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EFFECT OF METAL CRYSTALLATION PERIOD ON PRODUCT QUALITY

***Abstract**: This article presents the results of various studies on the direct effect of fluidity on the quality of castings during the molding process of a liquid alloy, as well as on how ductility can be determined. Methods for measuring readability have also been suggested by many researchers. In addition, various problems encountered during the casting of low-alloy alloys and methods for their detection are considered in detail.*

***Key words**: mould, measurement, pour, solidification, formed, liquid, metal, alloys, fluidity, liquid, fluid life, experimental, temperature, vacuum.*

***Language**: English*

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Introduction

The pouring of molten metal into the mould is one of the critical steps in founding, since the behavior of the liquid and its subsequent solidification and cooling determine whether the cast shape will be properly formed, internally sound and free from defects. Researcher has advanced the view that the great majority of scrap castings acquire that status during the first few seconds of pouring. Few would disagree with that assessment.

The success of the pouring operation depends partly upon certain qualities of the metal itself, for example its composition and temperature, which influence flow, and partly upon properties and design of the mould, including the nature of the moulding material and the gating technique used to introduce the metal into the mould cavity. Whilst the metal is in the liquid state the foundry man is also concerned with forces acting upon the mould and with volume contraction occurring during cooling to the solidification temperature. These aspects will be considered separately, beginning with the flow properties of the liquid metal under foundry conditions.

FLUIDITY OF LIQUID METALS

Although other terms such as cast ability have been used to describe certain aspects of flow behavior, the term fluidity is most widely recognized. In the broad sense it can be defined as that quality of the liquid metal which enables it to flow through mould passages and to fill all the interstices of the mould, providing sharp outlines and faithful reproduction of design details. It follows that inadequate fluidity may be a factor in short run castings or in poor definition of surface features. It can at once be appreciated that fluidity is not a single physical property in the same sense as density or viscosity, but a complex characteristic related to behaviour under specific conditions within a foundry mould.

In considering the factors influencing flow, viscosity might be expected to predominate. Viscosity is defined as the force required to move a surface of unit area at unit velocity past an equivalent parallel surface at unit distance: it is thus a measure of the capacity of a liquid to transmit a dynamic stress in shear. When liquid is flowing in an enclosed passage, its viscosity will determine the extent to which the drag imposed by the passage wall is transmitted to the bulk of the liquid: it will therefore influence the rate of flow, which is found to bear a simple reciprocal relation to the viscosity. More directly related to the capacity of a liquid to flow under its own pressure head is the kinematic viscosity, that is the absolute viscosity divided by the density.

Further consideration indicates that these properties will not be decisive in determining the relative mould filling capacities of metals under foundry conditions. One of the fundamental characteristics of the liquid state is the ability of any liquid, however viscous, to conform in time to the shape of its container. This would occur rapidly in the case of liquid metal held at constant temperature since viscosities of liquid metals are very low. Under casting conditions failure to fill the mould cavity results not from high viscosity but from premature solidification. Thermal conditions and mode of solidification are thus the critical factors with respect to cessation of flow. The concept of fluidity takes these aspects into account.

THE MEASUREMENT OF FLUIDITY

Since fluidity cannot be assessed from individual physical properties, empirical tests have been devised to measure the overall characteristics. These are based on conditions analogous to the casting of metals in the foundry and measure fluidity as the total distance covered by molten metal in standardized systems of enclosed channels before cessation of flow. A further parameter in such tests is the flow time or *fluid life.*

Much of the earlier experimental work on fluidity was the subject of detailed reviews by many researchers. Early uses of a straight flow channel, with its disadvantages of excessive length and sensitivity to angle, were discontinued in favor of the spiral test, of which numerous variations have been used researchers. A typical spiral fluidity test is illustrated in Figure 1. Variations in the spiral test have been mainly concerned with the problem of obtaining truly standard conditions of flow. This problem has been approached through various designs of reservoir system to regulate the pressure head, and constant speed pouring devices to ensure a uniform rate of metal delivery to the system [1]. Since fluidity measurements are also sensitive to small changes in thermal properties and surface characteristics of the mould, graphite and metal moulds were used by some investigators in attempts to minimize variation in these factors.

The closest approach to complete standardization, however, is achieved in the vacuum fluidity test devised. Using this apparatus, illustrated in Figure 2, the metal flows through a smooth glass tube under suction induced by a partial vacuum; the pressure head is thus accurately known and the human factor in pouring eliminated [2].

These refinements of technique approach the ideal of excluding mould variables and measuring fluidity as a property of the metal alone. Using these and other techniques the major factors in fluidity were established.

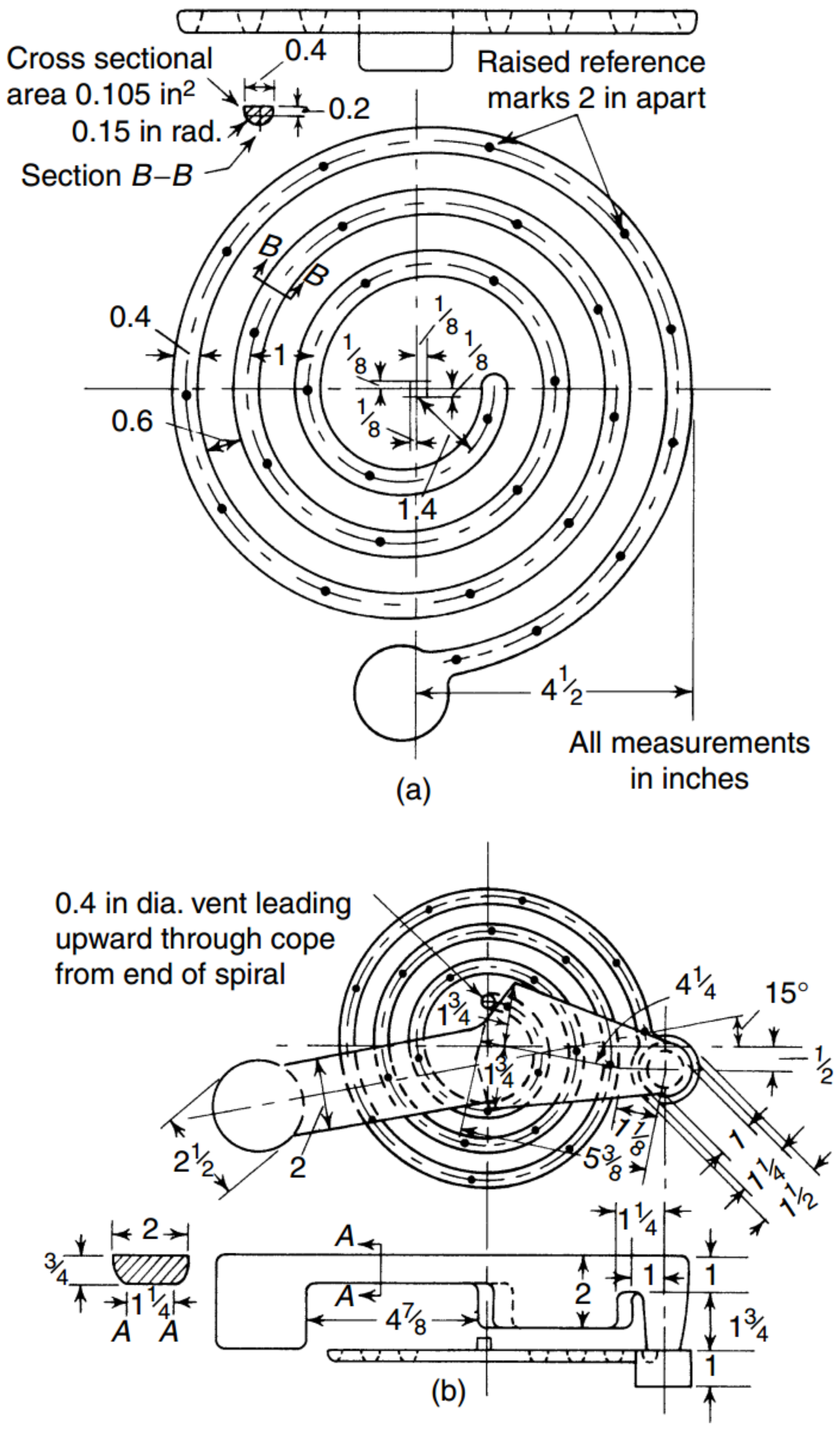


Figure 1. Spiral fluidity test casting. (a) Standard fluidity spiral, (b) arrangement of down-gate and pouring basin for standard fluidity spiral

VARIABLES INFLUENCING FLUIDITY

Temperature

The initial temperature of the metal is found to be the predominant factor, several investigators having shown the fluidity of a given alloy to be directly related to the superheat [3].

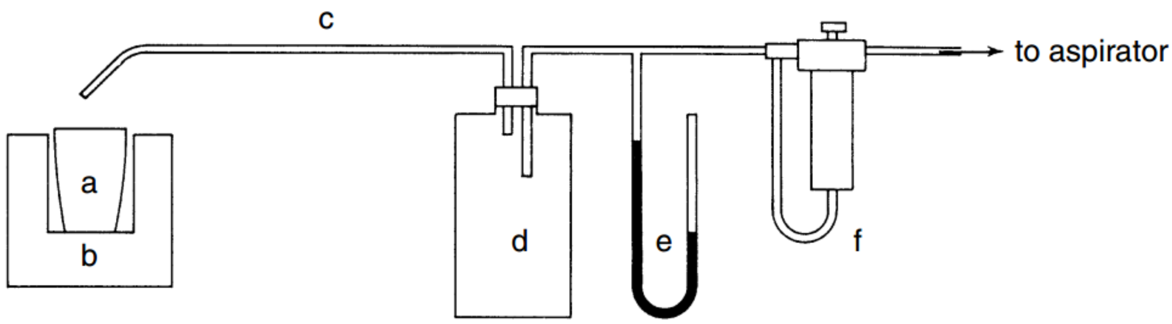


Figure 2. Vacuum fluidity test apparatus. (a) Crucible of metal; (b) electric resistance furnace; (c) fluidity test channel; (d) pressure reservoir; (e) manometer; (f) Cartesian manostat

This would be expected from the fundamental effect of solidification in controlling the duration of flow, since the superheat determines the quantity of heat to be dissipated before the onset of solidification. Typical fluidity–superheat relationships are illustrated in Figure 3.

Composition

The other major factor is metal composition. Valid comparisons of the fluidities of various alloys can only be made at constant superheat but under these conditions a marked relationship emerges between alloy constitution and fluidity.

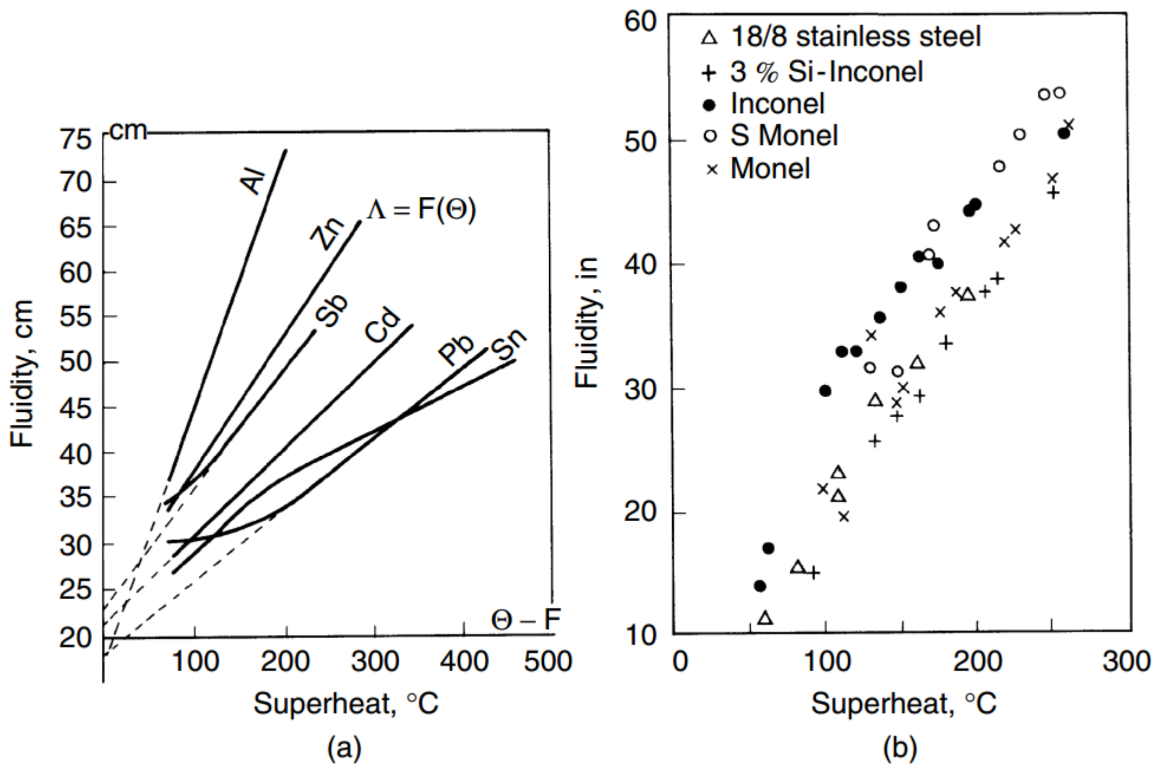


Figure 3. Influence of superheat on fluidity: (a) pure metals (b) alloys

High fluidity is commonly found to be associated with pure metals and with alloys of eutectic composition; alloys forming solid solutions, especially those with long freezing range, tend to show poor fluidity. Many researchers established an inverse relationship between fluidity and solidification range. This was later confirmed by other workers, for instance in their work with aluminum alloys. The relationship between composition and fluidity for one alloy system is illustrated in Figure 4.

Differences in the behavior of various types of alloy can be attributed primarily to their characteristic modes of freezing. In the case of alloys in which solidification occurs by progressive advance of a plane interface from the mould wall, flow can continue until the channel is finally choked; this is found to occur near to the point of entry. Pure metals solidify in this manner and show appreciable fluidity even when poured at the liquids temperature, flow continuing during evolution of the latent heat of crystallization [4].

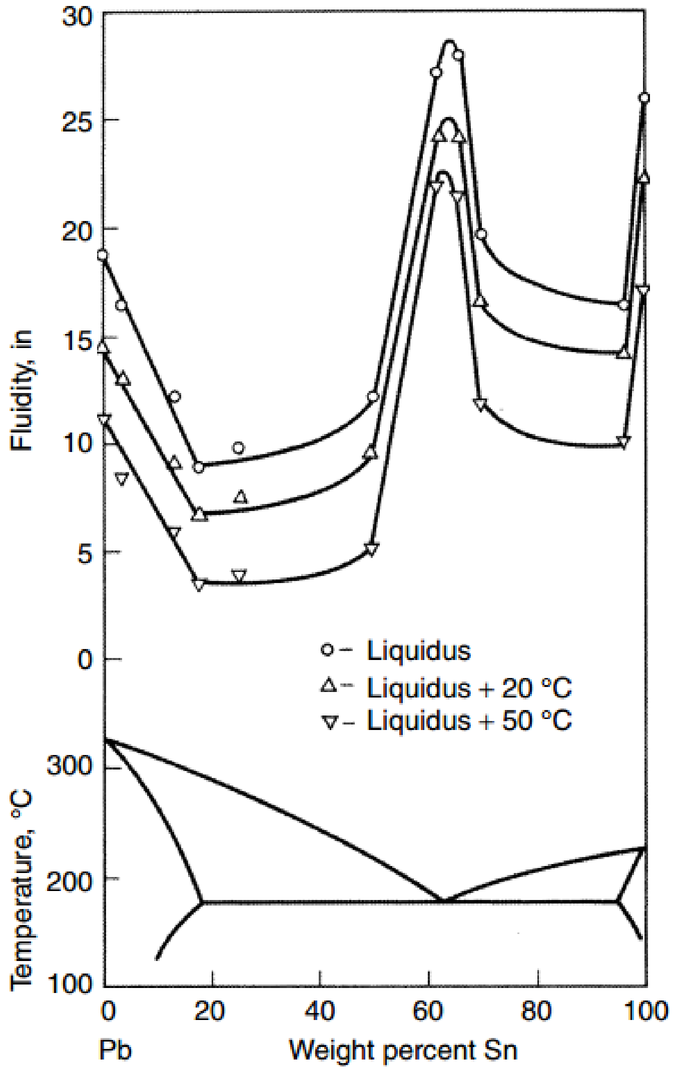


Figure 4. Relationship between composition and fluidity of lead–tin alloys

In alloys in which constitutional undercooling and other phenomena produce independent crystallization in the main mass of liquid, flow is arrested by the presence of free crystals in the liquid at the tip of the advancing stream. These alternative modes of freezing are illustrated in Figure 5, together with the intermediate situation involving a dendritic interface.

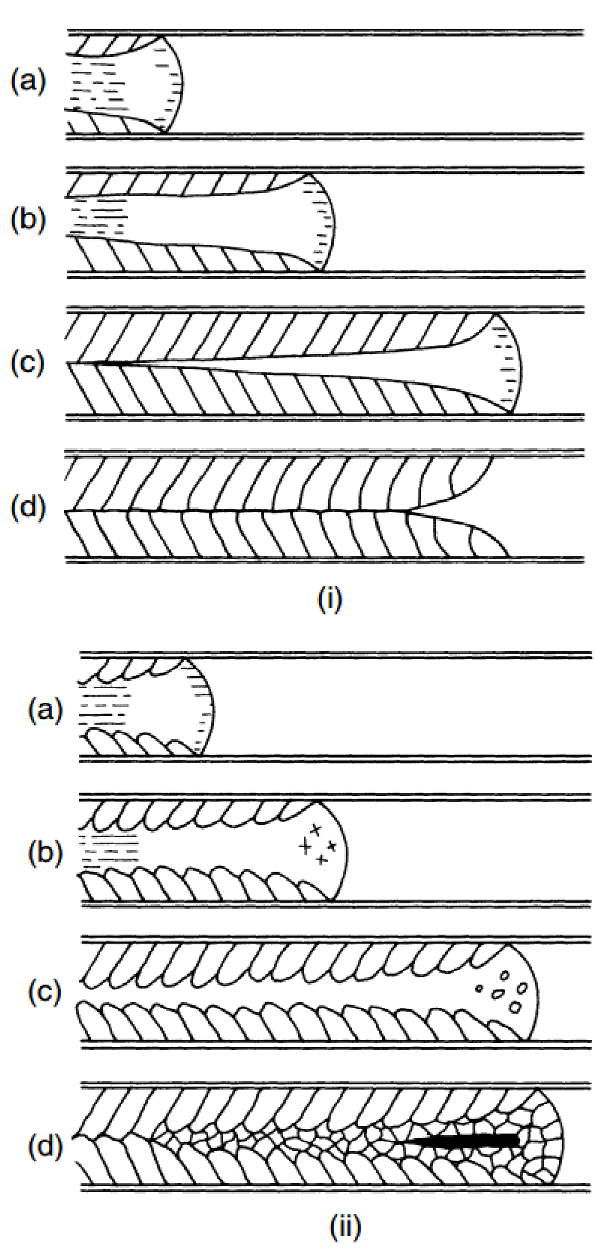
Although constitution and mode of freezing are of major significance in accounting for differences between alloys, fluidity comparisons depend upon additional factors. Even in the case of alloys exhibiting similar modes of freezing the fluidity–superheat relationships are not identical: the time to cool to the freezing temperature depends upon heat content and thermal properties rather than upon temperature alone. The distance of flow is thus affected by the volume specific heat, latent heat of fusion and thermal conductivity of the alloy. The influence of thermal properties is exemplified in the aluminum–silicon system, in which maximum fluidity does not occur at the eutectic composition as in many other alloy systems. In this case the hypereutectic alloys show greater fluidity due to the high heat of fusion of the primary silicon, although at least a part of this increase has been attributed to a shift to a non-equilibrium composition with a higher than normal silicon content [5].

Apart from basic composition, other characteristics affecting fluidity include the presence of dissolved gases and non-metallic inclusions in the liquid.

OTHER FACTORS IN FLUIDITY

Although the spiral and vacuum fluidity tests have achieved a high degree of refinement for fundamental work, other tests have been employed in attempts to obtain a more comprehensive representation of conditions in foundry moulds, especially those incorporating a wide range of passage sizes. Researchers used the vacuum test to investigate the flow of molten tin in channels of various diameters down to 3 mm and established a simple relationship between channel diameter and observed fluidity, a finding subsequently extended, down to 0.5 mm channels in various alloys. It is not clear, however, to what extent such relationships would hold good in extremely small mould passages for alloys and conditions susceptible to the growth of surface films. Under these circumstances, which are relevant to the reproduction of sharp corners and fine detail, surface phenomena must assume greater significance. The importance of surface tension with respect to flow in small passages was demonstrated, who found a direct relationship between surface tension and the pressure required to produce penetration of liquid metals into surface voids in sand compacts.

The distinction between this aspect of fluidity and that measured, for example, by the spiral test was drawn by researchers, who expressed



(i) Plane interface:
(a) Liquid enters flow channel and columnar grain formation with smooth liquid–solid interface begins,
(b) Columnar grains continue growing in upstream direction,
(c) Choking-off occurs,
(d) Remainder of casting solidifies with rapid grain growth and formation of shrinkage pipe;

(ii) Jagged interface:
(a) Liquid enters flow channel and columnar grain formation with jagged liquid–solid interface begins,
(b) Columnar grains continue to grow, fine grains nucleating at tip,
(c) Choking-off occurs at entrance to flow channel, though cross-section is not completely solid,
(d) Remainder of casting solidifies with equi-axed grains and formation of shrinkage cavity near tip;

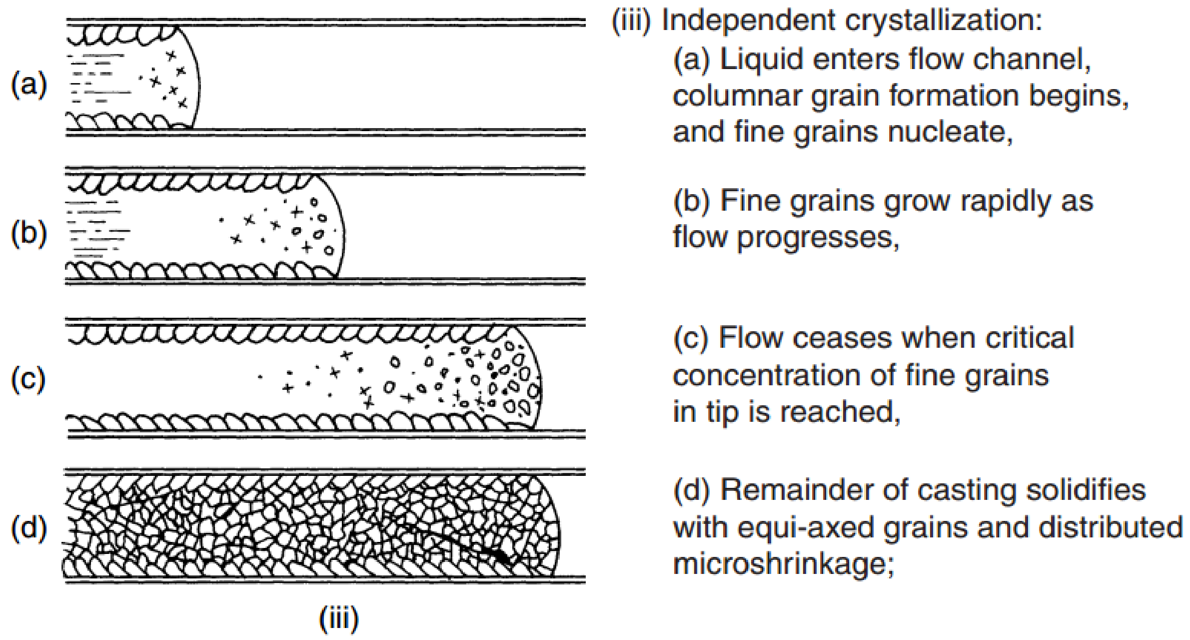


Figure 5. Modes of solidification in flow channel.

the capability of the metal to conform closely to the mould surface as casting quality, determined by making a separate measurement of the length of spiral perfectly formed and expressing this as a percentage of total length. Comparisons of values for casting quality and fluidity revealed significant differences between the two according to alloy type.

There is wide agreement that the surface tension factor becomes significant in the channel size range 0.5–5 mm. Under the conditions prevailing in casting, the surface tension of the metal itself, which may have a value as high as 1.5 N/m, is modified by the influence of the surface films existing on metals in normal atmospheres. Evidence of these films has long been available: in some cases, as in the aluminum bronzes, they may be visible, whilst in other cases they may be detected by their marked effect upon the emissivity of the metal surface. Liquid aluminum for instance, carries surface films which increase surface tension by a factor of three, whilst the reduced fluidity of steels containing aluminum has also been explained by the presence of an alumina film, preferentially formed because of the high oxygen affinity of the element; titanium produces similar oxide films on stabilized stainless steels and nickel base alloys. Chromium is yet another element known to produce strong surface films; Researchers used this fact in partial explanation of poor casting quality in some of their alloys. Researchers made direct determinations of the influence of surface films on the surface tension of liquid cast iron and found increases of up to 0.5 N/m, considered high enough to be significant with respect to flow in small passages [6-9].

The presence of a restrictive oxide film may mean, therefore, that the film rather than the mould will determine the final outline of the casting in confined corners. Alloys carrying the films are particularly susceptible to poor definition and to the formation of surface laps and wrinkles: they therefore need particular care in gating. The effect of oxide films is not, however, universally restrictive. A liquid film may exert the opposite effect and the influence of phosphorus in increasing the fluidity of copper alloys, for example, may be partly explained by such a film.

Flow behavior in very narrow channels has been incorporated in certain further techniques for fluidity measurement. In multiple channel systems, wider representation of casting conditions is sought by integrating flow distances obtained in channels of greatly differing thicknesses. Two such tests are illustrated in Figure 6. In a further test designed by researchers a mould cavity with a large surface area to volume ratio is used to provide an analogous mould filling problem to that encountered in investment castings of thin section. In this case the area of specimen produced is the test criterion. These types of test provide a wide range of conditions for the exercise of the solidification and surface influences upon flow distance. They thus offer some parallel with a similar range of actual mould conditions.

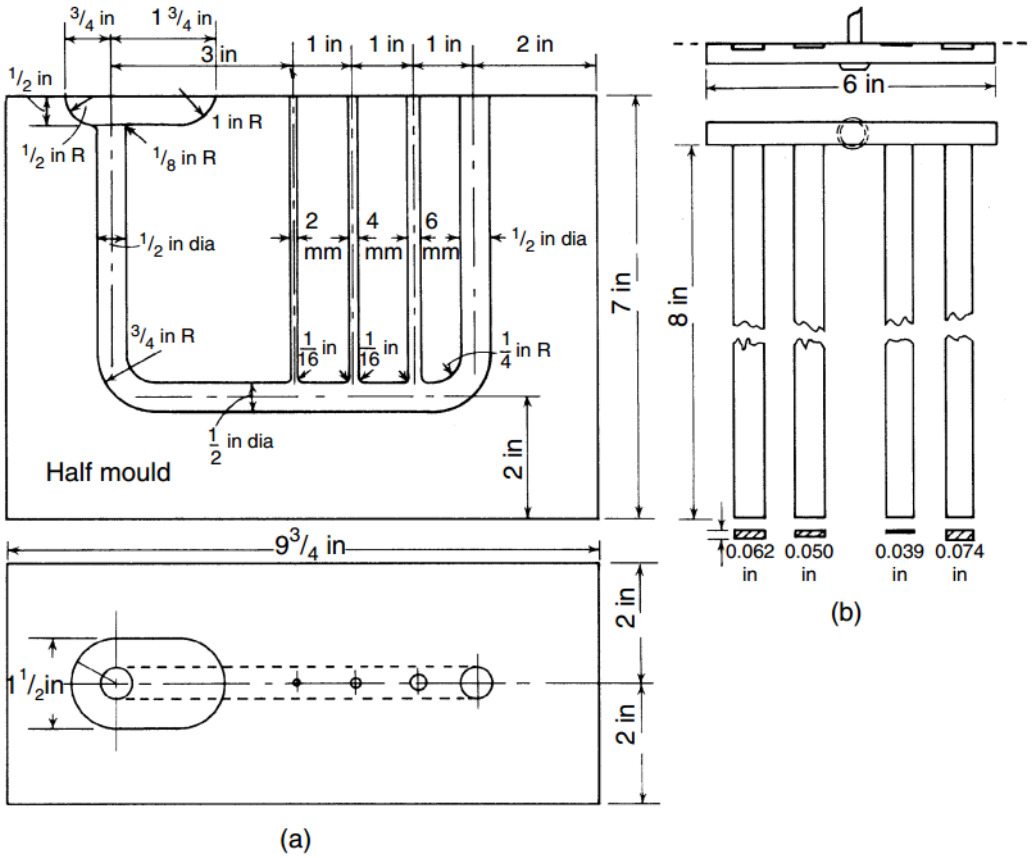


Figure 6. Multiple channel fluidity test castings. (a) test

Researchers subsequently carried out a close analysis and interpretation of the large body of fluidity results obtained by earlier investigators: it was concluded that the findings from the widely varying test methods employed could all be reconciled and brought to a common basis in terms of the fundamental influences on flow. Also included was a discussion of the separate but significant concept of continuous fluidity, representing flow behavior through short channel conditions, in which flow continues indefinitely without the arrest which determines normal fluidity test results.

CONCLUSION

Fluidity is one of the most important properties of alloys. Therefore, the fluidity of the alloy is important to obtain a quality cast. From the results of several tests mentioned above, we can know the limit of readability. We first used a spiral test to check the fluidity of the alloy. This means that in the process, air resistance to fluidity and a certain amount of resistance created by the friction of the liquid alloy against the surface of the helix have been investigated. Units of measurement are placed at a certain distance in the spiral, and from these measurements we can determine the yield strength of the alloy. In the next stage, the yield strength of the alloy was determined by means of a vacuum apparatus. Thus, two studies have shown that it is easy to determine the yield strength of an alloy by vacuum and that the degree of accuracy is high. In addition, the yield strength is directly related to the temperature of the alloy, and it has been observed that the yield strength increases with increasing temperature, and this experiment was comprehensively tested by testing different alloys. Currently, the most volatile metal is gray cast iron. Due to the low fluidity of steel, experiments have shown that up to 1% aluminum alloy should be added to the alloy to improve its fluidity.

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