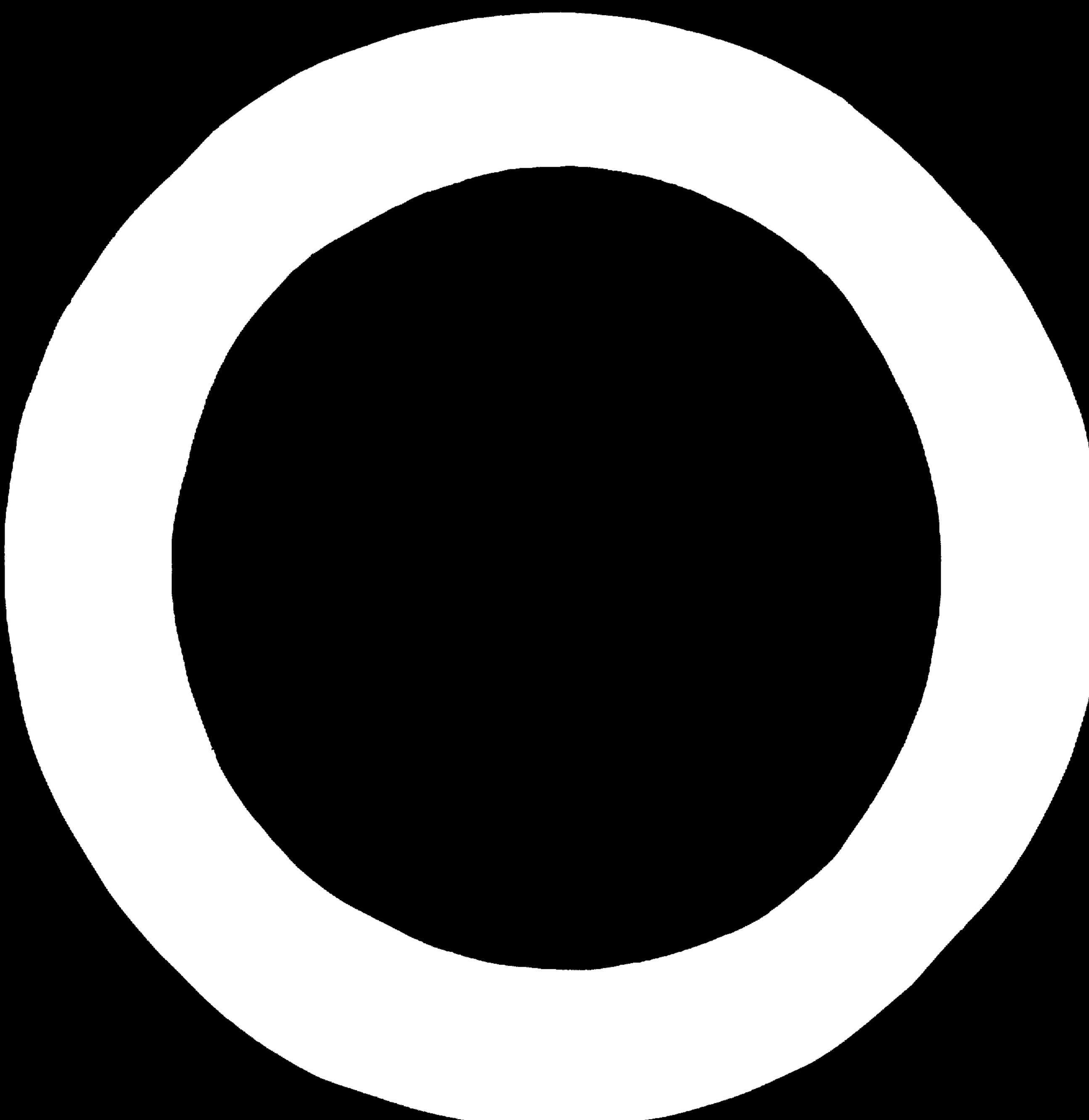


Fig. 3: Equivalent casting speeds and single mould tonnage rates for square sections ranging 2 - 12 ins. in size. (Based on the Barrow standard for 2 in. square billets.)



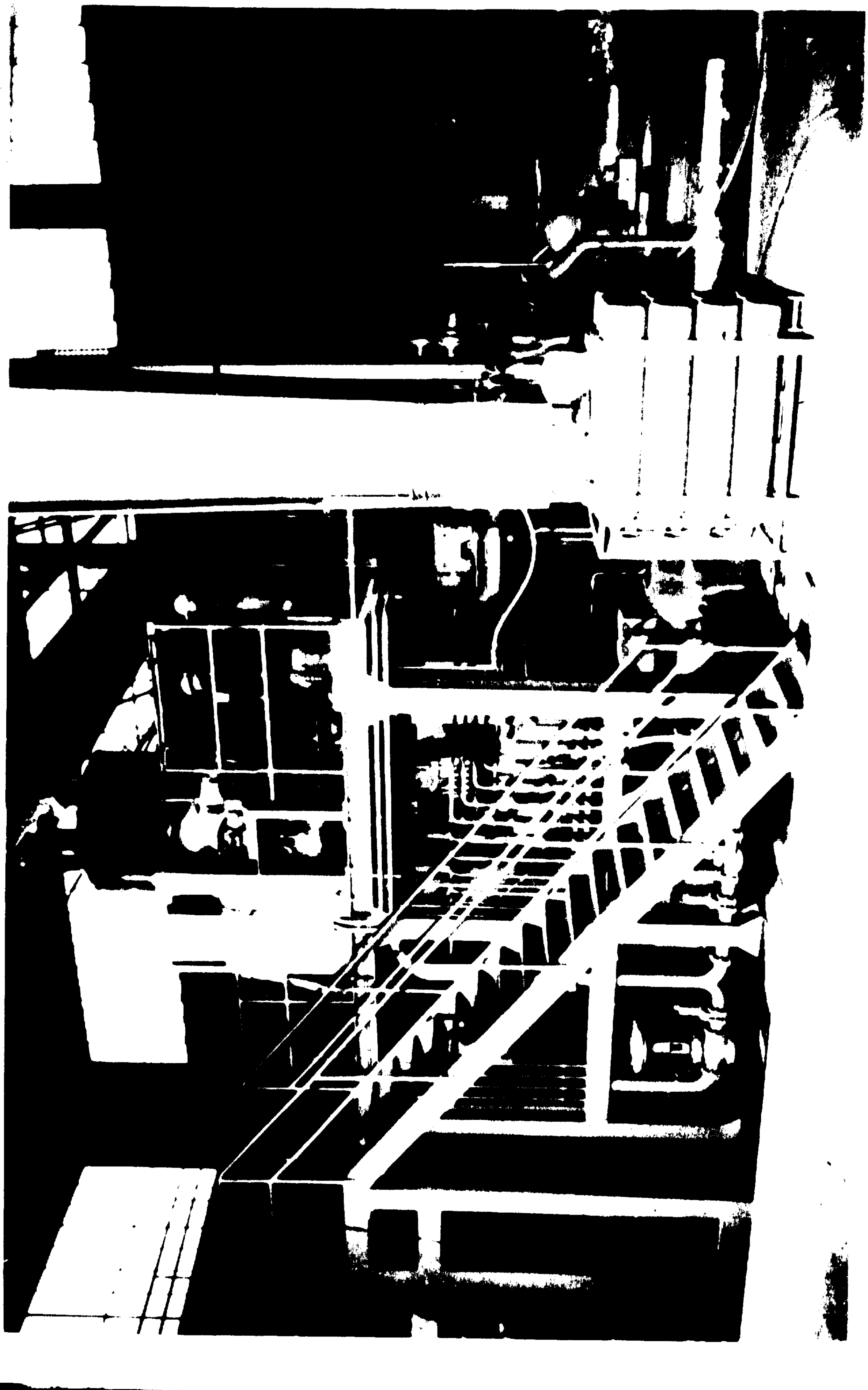
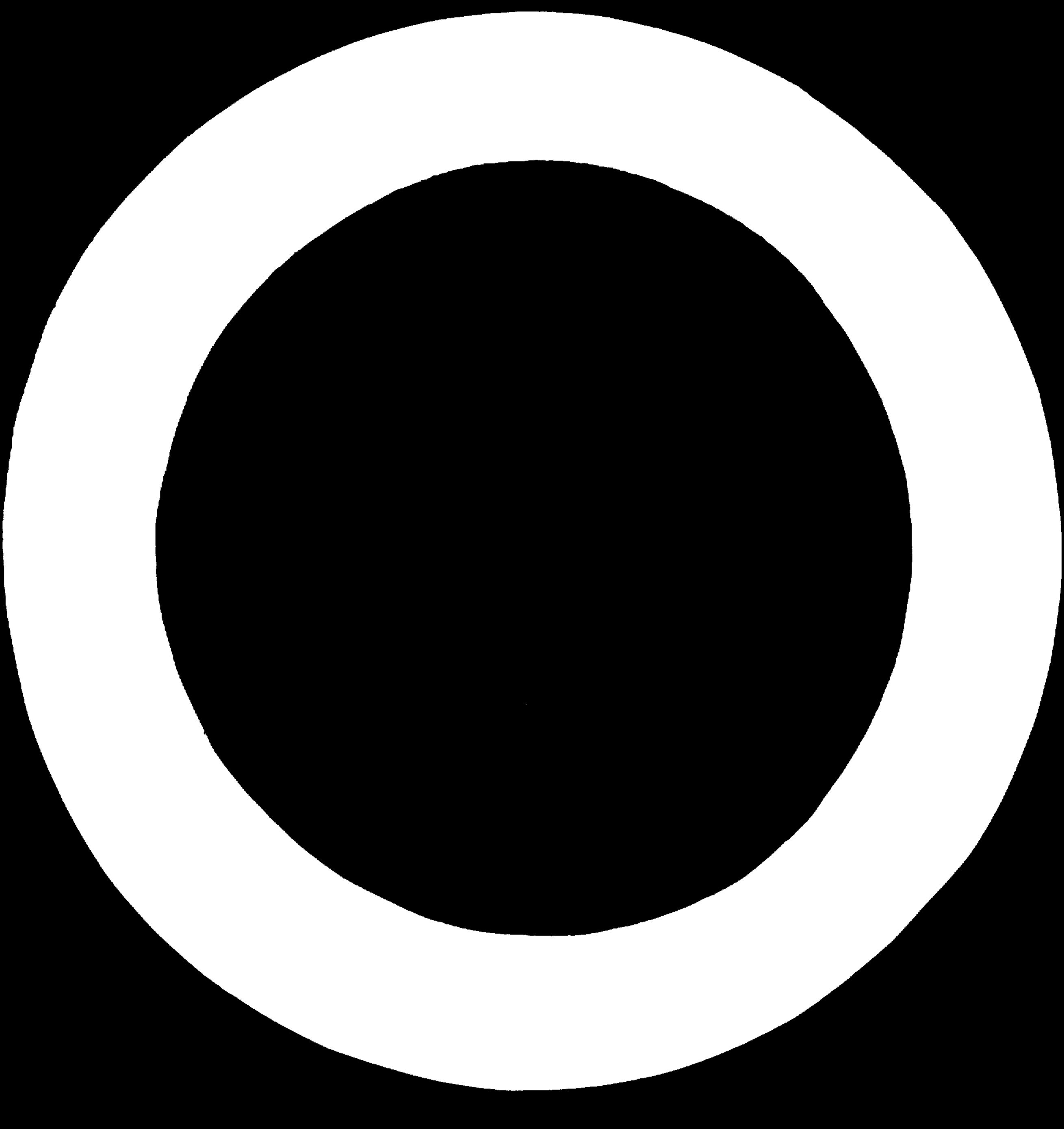


Fig. 4: Side view of 'S' type curved mould/curved spray machine at A.G. der Von Moos'schen Eisenwerke, Lucerne, in operation during a cast.



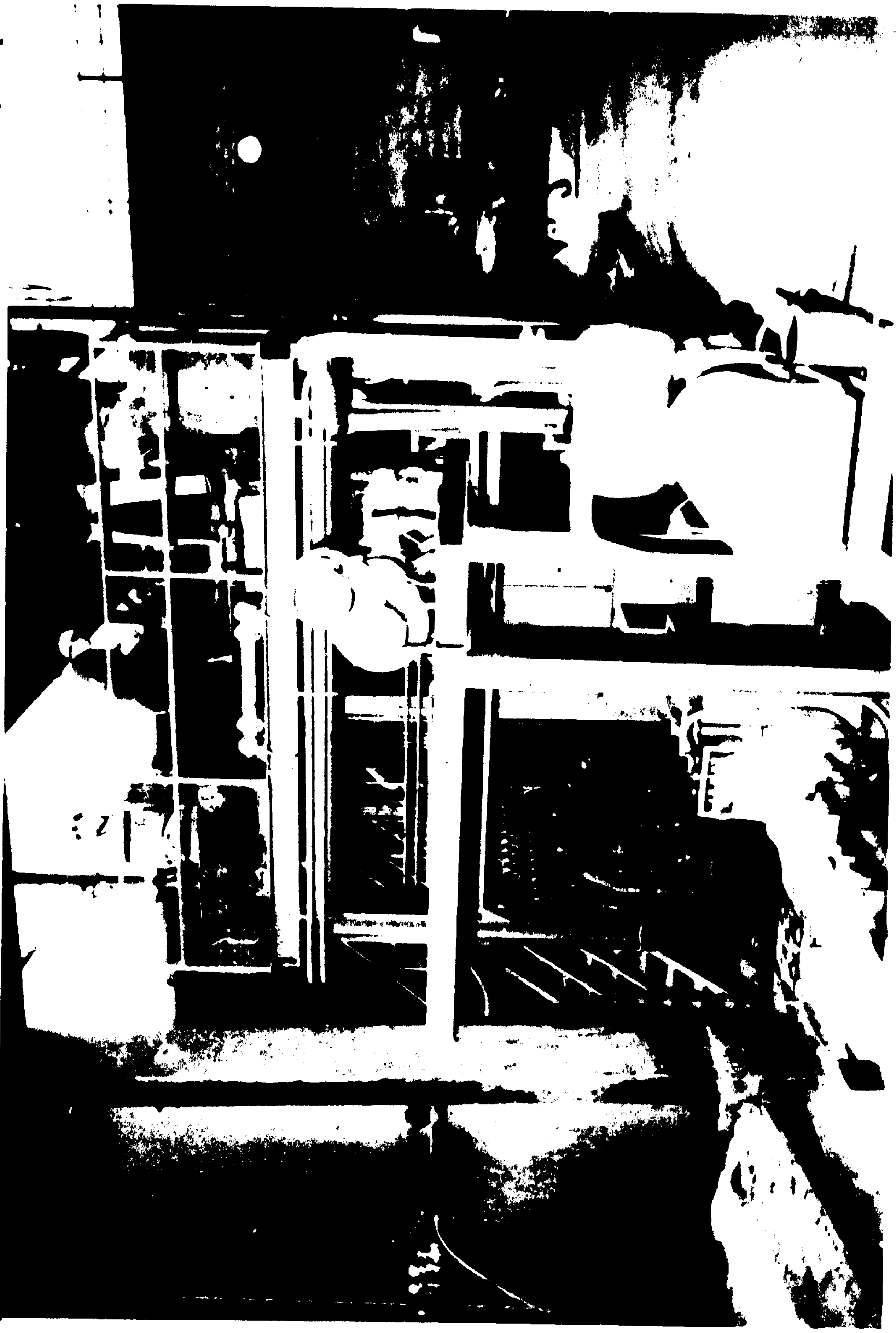


Fig. 5: Discharge end view of 'S' type casting machine at Von Moos', in operation during a cast.