

# Casting Fluidity of Metals and Alloys

Sanjeev Saxena<sup>1</sup>, Prof. Puspendra Kumar Sharma<sup>2</sup>

P.G. Student, Department of Mechanical Engineering, NIIST, Bhopal, MP, India<sup>1</sup>

HOD, Department of Mechanical Engineering, NIIST, Bhopal, MP, India<sup>2</sup>

**ABSTRACT:** Casting fluidity of metals and alloys is of vital importance to foundry men to produce overall soundness and surface features of the casting.

The filling of moulds of intricate casting design, particularly those which include thin casting sections, is usually difficult if the liquid metal has poor fluidity and casting defects such as shortruns or misruns are likely to occur. Actually fluidity of a liquid metal or alloy is a complex characteristics affected by a large number of variables. It is usually controlled by the rate and mode of solidification and the normal method of increasing the fluidity of given alloy in foundry is to increase the casting superheat for the production of premium quality casting with increased mechanical properties pouring temperature.

The use of such mould coating not only governs the heat transfer rate at the metal mould interface and hence the length of the metal flow, but it will also affect significantly the cast structures of the casting made.

**KEYWORDS:** Castable fluid, fluidity test mould, handling equipment, thermal instruments.

## I. INTRODUCTION

Casting fluidity of metals and alloys is of vital importance to foundry men as it affects the overall soundness and surface features of the casting produced.

The testing of the casting fluidity not only helps in choosing an alloy composition with best fluidity for a particular application but also assists in quality control and minimizing casting rejections. The filling of mould of intricate casting design, particularly those which include thin casting sections, is usually difficult if the liquid metal has poor fluidity and casting defects such as shortruns or misruns are likely to occur.

Fluidity of a liquid metal or alloy is a complex characteristics affected by a large Number of variables. It is usually controlled by the rate and mode of solidification and the normal method of increasing the fluidity of a given alloy in foundry is to increase the casting superheat. However, this procedure has a limitation in that, for production of premium quality casting with increased mechanical properties pouring temperature used should be as low as possible. Attempts have, therefore been made in recent past year to increase fluidity of aluminum alloys by use of different kinds of mould coating.

A number of mould coating materials have been tried and it has been generally found that such mould coating increased length of the time over which the flow of metal occurred by reducing the rate of solidification. However, limited information is available in the open literature about the composition and other details of the mould coating used and there is also controversy regarding the mechanism by which the increased length of the flow of metal occurred.

The present investigations therefore, have been undertaken to study systematically and simultaneously effect of mould coatings both on fluidity as well as the cast structure of aluminium casting using a number of alternative mould coating material by pouring at a constant melt superheat and evaluate their performance. The dissertation has been divided into five chapters. The first chapter presents a brief introduction of the investigations undertaken high-lighting the importance and relevance of the work undertaken. The second chapter deals with the survey of the pertinent literature on the effect of mould coatings.

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## II. FLUIDITY OF METAL AND ALLOYS

The pouring of molten metal into the mould and its subsequent filling are quite critical step in metal casting, since the behavior of the liquid metal and its freezing determine whether the cast shape will be properly formed and casting will be internally sound and free from defects. The fluidity of cast metal and alloys is thus of great importance to the foundry men as it governs the overall soundness and surface features of the cast products. The casting fluidity of a new or unfamiliar alloy composition should be determined so that the person responsible for casting operations can choose the alloy with best fluidity from among several equivalent compositions available for a specific application. This is of particular importance in foundries where thin sections and intricate shapes are cast. Fluidity testing on the shop floor can thus help in minimizing casting defects such as short runs or misruns and thereby the casting rejections.

### 1. FLUIDITY CONCEPT AND TERMINOLOGY

It has been generally in foundry practice that in filling mould of intricate design, particularly those which include thin section, some alloys fill the mould cavity and reproduce its details in the finished casting better than the other alloys. The particular property of a liquid metal or alloys has been termed by the foundry men as casting fluidity or just simple fluidity. This quality of the liquid is not a single physical but a complex characteristic affected by a large number of variable. It is, therefore described as 'Fluid life', 'Flow ability', 'Run ability', 'casting fluidity', or 'Cast ability', before such freezing may occur as would offer an obstruction to its further flow. For metallurgical application, fluidity cannot be taken as the reciprocal of the co-efficient of the viscosity as defined by physicists rather, it is a complex quality which depends on various metal and mould related properties of the metal.

### 2. FACTORS AFFECTING FLUIDITY:

A large number of variables affect the casting fluidity. The metal properties which usually influence fluidity are viscosity, surface tension, the character of surface oxide film ,inclusion content, manner in which particular alloy solidifies, superheat ,composition, specific weight and melting point. Hence all these variables may be grouped in two broad categories-

1. Metal related variables
2. Mould related variables.

#### 2.1 Effect of Metal Related Variables:

##### 2.1.1 Viscosity:

The coefficient of viscosity of a physical property of a liquid metal which determines its flow characteristics. It is affected by the temperature, presence of impurities, inclusions and composition of the melt. The higher the viscosity, the lower will be fluidity of the liquid metal.

##### 2.1.2 Surface Tension:

The surface tension acting at the mould-metal interface affects the mould surface wetting properties of the liquid metal. If the metal doesn't wet the mould, it will experience more fractional force during its flow through mould channels and hence the fluidity of the metal will be reduced.

##### 2.1.3 Superheat:

It is the temperature, by which the liquid metal is heated above the liquids temperature. This effects the fluidity of metal in various ways. By increasing superheat, viscosity is reduced and hence fluidity is increased. Secondly, a higher superheat increased the fluid life. As a consequences the metal can flow for a longer duration of time.

##### 2.1.4 Mechanism of Solidification:

Pure metals and short freezing range alloy solidify in a skin formation manner without affecting the flow of the liquid metal. On the other hand, alloys with large solidification range solidify in pasty manner and this hinder the flow of liquid (as the flow is a tested by the presence of free crystals in the liquid).

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## 2.1.5 Oxide film and Nonmetallic Inclusion Formation:

Oxide formation affects the surface tension and decreases the mould melting ability of the liquid metal and hence, the fluidity is reduced. Similarly the formation of non-metallic inclusion it was hung into the melt during the pouring puts drag on the liquid metal to flow and thus reduces the fluidity.

## 2.1.6 Specific Weight:

If specific weight of a liquid metal is more, metallostatic pressure exerted by it will be more. This increases the velocity of the liquid metal with which enters the mould and thus increases the fluidity of metal.

## 2.1.7 Melting Point (Or Temperature of Alloy Solidification):

The higher the melting temperature of the metal, the more intensive heat exchange will take place between the metal and the mould and thus, the heat extracted per unit time is increased. This will reduce the time for the metal to remain liquid and flow and hence, the fluidity of metal decreases, similarly, higher temperature of solidification of alloy will also lower the fluidity.

## 2.2 Effect of Mould Related Variables:

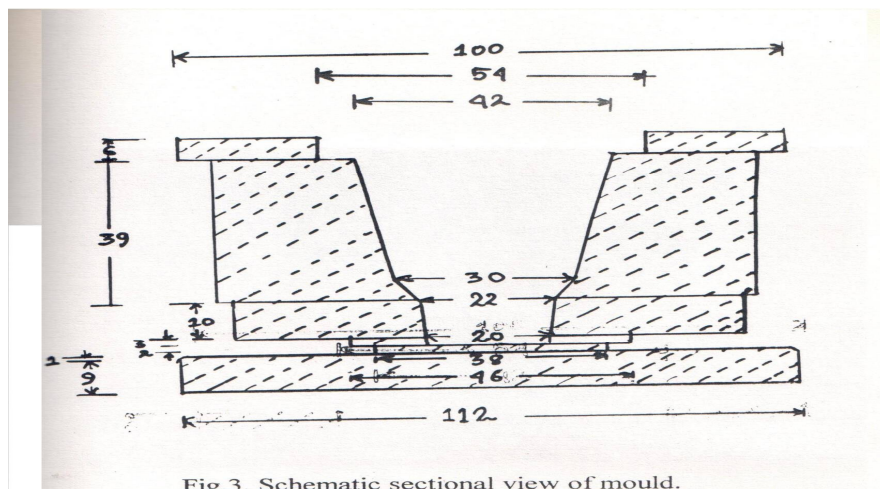


Fig.3. Schematic sectional view of mould.

### 2.2.1 Thermal physical properties of mould:

As the liquid metal is poured into a mould, mould will extract heat from the liquid. If the conductivity of the mould material is high, the rate of heat extraction by the mould will be high. This will result in lessening of the time for the liquid to be in mobile state and hence, lower fluidity. Therefore, the fluidity will be lower in a metallic mould, than in a sand mould.

### 2.2.2 Mould Temperature:

When the liquid metal is poured into a mould at lower temperature, the chilling effect will be more, when the mould is at higher temperature, the liquid remain in mobile state for a longer time. Hence, fluidity in a hot mould is higher than in a cold mould.

### 2.2.3 Gas permeability:

Gases produced during casting pre-existing air in the mould etc. Should escape with ease when metal is poured into the mould. Otherwise they can obstruct the flow of liquid metal. If the mould is permeable enough this retarding effect is reduced and metal attains higher fluidity. Hence sand mould casting gives higher fluidity than permanent mould casting.

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### 2.2.4 Metalostatic Pressure:

The increased higher of the spree will cause increase in the pressure on metal entering a mould. This will increase the fluidity of the mould. However this increasing effect is not to a greater extent.

### 2.2.5 Surface Characteristics of Mould:

A rough of the mould hinder the metal flow by increased frictional force .Hence ,a fine grained or smooth surface mould or the use of a mould casting improves the fluidity of the liquid metal. Beside the effect of mould coating in improving the surface finish of the mould, use of such coatings will also affect the heat transfer across the metal-mould interface.

## III. TECHNIQUES OF FLUIDITY MEASUREMENT

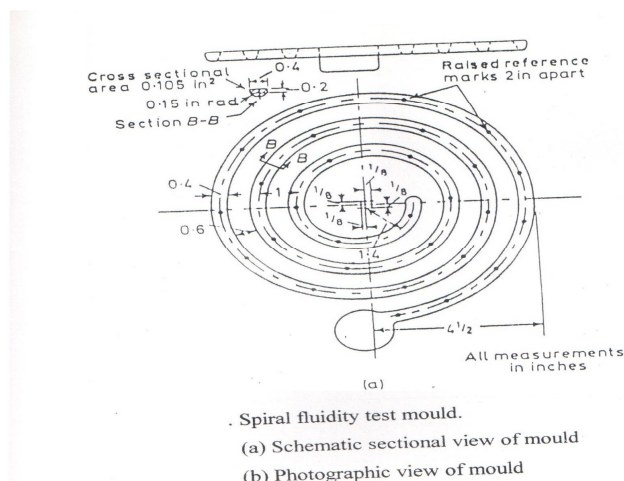
Some of the common and important methods of fluidity testing are

1. Spiral fluidity test.
2. Strip fluidity test
3. Vacuum fluidity test.

### 3.1 Spiral Fluidity Test:

The most common fluidity test used in foundries is the spiral fluidity test. In this method, the liquid metal is poured in a mould forming a long thin spiral and the length into which metal is able to run is taken as a measure of the fluidity. Spiral channels of cross section of 1/7 inch, 1/12 inch.

This test is simple and easy to carry out in foundry. It is, however, difficult to pour the metal into the mould at a standard flow rate it is also difficult to keep the casting temperature during pouring and there may be small variation sand mould used.



### 3.2 Strip Fluidity Test:

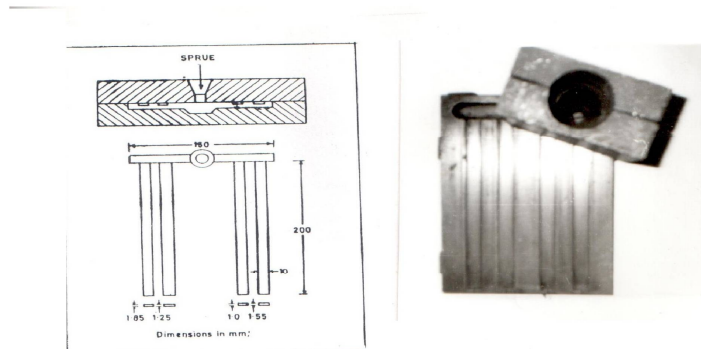
This test provides a true and wider representation of actual casting conditions and is therefore, also popularly called as 'Casting fluidity test' since it measures the ability of the metal to fill a mould of different cross section. In this test, the drag portion of the mould has four strip of equal length, equal width and of different thickness. These strips are fed by a perpendicular spree on the down runner which is also molded in the drag half. The length of the metal flow in all strip mould summed together or individual strip mould is taken as a measure of casting fluidity.

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Strip fluidity test mould.

(a) Schematic sectional view of mould

(b) Photographic view of mould

### 3.3 Vacuum Fluidity Test:

The difficulties of standardization in the above fluidity tests are overcome in the vacuum fluidity test in which metal is drawn up a long, thin, horizontal steel or fused silica glass tube by vacuum. In this case, consistent, pouring conditions are maintained during the test and the liquid metal is held in a carefully temperature controlled bath. The metal is sucked into the tube from a vertical ceramic central tube.

## IV. CAST STRUCTURE OF METALS AND ALLOYS

The structure of a casting is of great importance, since many properties of the cast product especially mechanical properties, depend on grain shape and grain size.

### 4.1 FORMATION OF PRIMARY GRAIN STRUCTURES IN CAST PRODUCTS:

There are three distinct zones of primary grain structures which can be formed on freezing as shown-

1. **The Chill Zone:** A boundary or peripheral layer, adjacent to the mould wall, of small equiaxed crystals with random orientation.
2. **The Columnar Zone:** A band of elongated crystals aligned parallel to the directions of heat flow.
3. **The Equiaxed Zone:** A central region of large equiaxed crystals randomly oriented.

## V. FACTORS AFFECTING FORMATION

For all but a few specialized applications fine grained equiaxed structures are required in castings and ingots as these structures are isotropic and their properties are markedly superior. To develop these structures requires the suppression of columnar growth and this can be achieved by encouraging conditions favorable to the formation of the equiaxed nuclei. As such, the following factors which govern the formation of the extent of columnar and equiaxed zones can be judiciously controlled.

1. Pouring Temperature:
2. Alloy Composition:
3. Fluid Flow Conditions
4. Addition of Inoculants
5. Use of Dynamic Nucleation Processes
6. Size of Ingot

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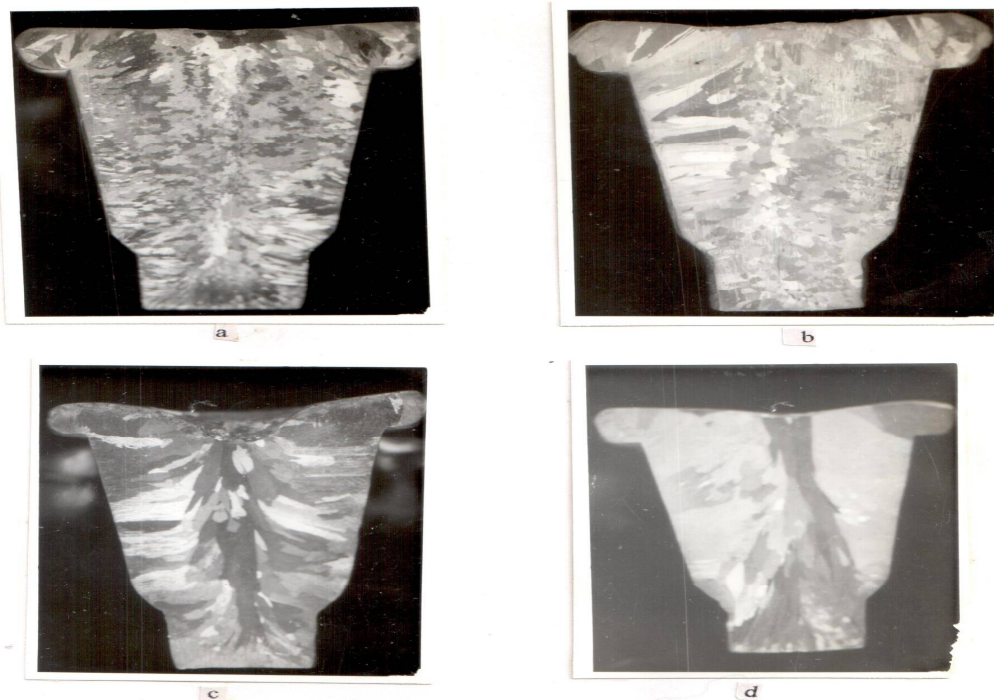
### VI. AIMS AND OBJECTIVES OF THE PRESENT INVESTIGATIONS

It is obvious from the above discussion of researches carried out that a few attempts have been made to improve the fluidity of metals and alloys using different kinds of mould coating materials. However, limited information is available in the open literature about the compositions and other details of the mould coating used. But many of such above studies have either limited to examine only the effect of mould coating on fluidity or on the mode of solidification of the metals used.

### VII. EXPERIMENTAL WORK

They include:

- Silica based mould wash
- Alumina based mould wash
- Silica based mould wash containing 10wt% of hexachloroethane
- Alumina based mould wash containing 10wt% of hexachloroethane
- Oxy-acetylene flame carbon



As-cast microstructures of aluminium ingot casting.

- (a) Test casting without any mould coating
- (b) Test casting with alumina mould coating
- (c) Test casting with silica mould coating
- (d) Test casting with flame carbon mould coating

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(e) Test casting with silica+10wt% hexachloroethane  
mould coating

(f) Test casting with alumina +10wt% hexachloroethane  
mould coating

### 7.1 MATERIALS USED:

1. Metal –commercial purity aluminium (98.5%) was used in all the experiments as the casting materials.
2. Silica based mould wash containing a mixture of -150 mesh size silica sand and water in the ratio of 60:40.
3. Alumina based mould wash containing of a mixture of -150 mesh size alumina powder and water in the ratio of 60:40.
4. Silica based mould wash containing 10 wt. % of -150 mesh size hexachloroethane powder.
5. Alumina based mould wash containing 10 wt. % of -150 mesh size hexachloroethane powder.
6. Oxy-acetylene flame carbon produced directly from the oxy-acetylene gas torch.

### 7.2 EQUIPMENTS USED:

1. Mould
2. Melting and Preheating Set-up
3. Spiral Fluidity Test Mould
4. Strip Fluidity Test Mould

## VIII. EXPERIMENTAL PROCEDURE

As outlined in the previous section of the experimental plan, commercial purity aluminium was used as the casting material. Before the commencement of the melting and casting, each of the mould coating was prepared using its various ingredients such as alumina or silica powder, water, hexachloroethane, in the desired proportions and this coating was applied carefully with the help of a brush over the inner surface of the steel mould coating of 2-3 mm thickness could be achieved. The mould were then dried in air at room temperature for 24 hours. Before pouring the aluminium melt, the steel mould along with fluidity test mould were preheated to 100°C in the preheating furnace. After the mould were dried and preheated, commercial purity aluminium was melted in the electric resistance furnace by

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adding small pieces of aluminium in a clay – graphite crucible under a cover of commercial flux. After skimming, the melt was poured into the preheated fluidity test mould followed by immediately pouring into preheated casting mould at required melt superheat of 50 °c.

This procedure was repeated for each of the different kinds of the mould coatings used.

After the metal was solidified in both types of fluidity test mould, the length of the flow of metal was measured in each of the mould. In case of the strip fluidity mould, both the individual strip lengths as well as the sum of all the four strip lengths were determined as the function of different coatings used.

## IX. RESULTS AND DISCUSSION

### EFFECT OF MOULD COATING ON CASTING FLUIDITY:

The photographic view of the effect of alternative mould coatings and that of no mould coating used on spiral fluidity of aluminium melt. The same effect is expressed when measured as a length of the metal flow and shown in the form of the bar diagrams against each of the mould coating used. It is obvious that spiral fluidity increases in all cases of mould coating on reducing the heat transfer through the mould during freezing of the melt. In this context, silica mould coating produces greater fluidity than alumina coating as the silica has lower thermal conductivity than alumina. Similarly, the flame carbon deposited from the oxy-acetylene torch over the steel mould also gives highest value of fluidity as compared to the above two since an amorphous carbon is formed and this coating behaves like an insulating material and hence, provides the maximum obstruction to the heat loss by conduction across the metal-mould interface.

This kind of increase in fluidity can be further noticed from figs, followed by the bar diagram representation in fig of the strip fluidity test substantiating the observations made in case of spiral fluidity test. Both the individual as well as the total length of metal flow taken place in strip channels provide a better representation of the casting conditions and it can be seen that the length of the metal flow increases with increase in the strip channel thickness irrespective of the mould coating used. Here, again the flame carbon mould coating provides

#### - Photographic view of spiral fluidity test mould

- (a) Test casting without any mould coating
- (b) Test casting with alumina mould coating
- (c) Test casting with silica mould coating
- (d) Test casting with flame carbon mould coating
- (e) Test casting with silica +10wt% hexachloroethane mould coating
- (f) Test casting with alumina +10wt% hexachloroethane mould coating

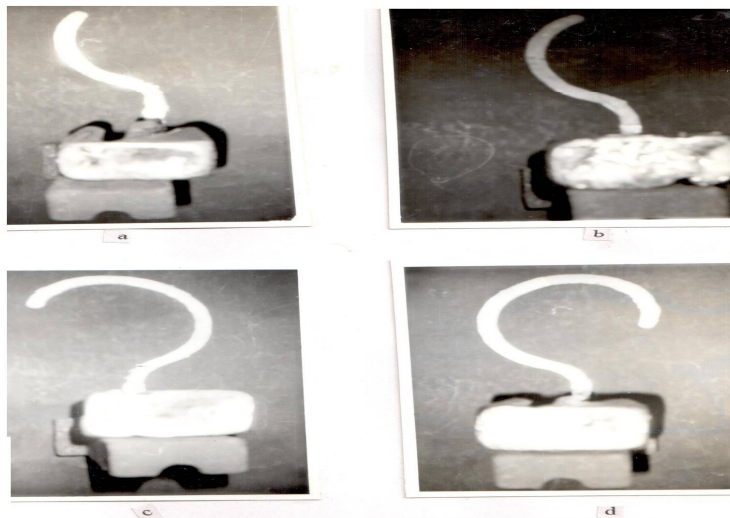


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Photographic view of spiral fluidity test  
(a) Test casting without any mould coating  
(b) Test casting with alumina mould coating  
(c) Test casting with silica mould coating  
(d) Test casting with flame carbon mould coating



(e) Test casting with silica+10wt% hexachloroethane  
mould coating  
(f) Test casting with alumina +10wt% hexachloroethane

### - Photographic view of strip fluidity test mould

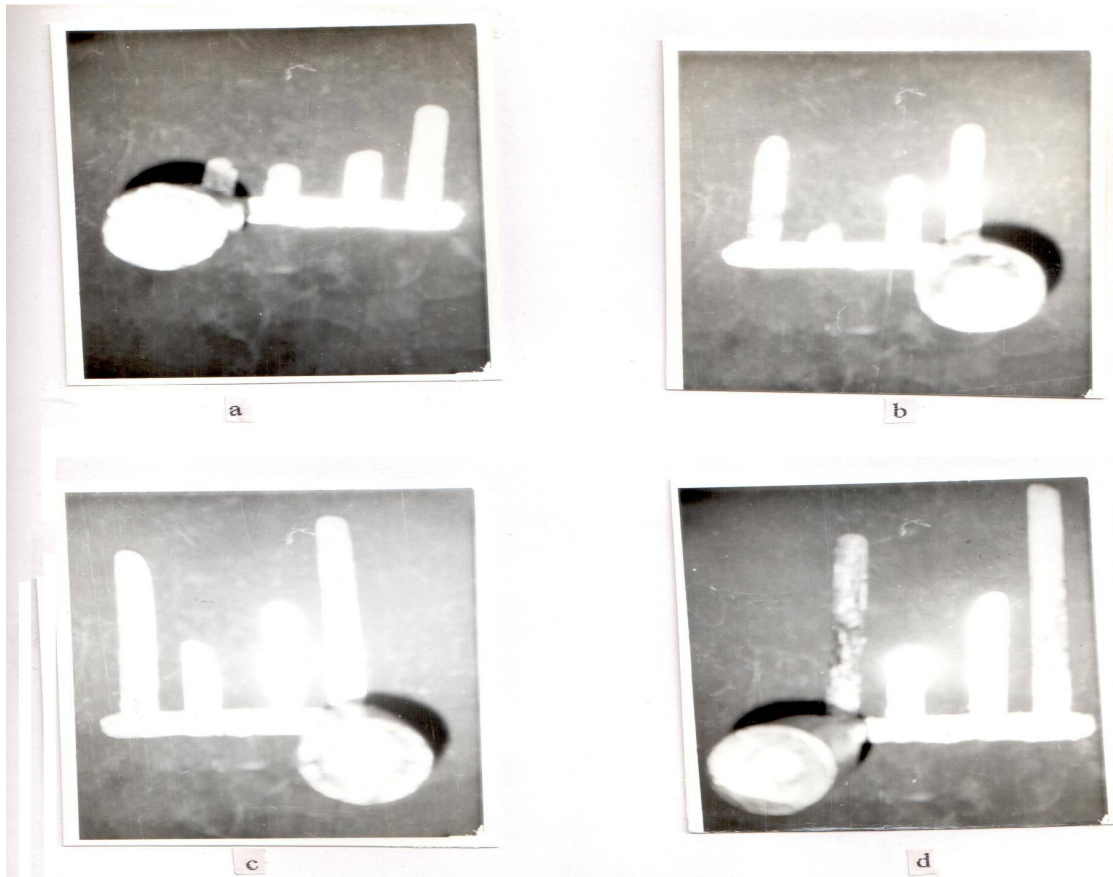
- (a) Test casting without any mould coating
- (b) Test casting with alumina mould coating
- (c) Test casting with silica mould coating
- (d) Test casting with flame carbon mould coating
- (e) Test casting with silica +10wt% hexachloroethane mould coating
- (f) Test casting with alumina +10wt% hexachloroethane mould coating

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Photographic view of strip fluidity test

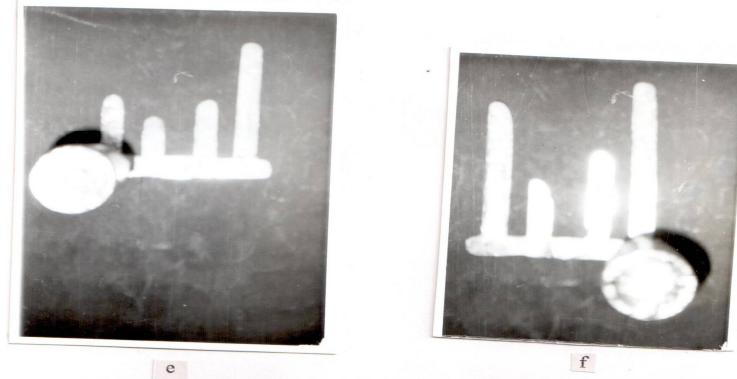
- (a) Test casting without any mould coating
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- (d) Test casting with flame carbon mould coating

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(e) Test casting with silica+10wt% hexachloroethane  
mould coating  
(f) Test casting with alumina +10wt% hexachloroethane  
mould coating

Maximum increase in fluidity than silica and mould coating depending on their effects on heat transfer, as explained above. However, it is interesting to note that addition of 10% hexachloroethane in both the silica and alumina based mould coating further increases the fluidity of the metal in cases of both the fluidity test. This may be due to the formation of a gas (formed by vaporizing hexachloroethane) partitioned at the metal/mould interface which has comparatively much less thermal conductivity (almost about one-tenth) 10 than that of silica and alumina. Hence, in both the cases of silica and alumina mould coatings, an additional layer of low thermal conductivity gas formation further checks the heat transfer across the metal-mould interface and thus increases the fluidity of the metal. It may be further noted that alumina based mould coating containing 10% hexachloroethane gives higher fluidity (in terms of both spiral and strip fluidity) than silica based mould coating containing similar amount of hexachloroethane.

It may be attributed to the behavior of alumina mould coating working as a more effective substrate over which nucleation also took place than silica. It has been reported<sup>38</sup> that the wettability of alumina by aluminium melt is better than other materials (like silica) and if there is some interaction between the hexachloroethane and alumina to form additional gaseous product (as pointed out above to explain the effect of increased fluidity by alumina mould coating containing hexachloroethane), then both the above factors will help in promoting nucleation by the alumina coated mould. However, such cases of grain refinement did not take place when flame carbon was used which could also have produced gas at the metal-mould interface, as explained earlier.

### X. CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

#### CONCLUSIONS:

The following conclusions can be drawn from the present investigations:

1. The use of alternative mould coatings substantially improves the fluidity of aluminium by reducing the heat transfer from the metal and hence, increasing the length of the flow.
2. It is possible to increase the casting fluidity of aluminium (to a maximum of 90 to 130%) by choosing a suitable mould coating material. Such increase in fluidity of the metal is very significant as this is obtained without increasing the melt superheat.
3. Each of the spiral fluidity and strip fluidity of the metal further increases as the mould coating is changed from alumina to silica and from silica to flame carbon due to increased insulating effect of the mould coating formed at the metal/mould interface.

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4. Use of 10 wt. % hexachloroethane in both the silica and alumina based mould wash further enhances the fluidity due to formation of gas at the metal/mould interface.
5. The use of alternative mould coatings also significantly affects the cast structure of the aluminium ingot. The cast structure can be altered from almost totally columnar to totally equiaxed by use of a suitable mould coating.

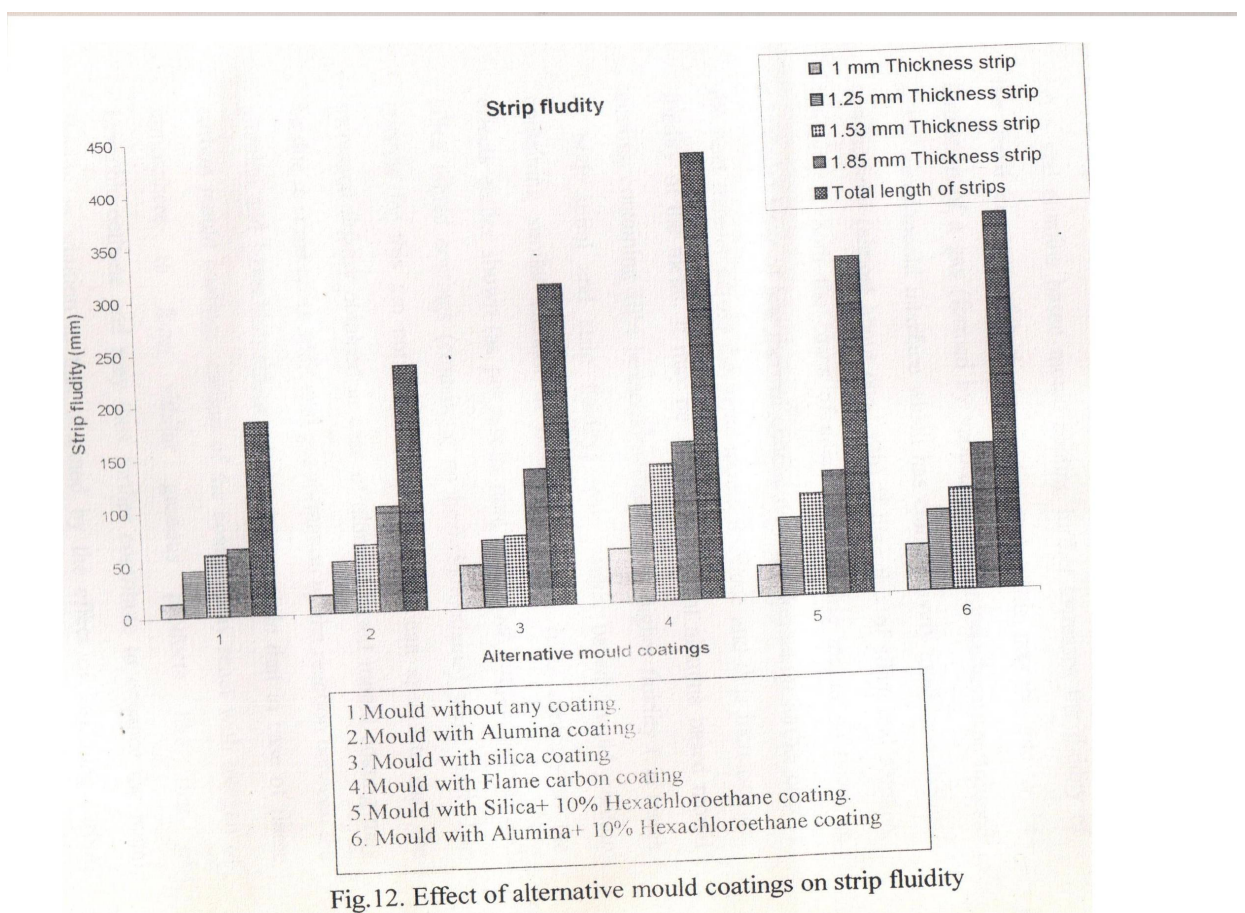


Fig.12. Effect of alternative mould coatings on strip fluidity

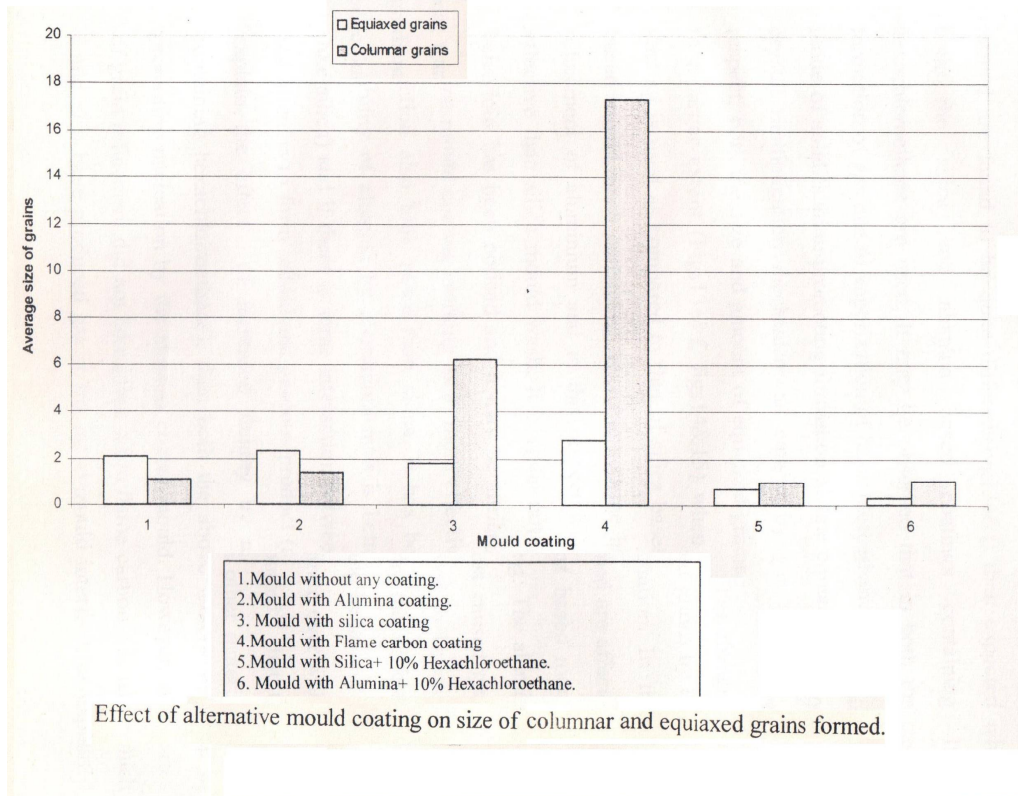
6. Both the amount and size of the columnar grains further increase as the mould coating from alumina to silica and from silica to flame carbon.

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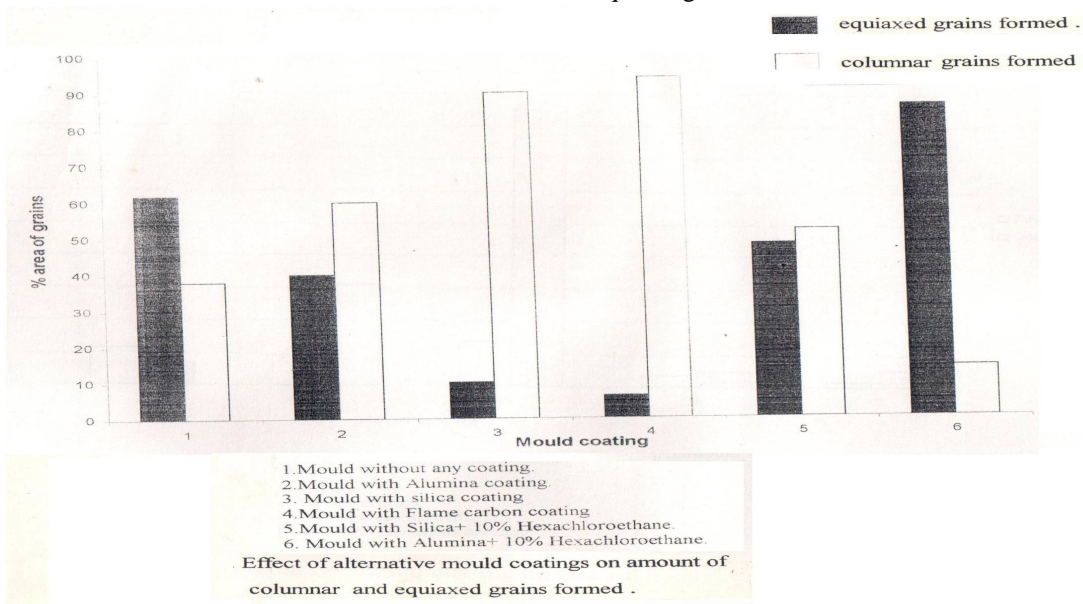
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7. Use of hexachloroethane in both the silica and alumina based mould coatings changes significantly the mode of solidification of the aluminium metal from columnar to equiaxed grains formation.



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8. It is possible to enhance significantly the casting fluidity and also to produce the grain refinement of aluminium by use of alumina based mould coating containing the hexachloroethane.

### SUGGESTIONS FOR FURTHER STUDY:

The following studies can be further undertaken:

1. A detailed study of the effects of mould coatings on the mode of solidification of metals and alloys can be undertaken.
2. A study on fluidity of metals as a function of heat transfer characteristics of different mould coatings may be worthwhile.
3. The use of different forms of carbon such as amorphous carbon, graphite, charcoal etc. on casting fluidity may be investigated.
4. A comparative study of the effects of mould coating as well as melt super heat both on fluidity as well as the cast structure should be undertaken.

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