THE CONTRADICTORY ASPECTS OF CERTAIN FACTORS AFFECTING THE QUALITY OF BRASS INGOT FOR WORKING

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Abstract

Practical difficulties for attaining a sound brass ingot have been outlined. The influences of casting temperature on entrapping of gases and dross, surface conditions of the ingot, crystallization, primary pipe and presence of dissolved gases have been outlined. The effects of rate of pouring and different mould dressings on the quality of the ingot are given. The importance of factors like the rate of cooling and the prevention of wide pasty zone has been stressed.

Introduction

IN the course of the general discussion on papers read at a " Symposium on Metallurgical Aspects of Non-Ferrous Metal Melting and Casting of Ingots for Working " held in London in 1949, it was remarked[1]: " In order to get tranquil pouring you dropped a stream of molten metal about three feet through the air on to a rising liquid surface in a mould. I also read of the necessity for achieving a fine macrostructure, and that in order to achieve that, one forced gas from a flaming dressing through metal in order to break up the structure and get a fine macrostructure. It does seem to me that the methods do not smack of the scientific or of the precise." It is indeed true that conventional methods and techniques of casting brass ingots appear to have been guided by the dictates of practical convenience rather than by metallurgical requirements for production of sound ingots. Thus features have been introduced which are contradictory to those necessary to obtain ingots and sheets free from defects. The position has, however, been made worse by the inevitable influence of factors whose effects are contradictory to one another and it is proposed to consider in this paper a few of these factors on which the quality of a brass ingot depends. The consideration will be entirely qualitative and will be restricted to binary brass slabs for rolling into sheet or strip.

All brass foundry men experience difficulty in minimizing the conflicting nature of these factors in spite of a sound metallurgical understanding of them and in spite of the vast amount of research work done on the subject. On a commercial scale it is impossible to produce a really sound ingot, each foundry attempting to keep the unsoundness down to a minimum. In fact to quote again from a paper read at the above-mentioned symposium[2]: " a satisfactory casting may be defined as one which is compositionally correct and which on processing by the appropriate technique yields an acceptably high proportion of marketable material ". This is a very appropriate definition and clearly shows the acceptance by metallurgists of the lack of attainable perfection in the technique of manufacture of sound ingots.

Casting Temperature

Entrapping of Gases and Dross — The importance of the temperature at which brass is cast cannot be over-estimated. When molten brass is poured into a mould, the falling stream produces an injector effect and draws gas as well as the rapidly forming zinc oxide into the mass of liquid metal. If solidification is delayed until after the metal attains a tranquil state, the injected gas and

zinc oxide, both of which are inclined to rise rapidly to the surface, are allowed to escape. A melt solidifying quickly will increase the chance of entrapping of gases and dross in the ingot. The temperature of the metal will affect in the same way the gases liberated by the combustion of 'flaming' mould dressings which are very frequently used in brass casting practice. An ingot cast at a low temperature is found on examination to contain numerous subsurface spherical cavities. An unsoundness of this nature reveals itself when the ingot is rolled into sheet as that characteristic defect known as a 'spill' which is only too familiar to a brass sheet producer.

Surface Conditions of Ingot — High temperature pouring normally produces a clean surface as it prevents folds and remelts solidified globules of metal splashed on to the mould face.

Effects of Crystallization — Columnar and Equiaxial — On the other hand, the hot metal maintains a steep temperature gradient between the mould faces and the centre of the casting, a condition favourable to columnar crystallization. This causes the crystals which are rapidly advancing from the two faces to form bridges which in turn prevent the feeding of liquid metal and thus create interdendritic or shrinkage cavities of serious dimensions. Incidentally, while considering temperature gradients within an ingot mould the importance of the vertical gradient should not be underestimated. The effect of the steep lateral temperature gradient mentioned here is dependent on the vertical temperature gradient being less and in all subsequent discussions on lateral temperature gradients this relative aspect of the two gradients must be borne in mind. Low temperature pouring promotes undercooling of the metal in the centre of the mould and equiaxed crystals begin to form between the advancing planes of the columnar crystals around numerous independent nuclei provided by the suspended solid particles either injected with the pouring stream or loosened by erosion of the solidifying metal. The formation of these equiaxed crystals, though not undesirable, gives rise to small contraction cavities at the grain boundaries. Such cavities cannot be fed and produce a region of unsoundness at the centre of the ingot. The columnar crystals are substantially free from shrinkage cavities except, as has already been pointed out, when they meet from opposite directions. The unsoundness caused by equiaxial crystallization is, however, less serious than that caused by the bridging of columnar crystals, and from this point of view, therefore, pouring at temperatures within reasonable limits lower than the correct temperature is to be preferred.

Primary Pipe — The steep lateral temperature gradient caused by casting at a high temperature increases the depth of the primary pipe. The formation of the pipe can be restricted by increasing the vertical temperature gradient relative to the lateral gradient thus causing solidification to proceed from the bottom upwards. This will be discussed in detail later.

Dissolved Gases — The solubility of gases in a molten metal increases with the rise in temperature. These dissolved gases are liberated at the time of solidification and constitute one of the important sources of porosity. It can, however, be ignored in the case of brasses with high zinc content as the solution of gases is effectively inhibited by the high vapour pressure of zinc which is of the order of 500-600 mm. of mercury at the casting temperature. Therefore, from the point of view of solution of gases in brass high casting temperature can be used without danger.

Rate of Pouring

Before considering the way in which a compromise has been reached between the conflicting effects of casting temperatures, it is proposed to discuss how the quality of a brass ingot is influenced by the pouring speed or, in other words, the rate of rise of the liquid metal in the mould. The casting

temperature and the pouring speed are so intimately related to each other that it is almost impossible to treat them separately.

Similarity to Casting Temperature — In some of its effects a high rate of rise is very similar to casting at a high temperature. It ensures a clean ingot surface as the rapidly rising liquid metal maintains a high temperature enough to prevent folds and cold shuts. The fact that the metal is not likely to solidify while the turbulent state exists is conducive to soundness of ingots. Fast pouring as a means of deferring solidification is of particular importance where a thin ingot is concerned, since in a thick ingot solidification is normally retarded on account of its mass. Greater pouring speed, however, means increased momentum and a greater injector effect drawing the dross and gases deeper into the metal and increasing the likelihood of their being trapped.

Depth of Penetration — The deep penetration caused by fast pouring increases the lateral temperature gradient and reduces the vertical. Unless the temperature of the metal is very near the liquidus such a combination of temperature gradients will promote bridging with concomitant porosity.

Ideal Conditions of Directional Solidification — The ideal way to prevent contraction cavities is to direct the solidification of the ingot from the bottom to the top and the nearest approach to this ideal can be secured by casting the metal at as low a temperature as possible and by decreasing the rate of rise of the metal in the mould. Direction of solidification is governed by the temperature isothermals inside the mould and slow pouring results in these isothermals being more horizontal which is a prerequisite to the progress of solidification from the bottom upwards. In this ideal state of directional solidification, where the rate of solidification equals that of the rate of rise of the metal, an adequate supply of liquid metal is always available to feed shrinkage caused by solidification. Consequently, neither a large pipe nor any shrinkage cavity will form except for a certain amount of porosity at the ingot top where no additional molten metal is available to fill the cavities. This applies also to brasses with long ranges of solidification in which it is more difficult to secure freedom from contraction cavities than in 60/40 brass which has a short range.

This ideal solidification technique can be readily applied to continuous casting methods, but is not practicable for individual ingot casting as a low rate of rise will produce a poor surface unless the temperature of pouring is high.

Undecomposed Mould Dressing — The rate of rise is also very closely related to the effect of the mould dressing particularly if the latter is of the flaming type. If the metal rises rapidly, it reaches the top before the evolution of the gases has ceased and hence the likelihood of gas entrapping increases. In order to obtain a clean surface complete combustion of the flaming dressing is necessary. Undecomposed mould dressing entrapped by fast rising metal is likely to produce a poor surface. Undecomposed substances may also be absorbed into the liquid metal and give rise to defects similar to those caused by dross inclusion.

High Temperature and Slow Pouring — In practice a compromise has been effectively found by raising the casting temperature and reducing the pouring speed. The high temperature allows all gases and non-metallic inclusions to rise to the surface, which process is aided by the lower pouring rate as already pointed out.

Holed Tundish — Reduction of turbulence by the low pouring speed decreases the extent of oxidation of the zinc. The absence of deep penetration of the molten metal stream, another result of a lower pouring speed, reduces the injection of zinc oxide and gases. The high temperature steepens the temperature gradient between the mould faces and the centre of the casting, but this is counterbalanced by the lower penetration, which decreases the slope of the gradient, the

resultant effect being a substantial reduction in shrinkage porosity in the central region. This position can be further improved by using a tundish preferably with holes, as both the tundish as well as small individual streams reduce the kinetic energy of each of these pouring streams on which depends penetration.

Rate of Cooling

The next subject to be considered is the rate of heat extraction from the mould, which has a profound bearing on the quality of an ingot. More rapid heat extraction induces a steeper lateral temperature gradient and automatically increases the rate of solidification. The effect of these features has already been mentioned while discussing casting temperatures and rates of pouring.

Zones of Solidification — Adverse Effect of Wide Pasty Zone — The zones of solidification have an important influence on the soundness of the resulting brass ingot. The pasty zone intermediate between the solid and liquid in a solidifying alloy consists of numerous narrow deep fissures lying between advancing dendrites and become likely source of contraction cavities. The thicker the pasty zone, the greater will be the probability of unsoundness. The thickness of this zone is mainly affected by the solidification range of the alloy and by its rate of cooling. The faster the cooling, the greater is the departure from equilibrium conditions and it follows, therefore, that a rapid cooling will increase the range of solidification. As the thickness of the pasty zone is dependent on the length of the solidification range, it would be thought that an increase in the rate of cooling would adversely affect the soundness of the ingot. In actual fact, however, an increased rate of cooling steepens the temperature gradient and thus narrows the pasty zone.

Stresses Caused by Body Contraction — On the other hand, when body contraction occurs after solidification is complete, the contraction differential caused by a steep temperature gradient may be very large. This sets up tensile and compressive stresses in cooling layers in alternate relation to each other — a condition not only promoting hot cracking but also giving rise to residual stresses of a considerable magnitude.

In considering the whole question of the rate of cooling it must be remembered that the thermal conductivity of the mould material is by no means the sole factor governing the rate of heat extraction. The flow of heat through a good conductor is mitigated to a great extent by the mould dressing and by the air gap between the mould faces and the solidified shell of the cast metal. The thermal characteristics of the liquid, solid and the solidifying metal also play an important part.

Junker Moulds — A compromise between these contradictory features is generally obtained by using water-cooled Junker type moulds in which the severe chilling effect is reduced by a suitable mould dressing. The rate of cooling in these moulds can also be effectively controlled by regulating the temperature and the rate of flow of the cooling water.

Mould Dressings

Extraction of heat from the mould is inseparably linked with mould dressings, the effect of which will now be considered.

Flaming and Inert Dressings — Mould dressings are nearly as many in number as foundries that use them, but they can all be divided into two broad classes, viz. flaming and inert. Each foundry favours a particular variation of one or other of these two. In brass foundries today flaming dressings are most widely used and the advantages and disadvantages of these dressings will be discussed in some detail.

Gases from Flaming Dressings — Reference has already been made to the entrapping of gases evolved by the combustion of the mould dressing. In fact, the source of the

majority of the trapped gas cavities is the mould dressing, and this contributes substantially to subsurface unsoundness. The turbulence maintained by the liberated gases reduces the crystal size as well as the temperature gradient in the mould — a condition not conducive to the formation of columnar crystals.

Grain Refinement Caused by Flaming Dressing — With a large volume of metal solidifying simultaneously into small equiaxed crystals, a widely distributed region is likely to be full of fine shrinkage cavities. In the case of 60/40 brass this effect is less severe by virtue of its short range of solidification which gives it a strong preference for columnar crystallization. It is doubtful whether the grain refining effect of a flaming dressing has any distinct advantage in brasses though it is essential for successful plastic deformation in cases of metals such as zinc which crystallize hexagonally. Although hot rolling properties of brass, especially in regard to edge-cracking, seem to be influenced by the grain size, orientation of crystals is probably the over-riding factor.

Functions of Mould Dressings — The most important functions of mould dressings are:

a) to protect the mould faces
b) to liberate a large volume of reducing gases
c) to prevent a too severe chilling effect
d) to prevent 'blowing' of ingot surface when cast iron moulds are used
e) to prevent solidification of metal splashes.

Reducing Gases from Flaming Dressing and Its Drawbacks — Of these functions, protection of the mould face is afforded and, though less efficiently, the chilling effect and the blowing of ingot surface are prevented by inert mould dressings. Evolution of reducing gases, however, is only possible by the complete or partial burning of an inflammable dressing. These reducing gases protect from oxidation the down-coming stream as well as the rising surface of liquid metal, oxide inclusions being one of the major causes of defective ingots. The flaming dressings also assist in remelting any splashes which have adhered to the mould faces. It has been further suggested that the agitation produced by combustion of the dressing helps by a 'scouring' effect the removal of dross and dirt and to prevent their inclusion in the ingot. These functions are so important that flaming dressings are generally preferred to inert dressings in spite of the fact that the former give rise to subsurface cavities and inhibit columnar crystallization. These defects in the ingot, however, are very real and are responsible for the rejection of a considerable proportion of rolled sheet, so that efforts have been made to overcome them.

The following two methods have been suggested as possible remedies:

(a) *Inert Dressing with Reducing Atmosphere* — To obtain a reducing atmosphere without the harmful effects of a flaming dressing, the mould is coated with an inert dressing and the reducing atmosphere is created in and over the mould by partially burning a carbonaceous gas such as coal gas.

(b) *Preference for Thicker Ingots* — Increased thickness of the ingot reduces the unsoundness caused by metal rising in the mould faster than the rate of combustion of the mould dressing, and hence the slab is cast as thick as rolling and other conditions permit. In the case of a thin chill cast ingot solidification is so rapid that no composition gradient can be set up. In a thicker slab solidification from the mould face inwards proceeds slowly enough to afford time for coring and grain growth. As a consequence, segregation is likely to take place, the residual liquid becoming richer and richer in zinc. The disadvantages, however, of segregation on a microscopic as well as macroscopic scale are minor as compared to the advantages already discussed and thicker ingots are, therefore, generally to be preferred.

Tilted Moulds

Efforts have been made to produce sound ingots by inclining the moulds at an angle to the pouring stream. The points in favour of this practice are the absence of the central region of unsoundness due to shrinkage porosity and all the good effects associated with more quiescent pouring.

Increased Entrapping of Gases — The gas bubbles, however, while rising to the surface are apt to be trapped against the upper face of the mould. This happens not only to the products of combustion of the mould dressing but also to the gases drawn in by the injector effect of the pouring stream which is not entirely absent. The compromise in this case has been made by reducing the angle of tilt to about 5° to the vertical. The first impingement is taken by the lower mould plate and pouring is quiet for about one-third of the height of the mould. Above this point the short distance through which the metal has to fall produces a less turbulence than would normally occur.

Reduced Angle of Tilt — The slight tilt does not significantly increase the entrapping of gas bubbles against the mould face. Any gas cavities are found to be concentrated on the upper surface of the ingot and heavy scalping of this surface substantially reduces 'spills' in the finished sheet. The impact of liquid metal against the mould plate causes local overheating and it is necessary to guard against the consequent danger of blowing by applying an adequate thickness of mould dressing. In the case of water-cooled copper moulds the belief that the impingement of the molten metal on the mould plates increases their wear does not appear to be correct.

Conclusion

In conclusion I should like to emphasize that these various factors are really too closely related to one another to be discussed separately. However, to make the presentation clearer, I have endeavoured to deal with them under separate heads and this has led to a certain amount of unavoidable repetition.

Acknowledgement

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References

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2. Cook, Maurice & Fletcher, N. F.

Discussion

MR. P. N. GANDHI (Indian Ordnance Factories)

Could you enlighten me as to what are the factors that produce blisters in rolled brass sheet ?

MR. M. M. RAY (Indian Copper Corporation, Ghatsila)

In my opinion a blister is the same as a deep-seated 'spill'. A gas cavity that is too deep-seated to tear the skin under stress may produce enough pressure to cause a bulge in the sheet giving rise to a blister. All factors producing gas cavities inside a brass ingot are, therefore, likely to originate blisters.