

Horizontal continuous casting of high-strength aluminium-bronze and other copper-base alloys

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IT is known from the literature that a whole range of copper-base alloys are already being cast in horizontal continuous casting plants.^{1,2,3} Continuous casting plants with horizontal moulds have several basic economic advantages when compared to their vertical counterparts. In particular, compared with vertical continuous casting plants their cost of purchase, installation and operation as well as the floor area requirements are much less. On the other hand, different solidifying conditions arise basically because of the horizontal arrangement of the mould.

The present plant in the non-ferrous metal foundry of Sulzer Brothers Limited is essentially an oil-fired clay-bonded graphite crucible which keeps the melt hot (Fig. 1). The melt flows out of the heated crucible into the graphite horizontal mould that is surrounded by a water cooler. A graphite mandrel can be inserted for the production of tubes and other hollow sections. The billet emerging from the mould is pulled over a series of transport rollers in stages by hydraulic drawgear. The length and speed of traverse as well as the time between the individual draws are adjustable.

Investigation of continuous cast products

*Complex aluminium-bronzes 'INOXYDA'**

Complex aluminium-bronzes are copper alloys with 9-15% Al with additions of Fe, Ni and Mn. In contrast to other copper-based casting alloys they contain neither tin nor zinc. The strength and toughness values that are attained lie in the same range as high tensile brass alloys containing zinc, and are practically constant over a large temperature range. The resistance to corrosion and abrasion is considerably greater than that of high tensile brasses and other copper alloys.⁴ The very good resistance to corrosion by seawater and cavitation has found for these alloys a wide range of marine applications. The relatively good weldability should also be mentioned. By adjusting the chemical composition to suit the requirements, complex aluminium-bronzes can solve a whole range of the most varied material problems. A detailed information con-

SYNOPSIS

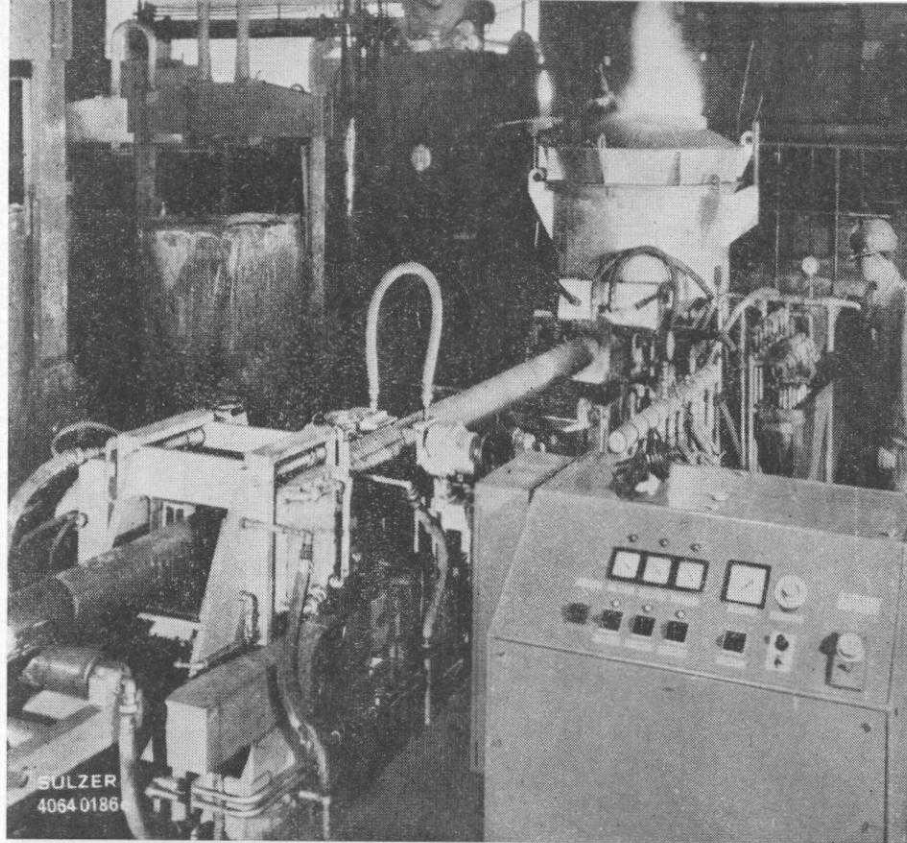
A whole range of copper-base alloys are being cast in horizontal continuous casting plants. Continuous casting plants with moulds lying horizontally have several basic economic advantages when compared to their vertical counterparts. In particular, compared with vertical continuous casting plants their cost of purchase, installation and running as well as the floor area taken up is much less. On the other hand, different solidifying conditions arise because of the horizontal arrangement of the mould.

The results of investigations into the horizontal continuous casting of hollow billets from various copper alloys are available. Continuous cast billets of INOXYDA 53 complex aluminium-bronze exhibit a very favourable structure on account of the cooling conditions arising in the casting mould. The mechanical properties gained are superior to those of a sand casting of the same composition. While the strength and yield point increase, the elongation and notch impact strength of the continuous casting are even more. Above all, in contrast to extruded aluminium-bronze the mechanical properties of continuously cast aluminium-bronze are independent of the position of the test pieces in relation to the billet axis due to the absence of a deformation texture.

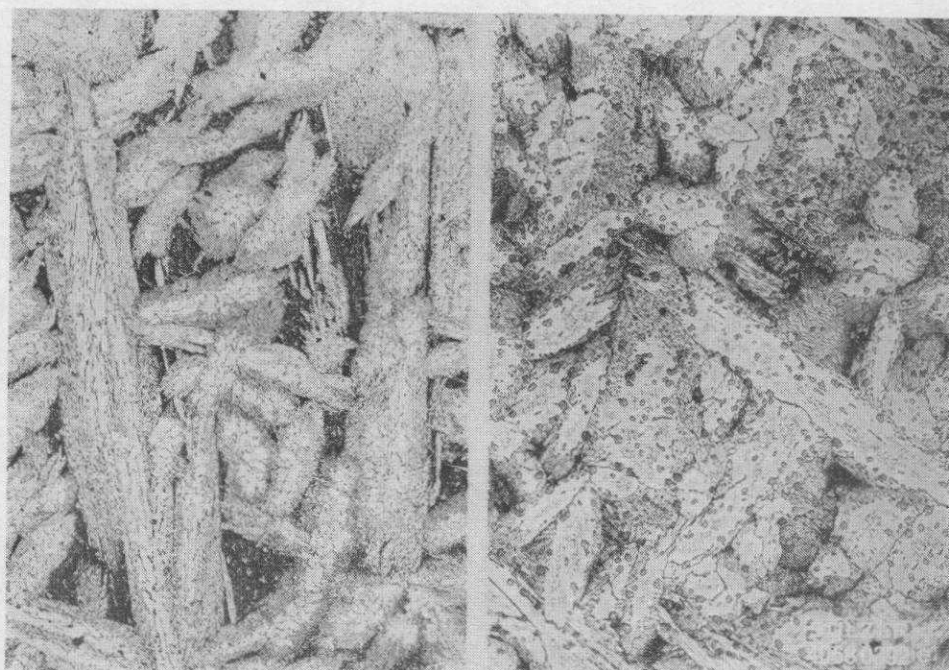
Investigation on hollow billets of CuSn 14, CuSn 10, CuSn 5 ZnPb and CuPb 15 Sn ingots shows that the mechanical properties recorded in the literature for vertical continuous casting are attained. The macrostructure clearly shows that the horizontal continuous casting process produces a symmetrical solidification. The underside of the billet is more finely grained, while relative to the geometric centre the thermal centre is displaced upwards. But what matters to the user is that in practical terms this non-uniformity in the macrostructure does not influence the mechanical properties. The results set out indicate conditions and possibilities for casting the alloys mentioned with acceptable quality by the horizontal continuous casting process.

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*Registered tradename.



1 Horizontal continuous casting plant (Wertli system)



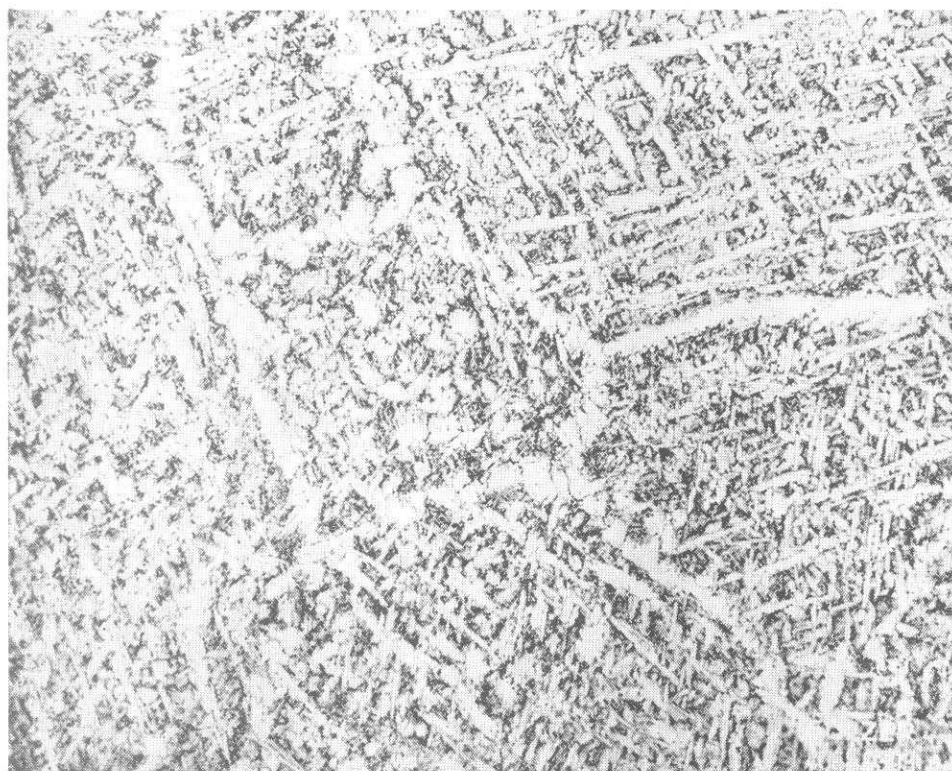
0.1mm

INOXYDA 53

Held at 1000 °C for 10 min
Cooled to 200 °C at a rate
of 1.02 °C/min
HB: 167 kp/mm²

Held at 1000 °C for 10 min
Cooled to 200 °C at a rate
of 0.08 °C/min
HB: 140 kp/mm²

2 Effect of rate of cooling on the structure of Inoxyda 53



3 Microstructure of Cu Al 10 Ni Fe : Inoxyda 53 continuous casting; hollow billet 95/45 mm diameter

cerning material problems etc. is given in the publication of Copper Development Association.⁵

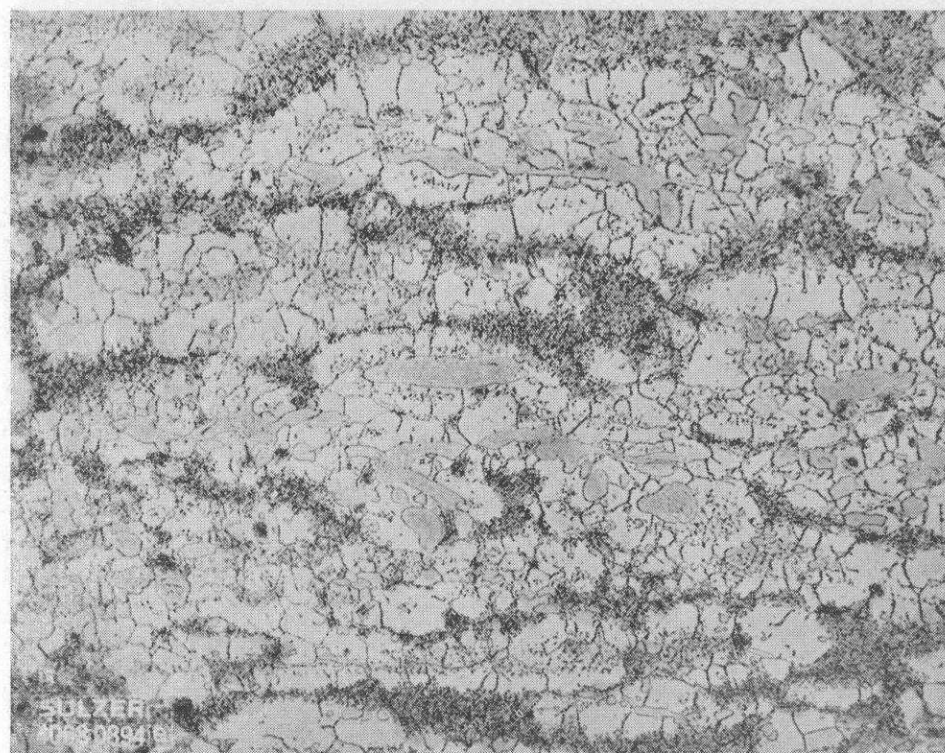
The alloy INOXYDA 53 contains approx. 10% Al and Fe, Ni and Mn and because of its antifriction properties, high resistance to fatigue and abrasion resistance, it is above all suited for cast worm gears, worms, lead nuts and other highly stressed parts. It has been supplied for several years now also in the form of horizontal continuous cast billets.

It is known that the mechanical properties of this type of alloy are above all dependent on the aluminium content and the rate of cooling and are less affected by deviations in the iron, nickel and manganese contents.⁶ Hence not only the rate of solidification is important, but also the cooling rate after solidification. This is shown by Fig. 2. The microstructure of two samples of INOXYDA 53 can be seen which have both been annealed for 10 minutes at 1000°C and then cooled at different controlled rates. The average cooling rates between 1000°C and 200°C were 1.02°C/min. and 0.08°C/min. respectively. The structure consists of an alpha solid-solution of bright appearance, a grey etched kappa-phase and a dark matrix of martensitic character. It can be seen that the kappa-phase appears as coagulated precipitates as well as a laminar structure.⁷ The slower cooling brings about a clear decrease in the amount of martensitic

structure and a coarsening of the kappa precipitates. It can be seen in the hardness values that these differences in microstructure affect the mechanical properties. The retarded cooling brings about a reduction in hardness, tensile strength and yield point. It should be pointed out that extremely slow cooling was involved here. The rate of cooling is in all cases much higher with continuous casting than sand casting, bringing about an improvement in the mechanical properties on the grounds already mentioned.

Figure 3 shows the microstructure of a sample taken from a horizontal continuous cast hollow billet with an outer and inner diameter of 95 mm and 45 mm respectively (Fig. 3). In spite of a relatively higher magnification the kappa-laminas cannot still be discerned. As shown later these microstructure formations point to good mechanical properties. The relatively fast cooling of the continuous casting to 700°C has favourable effects on the mechanical properties of the material. The cooling through the critical temperature range can be accelerated by secondary cooling of the casting. In practice this is carried out with a high pressure air-water mixture.

This Al-bronze is capable of being worked hot and is also available in the form of extruded bars. For this reason the microstructures and the properties of continuous cast and extruded bars were compared out



0.1 mm

4 Micrograph of polished surface parallel to direction of deformation. Cu Al 10 Ni Fe—extruded hollow billet : 95/45 mm diameter

of interest. The following microphotograph shows the structure of an extruded complex aluminium-bronze of approximately the same chemical composition (Fig. 4). The structure due to working is easily recognised in the microstructure and leads one to expect the mechanical properties to be anisotropic. This effect on the deformed texture may sometimes be made more noticeable by elongated non-metallic inclusion in the direction of working. The results recorded from the tests on mechanical properties in Table I confirm the metallographic findings. The greater strengths of INOXYDA 53 sand and continuous castings are partly the result of the higher aluminium content than in the deformed bronze. In spite of the higher strength and yield point of the continuous casting samples, they show a greater elongation and very uniform notch impact strength. The elongation values gained for the worked bronze depend upon the direction of sampling and vary very much. The same holds true for the notch impact strength. Thus this complex Al-bronze has the best mechanical properties in the continuous-cast state. With continuous castings test results are not dependent upon the direction of sampling, unlike worked bronzes.

To test the uniformity of the structure across the billet section, microsections were taken from the centre and periphery of a solid 100 mm billet (Fig. 5). In Fig. 5 one can see the structure of the billet at the

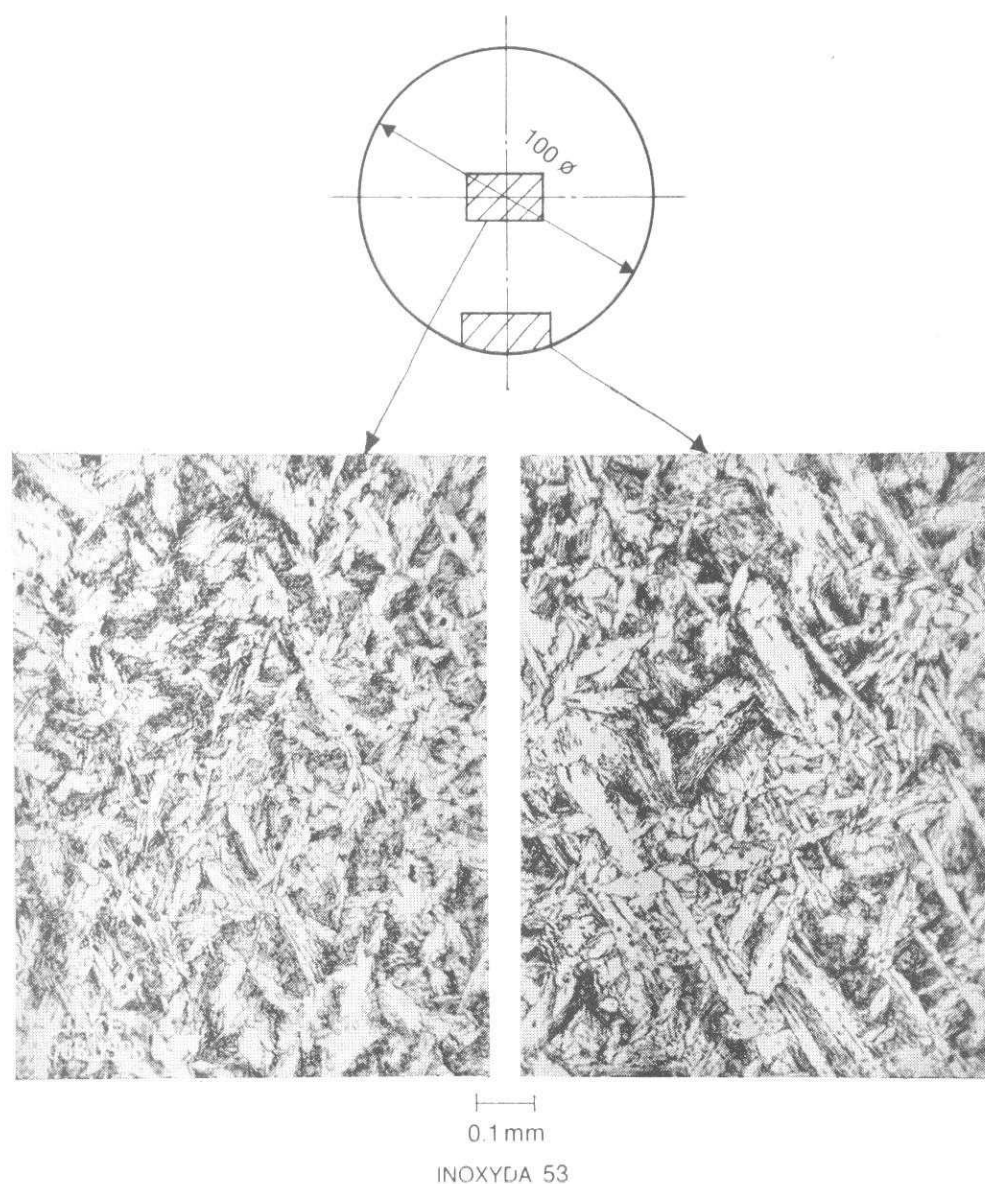
centre and underside of the periphery. Not only are the structures similar but also the hardness values.

The production of hollow and solid castings from Al-bronze is made difficult by their typical casting properties. The tendency for an oxide skin to form (Al-oxide) as well as great shrinkage require special casting procedures which impair their rate of production as sand castings. These disadvantages are of less importance when casting is continuous. The danger of oxide inclusions is very much less and the rate of production notably better.

Tin bronzes, leaded gun metal and lead bronze

As with the complex aluminium-bronze INOXYDA 53 previously described, advantages result in the structure from the cooling conditions prevailing in continuous casting. Tin-bronze and gun metal alloys have a relatively large solidification range. As a consequence of the solidification characteristics of these alloys in thick sections, micropores appear especially at the dendrite boundary in the zone rich in alloying elements which solidifies last. The accelerated extraction of heat during solidification in continuous casting, as against sand casting, inhibits porosity.

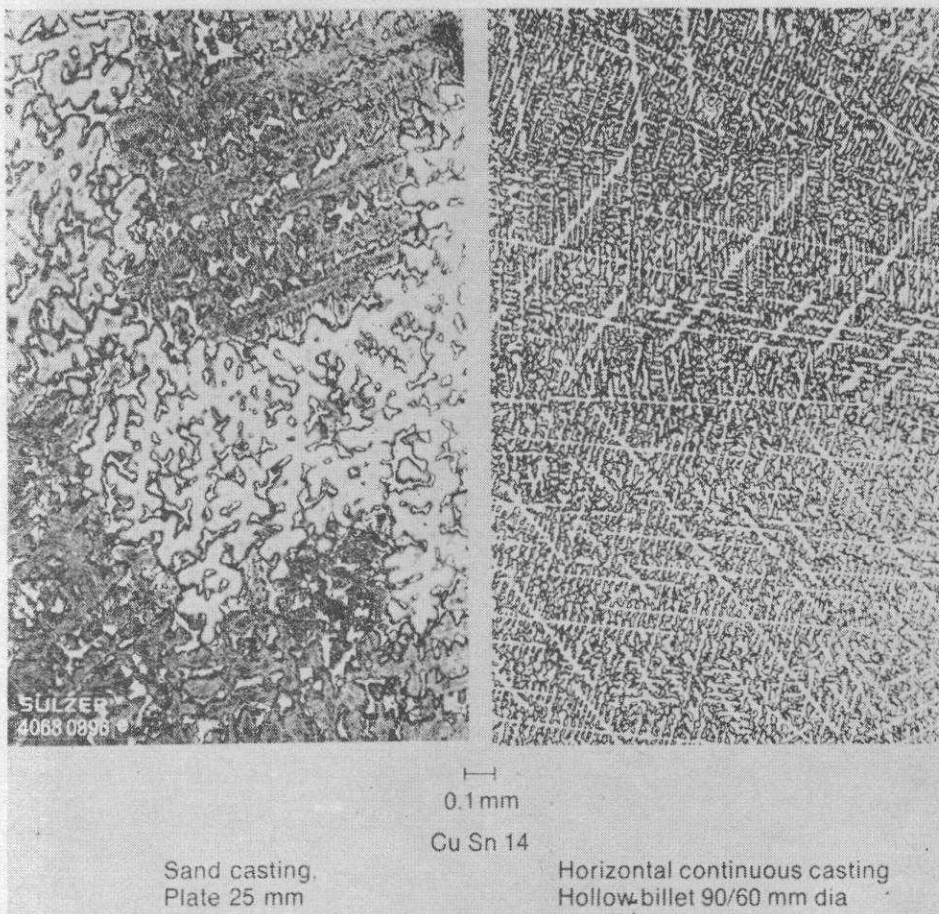
When examined in the as-cast state at room temperature, the structures, of two tin-bronzes with respectively 10 and 14% tin, consist of an alpha solid solution



5 Horizontal continuous cast billet 100 mm dia. Inoxyda 53-210 kg/mm². HB_{10/3000/30}, 207 kg/mm²

TABLE I Mechanical properties of complex Al-bronze continuously cast, sand cast and extruded

Results from at least 5 parallel tests	INOXYDA 53 sand casting plate with thickness of 25 mm 9.80% Al	INOXYDA 53 continuous casting hollow billet 95/45 mm 9.82% Al	Complex Al-bronze hollow billet 95/45 mm extruded 9.27% Al	
			At right angles to direction of deformation	Parallel to direction of deformation
Tensile strength σ_B [kg/mm ²]	76.9—77.2	79.2—81.8	63.2—68.6	70.5—70.7
Yield point $\sigma_{0.2}$ [kg/mm ²]	40.6—41.8	46.3—47.7	35.3—37.1	33.3—34.4
Elongation δ_{5d} [%]	14.9—15.8	16.3—17.3	8.0—13.0	18.6—18.8
Impact strength charpy V-notch at 20°C [mkp/cm ²]	1.9—2.0	2.0	1.0	1.5—2.3



6 Microstructures of Cu Sn 14 as sand casting and continuous casting

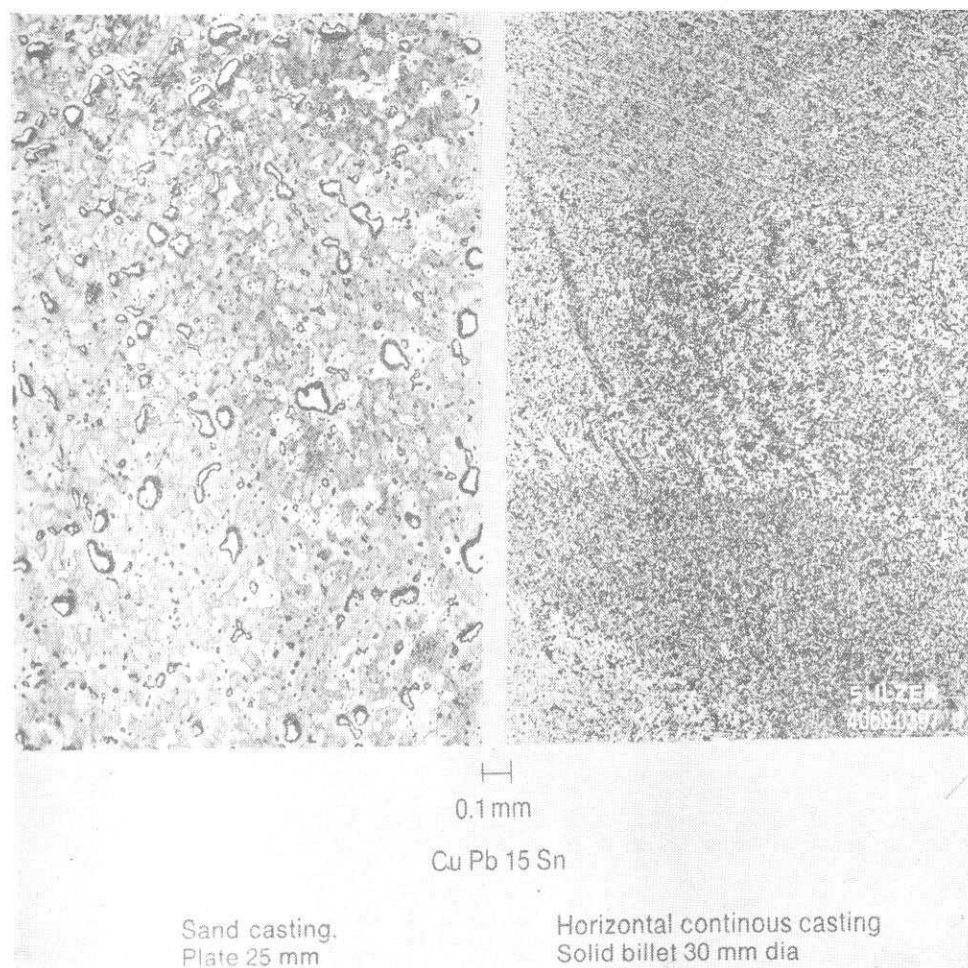
and an $\alpha + \delta$ eutectoid. The amount of $\alpha + \delta$ eutectoid is influenced not only by the composition of the alloy but by the rate of cooling.⁸ With greater rates of cooling the solubility for tin of the α solution is decreased and brings about an increase of the structures $\alpha + \delta$ content. Fig. 6 compares the microstructures of Cu Sn 14 both as a sand casting and continuous casting. On comparison it can be seen clearly that the $\alpha + \delta$ eutectoid content is greater in the continuous casting. The greater content of hard eutectoid as well as its finer distribution leads one to expect better mechanical properties.

Fine structures and even distribution of lead are noticeable in continuous-cast alloys containing lead such as Cu Sn 5 Zn Pb, or lead bronze Cu Pb 15 Sn (Fig. 7).

A characteristic feature of the horizontal arrangement of the mould is that the extraction of heat is not uniform and that therefore solidification proceeds asymmetrically. The underside of the billet is pressed against the mould due to gravity. Air gaps due to contraction between the mould and the billet appear on top and at the sides as solidification proceeds. The favourable tendency of the heat to flow downwards

TABLE II Mechanical properties of CuSn 14

		Horizontal continuous casting hollow billet 90/60mm	Vertical continuous casting according to Deutsches Kupferinstitut ⁹	Sand casting 25 mm test plate
Tensile strength σ_B	[kg/mm ²]	36.0—37.4	30	26.5—27.1
Yield point $\sigma_{0.2}$	[kg/mm ²]	23.4—24.4	19	16.2—17.0
Elongation δ_5	[%]	6.0—7.5	5	4.2—4.9
Brinell hardness	[kg/mm ²]	113—123	120	104—109
HB _{10/500}				
Analysis : Cu	%	86.07	—	86.38
Sn	%	14.36	—	13.56
P	%	0.04	—	0.054



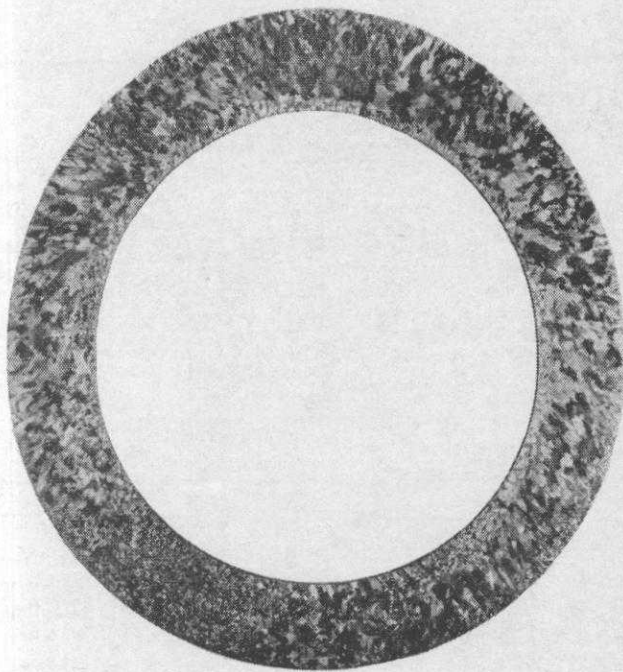
7 Microstructures of Cu Pb 15 Sn as sand casting and continuous casting

TABLE III Mechanical properties of CuSn 10

		Horizontal continuous casting hollow billet 90/60 mm	Vertical continuous casting according to Vanderbeck ²	Sand casting 25 mm test plate
Tensile strength σ_B	[kg/mm ²]	35.2—38.1	31—33	32.3—33.5
Yield point $\sigma_{0.2}$	[kg/mm ²]	17.4—18.4	15	13.5—14.7
Elongation δ_{5d}	[%]	20.3—29.2	12—25	35.6—42.4
Brinell hardness	[kg/mm ²]	90—104	80—90	78—81
HB _{10/500}				
Analysis :				
Cu	%	89.87	—	90.08
Sn	%	9.55	—	9.42
P	%	0.08	—	0.06

can be clearly seen in the macrostructure (Figs. 8 and 9). On the underside of the billet section a fine grained zone is found and the thermal centre is displaced upwards relative to the geometric centre. In view of this non-uniformity in the macrostructure, care had to be taken when testing mechanical properties to examine all structures present, i. e. test-pieces from top, bottom and side were taken from the billet and tested. As the following results show, the various macrostructure formations have little effect on the mechanical proper-

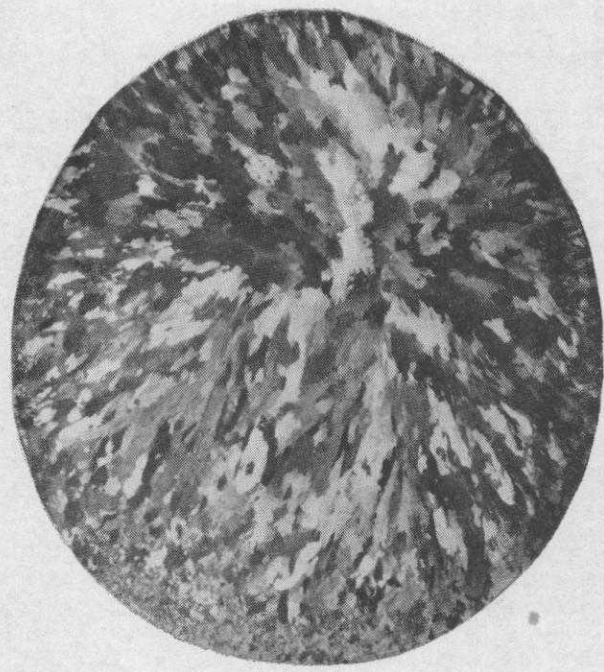
ties. This can be judged by the relatively small deviation of the test values, recorded in the table. The values obtained for CuSn 14 are recorded in Table II and are compared with those of vertical continuous castings quoted in literature. The values for a sand casting are recorded in the third column and are determined with a 25 mm thick sample plate with a cast weight of 5 kg. The tensile strength, yield point as well as elongation are better than the corresponding values for the sand casting. The values for vertical



20 mm

Cu Sn 5 Zn Pb

8 Macrostructure of hollow billet showing asymmetric solidification



20 mm

Cu Sn 10

9 Macrostructure of solid billet showing asymmetric solidification

TABLE IV Mechanical properties of CuSn 5 Zn Pb

	Horizontal continuous casting hollow billet 210/153 mm	Vertical continuous casting according to Vanderbeck ²	Sand casting 25 mm test plate
Tensile strength σ_B [kg/mm ²]	30.6—33.7	27—30	29.0—29.6
Yield point $\sigma_{0.2}$ [kg/mm ²]	15.4—16.5	15	12.4—13.0
Elongation δ_{5d} [%]	32.2—35.3	15—25	32.0—35.8
Brinell hardness [kg/mm ²]	81—82	80—75	67—70
HB _{10/500}			
Analysis : Cu	86.23	—	85.48
Sn	5.03	—	5.14
Zn	3.20	—	3.32
Pb	4.07	—	4.06
P	0.07	—	0.005
Ni	1.44	—	1.67

continuous-cast samples given in the literature are equalled and exceeded throughout by horizontal continuous casting. The same is true for CuSn 10. The percentage elongation determined for the continuous casting was lower than that of the sand casting, probably a result of the greater $\alpha + \delta$ eutectoid constituent in the structure due to the high rate of cooling (Table III).

This is also true for CuSn 5 Zn Pb. It should be noted that the values determined for the horizontal continuous casting were determined from a hollow cylinder with an outside diameter of 210 mm and an inside diameter of 153 mm. This was the largest cross-section for a hollow billet yet produced by the horizontal continuous casting process in the foundry of Sulzer Brothers (Table IV). Finally it should be stated

TABLE V Mechanical properties of CuPb 15 Sn

		Horizontal continuous casting hollow billet 90/60 mm	Vertical continuous casting according to Deutsches Kupferinstitut ⁹	Sand casting 25 mm test plate
Tensile strength σ_B	[kg/mm ²]	26.1—27.4	24	25.6—27.0
Yield point $\sigma_{0.2}$	[kg/mm ²]	14.2—15.2	15	14.5—15.1
Elongation δ_{5d}	[%]	15.0—19.8	15	16.4—72.2
Brinell hardness	[kg/mm ²]	73—75	75	71—72
HB _{10/500}				
Analysis : Cu	%	77.85	—	77.53
Pb	%	14.53	—	14.00
Sn	%	7.38	—	7.93
P	%	0.09	—	0.03

that values were also obtained for leaded bronze CuPb 15 Sn corresponding throughout to those given for vertical continuous castings (Table V).

Summary and conclusion

The results of investigations on the horizontal continuous casting of hollow billets from various copper alloys are available. Continuous-cast billets of INOXYDA 53, a complex aluminium-bronze, exhibit a very favourable structure on account of the cooling conditions arising in the casting mould. The mechanical properties attained are superior to those of a sand casting of the same composition. While the strength and yield point increase, the elongation and notch impact strength of the continuous casting are more even. Above all, in contrast to extruded aluminium-bronze the mechanical properties of continuously cast aluminium-bronze are independent of the direction of sampling due to the absence of a deformation texture. Investigation on hollow billets of CuSn 14, CuSn 10, Cu Sn 5 Zn Pb and Cu Pb 15 Sn shows that the mechanical properties recorded in the literature for vertical continuous casting are attained. The macrostructure clearly shows that the horizontal continuous casting process produces asymmetrical solidification. On the one hand the underside of the billet is more finely grained, while relative to the geometric centre the

thermal centre is displaced upwards. But what matters most to the user is that in practice this non-uniformity in the macrostructure does not influence the mechanical properties even in the largest hollow billets produced to date, with an outer diameter of 210 mm and an inner diameter of 153 mm. The results set out indicate conditions and possibilities for casting the alloys mentioned with acceptable quality by the horizontal continuous casting process.

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