# Investment Casting of Gold Jewellery

## FACTORS AFFECTING THE FILLING OF MOULDS

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***The efficiency with which the moulds are filled is one of the most important aspects in the lost wax procedure for casting jewellery. The factors which affect it are briefly discussed and the results of a number of experiments aimed at increasing knowledge of the complex interrelationships between them are presented.***

The extent to which mould filling is achieved in casting jewellery is determined by various factors, which differ in their significance and which cannot be studied independently of one another. The casting temperature, for example, affects the heat content, the surface and interfacial tensions and the viscosity of the melt, as well as the pressure relationships during casting.

The casting temperature, however, is less important than the temperature of the melt when it enters the mould. Thus, when using different casting techniques, at the same casting temperature, differences in mould filling efficiency are observed. They can be attributed, at least in part, to the different rates at which the melt undergoes rapid cooling in various types of casting equipment before it reaches the mould inlet. Thus, in general, mould filling tends to be worse when casting in a closed chamber by gravity feed than when it is vacuum assisted. Therefore, the optimum casting temperature varies with the casting technique. For best results the preferred technique is one which, under otherwise identical operating conditions, leads to the smallest loss of temperature in pouring. Techniques in which the inductively heated melt is poured over the top of the crucible are generally unsatisfactory from this point of view. Also bad cooling characteristics prevail if ceramic or quartz crucibles are used since, unlike carbon crucibles, they do not themselves heat up inductively. With small quantities of melt it is not possible to adhere to a definite casting temperature under such conditions.

The effects of pressure on mould filling are also complex. Thus, it is necessary to distinguish between the pressures of the melt arising from gravity, and those arising from centrifugal acceleration or from externally applied pressure differences. Account must also be taken of rises in air pressure in the mould cavities which develop if the air trapped in the mould cannot escape rapidly enough through the pores in the investment. The properties of the investment are therefore important.

Moreover, since the filling of a mould is a dynamic process, the static pressure of the melt is less important than its kinetic energy. The maximum in the air pressure in the mould, which normally builds up when the metal is poured, depends not only on volume relationships and the permeability of the investment to gases, but also on the rate at which the kinetic energy of the flowing metal is transmitted to the gas trapped in the mould. This rate of kinetic energy input (or 'casting power' input) is determined by the kinetic energy of the melt, as determined by its flow velocity and the rate (volume/s) at which it enters the mould.

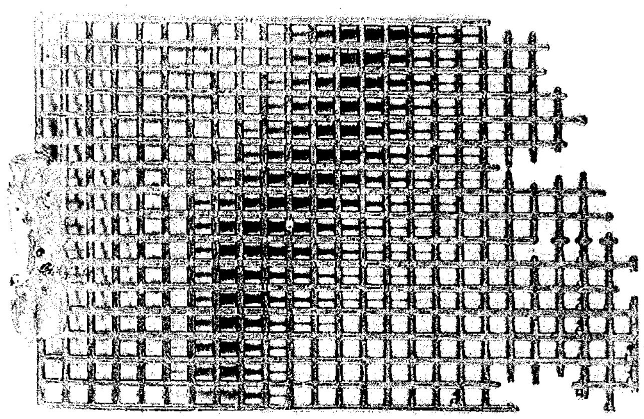
To achieve a high casting power, the melt must be accelerated to a sufficiently high velocity and delivered quickly and uniformly from the crucible to the mould. The casting power must be adequate to overcome the pressure developed by the confined air, and to keep the molten metal flowing. Experimental results demonstrate unequivocally that, at a given casting temperature, the pressure of the air trapped in the mould is one of the important causes of bad mould filling. Thus Figures 1 and 2 show two lattices which were cast in an enclosed vessel. The difference between the pressure in the vessel and the external pressure was 300 mbar in each case, the casting temperature was 1050 °C, and the mould temperature was 600 °C. In casting the lattice shown in Figure 1, the initial pressure in the casting vessel was less than 1 mbar, while in casting the lattice shown in Figure 2, this initial pressure was 670 mbar. The negative effect of the gases trapped in the mould cavities under the latter conditions can be clearly seen.

### Experimental Procedures

Casting of the retention lattice, described in an earlier article in this series (Gold Bull., 1985, **18**, (2), 58-68), proved very suitable as a means of evaluating the efficiency of mould filling in different casting procedures. It could be mounted along with other test models on the same casting tree so that the influence of various parameters on casting qualities could be studied simultaneously. Casting of spirals, such as has also been described in this article, also proved an effective means of assessing the effectiveness of mould filling. Thus, several spirals could be attached horizontally to the casting tree at different distances from the point of entry of the melt. This made it possible to compare the efficiency of mould filling with different heads of molten metal in the casting tree after pouring. For this purpose, the percentage (FF) of the mould filled was measured for each casting:

$$FF = \frac{\text{Length of the spiral casting produced}}{\text{Length of the spiral mould used}}$$

Three casting procedures have been evaluated in this way. In the case of centrifugal casting, the shape of the crucible and the angle of the casting arm were varied, just as they were in studying the development of mould air pressures.



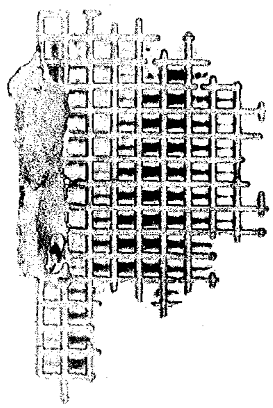


Fig. 1 (Top) Filling of a retention lattice mould, when casting with a pressure difference of 300 mbar in a vessel evacuated prior to pouring of the melt

Fig. 2 (Above) Filling of a retention lattice mould, when casting with a pressure difference of 300 mbar, in a vessel adjusted to a pressure of 600 mbar before pouring of the melt

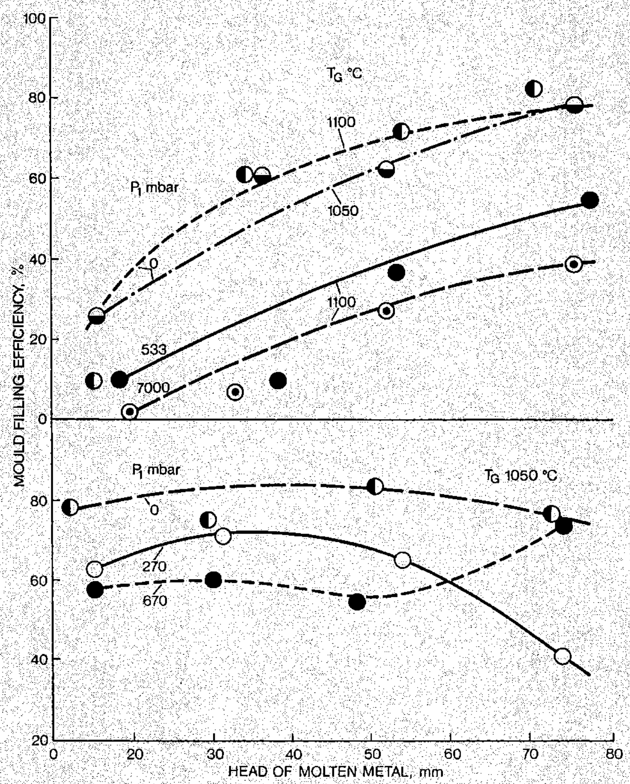



Fig. 3 Mould filling in the casting of spirals in a vessel: its dependence on the head of molten metal in the trunk of the casting tree after pouring; and various pressures ($P_1$) in the casting chamber
(a) without increase of pressure after pouring at casting temperatures ($T_G$) of 1 050 and 1 100 °C respectively
(b) with increases of pressure of about 250 mbar after pouring at a casting temperature of 1 050 °C

## Results

### Static Casting Without Vacuum Assistance

The dependence of the extent of filling of a spiral mould on the distance between the top of the casting tree and the point of entry to the spiral mould at various vessel pressures is illustrated in Figure 3 (a). No additional increase in the pressure in the casting chamber immediately after the inflow of the melt was applied, so that the extent of filling of the mould in these experiments was dependent on the head of metal in the trunk of the casting tree (Figure 4). Taking into account the considerable scatter in the results, it would appear as if, to a first approximation, this dependence is a linear one. This finding can be explained in terms of the dependence of the kinetic energy of the melt on the position of attachment of the spiral mould to the casting tree. Comparison between the results illustrated in Figures 3a and 3b shows that casting without an additional increase in pressure is not effective because of the dependence of the efficiency of mould filling on the attachment position of the spiral mould.

The pressure in the casting chamber before casting has a decisive influence. With the spiral mould attached at a greater distance (e.g. 70 mm) from the head of the casting tree, and a vacuum in the chamber, a mould filling efficiency of about 80% can be achieved. With the chamber pressure increased to 530 mbar, this efficiency is reduced to 40 per cent. In figure 5(a), the dependence of the mould filling efficiency on the pressure in the chamber, is plotted and is approximately linear. With the pressure in the chamber reduced to zero, an increase in the casting temperature did not significantly affect the mould filling efficiency. By increasing the

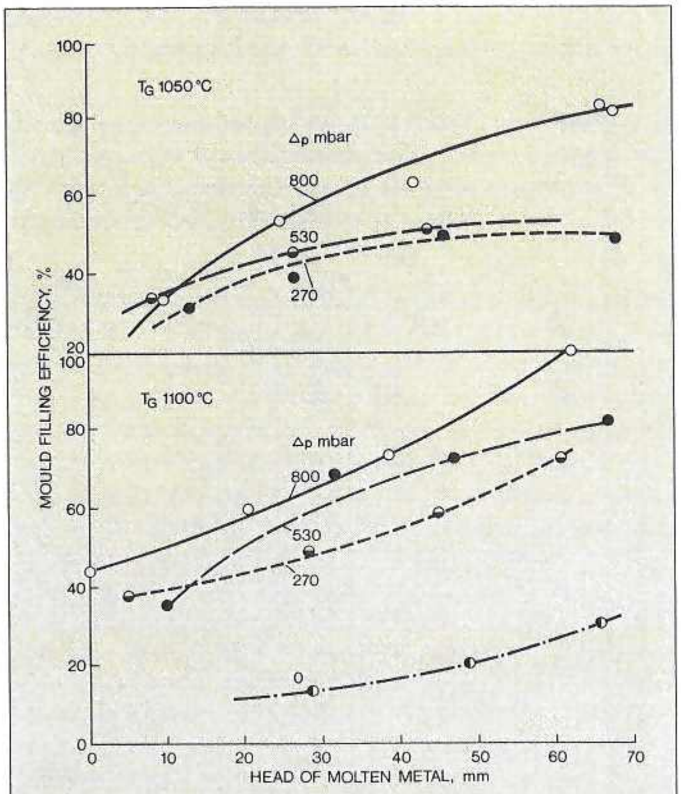
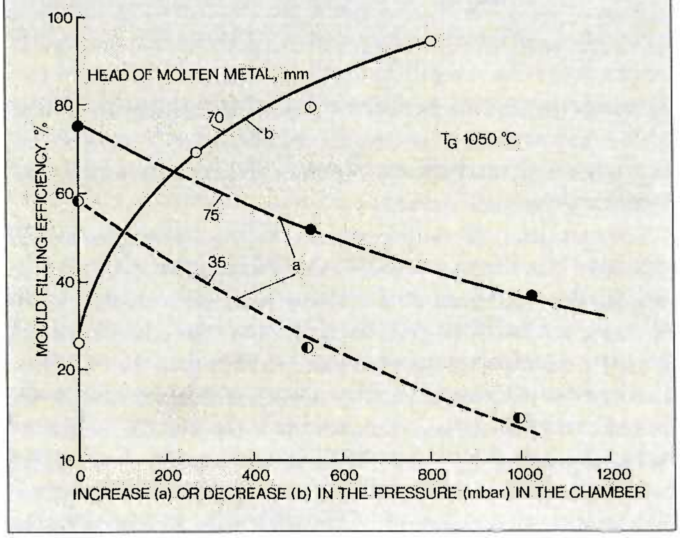



**Fig. 4** Dependence of mould filling in the vacuum assisted casting of spirals on the head of molten metal in the trunk of the casting tree, after pouring at various levels of pressure reduction ($\triangle_p$) and at casting temperatures $T_G$ of 1 050 and 1 100 °C

**Fig. 5** Effect on the filling of spiral moulds of increased (curve a) and decreased (curve b) chamber pressures at a casting temperature ($T_G$) of 1 050 °C




chamber pressure after pouring (see Figure 3(b)), the mould filling efficiency was improved and, at the same time, its dependence on the position of the spiral mould upon the casting tree was eliminated.

In these studies using different starting pressures, the pressure was sometimes increased by about 250 mbar. A small effect of the starting pressure was observed. This was more evident in casting retention lattices than in casting test spirals.

A possible reason for this may be a more rapid crystallisation of the melt in the lattice than in the spiral moulds. A pressure increase, if delayed until after pouring of the melt, has more opportunity to act on the melt in a spiral mould, where it stays liquid longer, than in the lattice mould.

An evaluation of numerous casting studies showed that in making both spiral and lattice castings, but especially the latter, a pressure difference of 250 to 550 mbar gives optimum filling of the moulds.

An additional increase in the pressure has no significant further effect, probably because the melt has already solidified in the finer parts of the cast structure before the higher pressure becomes effective.

### Vacuum Assisted Casting

The results of casting studies carried out without use of reduced pressures in the casting chamber correspond naturally with those illustrated in Figure 3(a), in respect of castings made using 1 000 mbar pressure in the chamber without application of additional (external) pressure. If reduced chamber pressures are used, mould filling is improved substantially. As Figure 5(b) shows, the effect is strongly dependent on the magnitude of the pressure reduction. The best results were obtained, with the apparatus used, when the maximum achievable pressure difference of about 800 mbar was applied.

In contrast to the technique, as generally applied in practice, of starting evacuation of the casting vessel only at the time of casting, it was found beneficial to evacuate the casting chamber to the desired pressure before pouring the melt. Using large reductions in pressure, mould-filling could be significantly improved and, in general, good results achieved. The dependence of the efficiency of mould filling on the position of attachment of the model to the casting tree was not, however, eliminated.

Techniques such as that illustrated schematically in Figure 6 of an earlier article in this series (Gold Bull., 1985, **18**, (2), 58-68) should help to remedy this. The combination of vacuum assisted and enclosed chamber casting, as illustrated in the central part of this figure, proved not very effective in preliminary tests. However, the arrangement as shown in the left-hand part of this figure should be capable of realisation without technical difficulties.

The influence of the casting temperature in vacuum-assisted casting on the efficiency of mould filling can be seen in Figure 4.

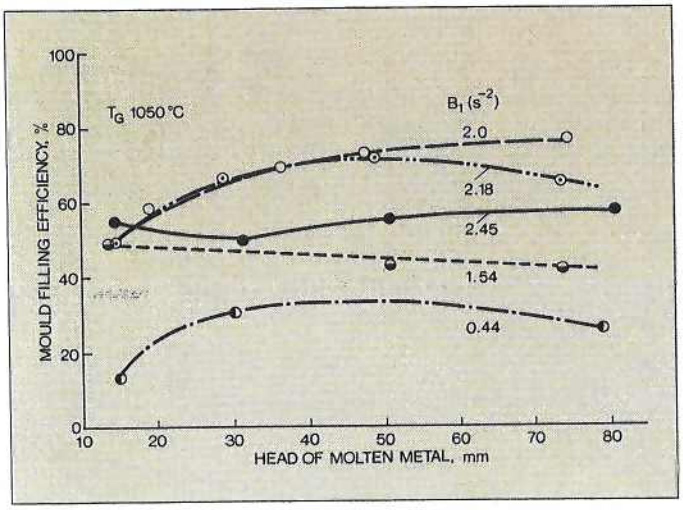



**Fig. 6 (Left) Variation in the filling of spiral moulds during centrifugal casting with the head of molten metal in the trunk of the casting tree at different values ($B_1$) of the centrifugal acceleration of the melt on entry. Casting arm angle of 0°, horizontal crucible**

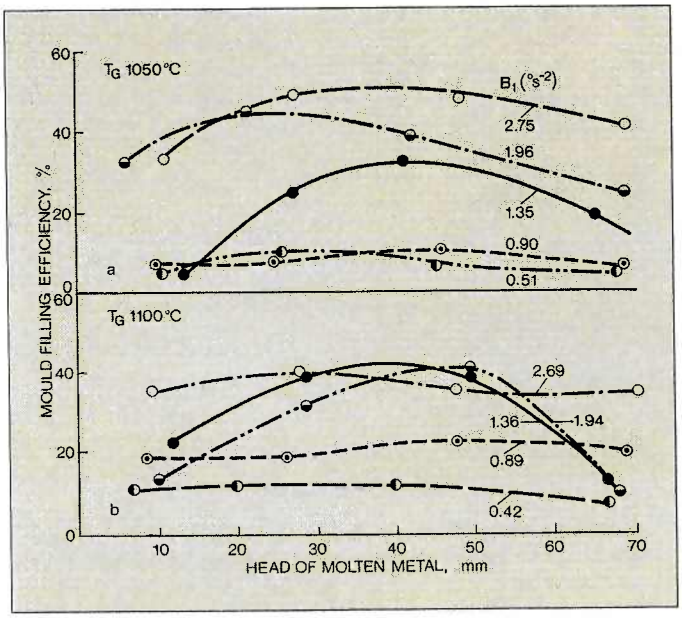



**Fig. 8 (Above) Variation in the filling of spiral moulds during centrifugal casting with the head of molten metal in the casting tree. Casting arm angle of 15°, and an upright crucible**
**(a) crucible wall slope 8° and casting temperature ($T_G$) 1 050 °C**
**(b) crucible wall slope 15° and casting temperature ($T_G$) 1 100 °C**

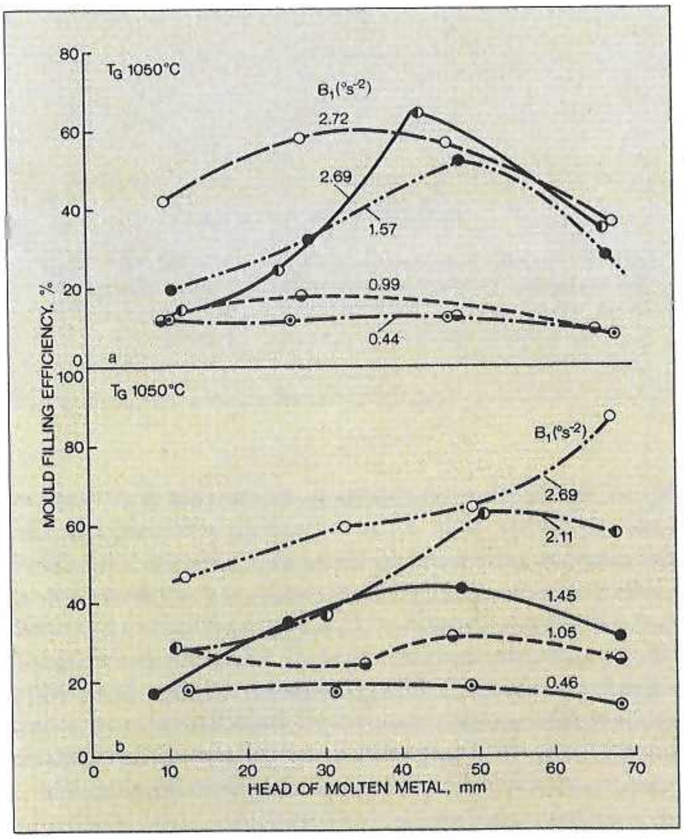



**Fig. 7 (Left) Variation in the filling of spiral moulds during centrifugal casting with the head of molten metal in the casting tree. Casting arm angle of 10°, upright crucible, at different values of the centrifugal acceleration $B_1$**
**(a) crucible wall slope 8°**
**(b) crucible wall slope 15°**

## Centrifugal Casting

Variations in the efficiency of mould filling with first, the distance between the top of the casting tree and the point of attachment of the model and, secondly, with the acceleration of melt on entering the mould, are illustrated in Figure 6. The results were obtained with the standard equipment of the machine (crucible horizontal, straight casting arm). Surprisingly, the position of attachment of the model to the casting tree is revealed as having little effect on mould filling efficiency.

Experiments were also carried out using upright crucibles with wall slopes of 8° and 15° respectively, and various casting arm angles. The results are presented in Figures 7, 8 and 9 and indicate clearly

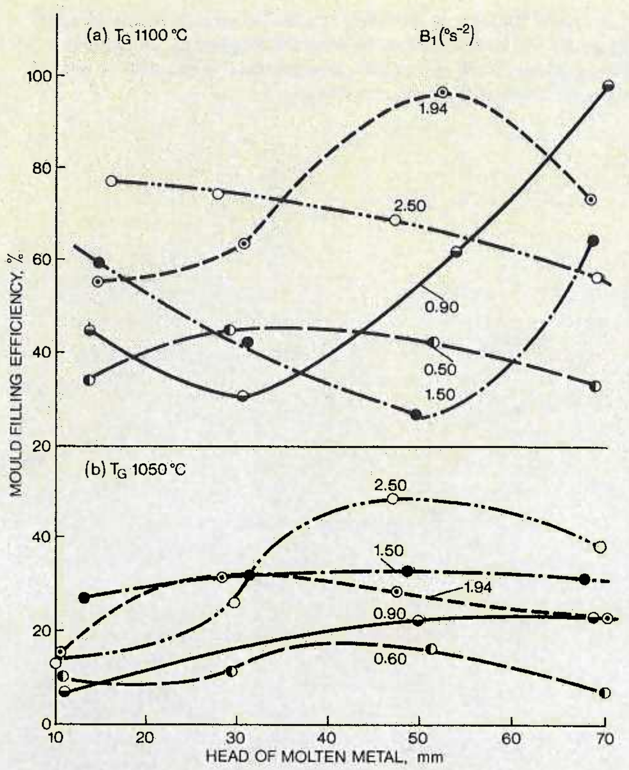



**Fig. 9** Variation in the filling of spiral moulds during centrifugal casting with the head of molten metal in the casting tree. Casting arm angle 20°, upright crucible
(a) crucible wall slope 8° and casting temperature ($T_G$) 1 100 °C
(b) crucible wall slope 15° and casting temperature ($T_G$) 1 050 °C

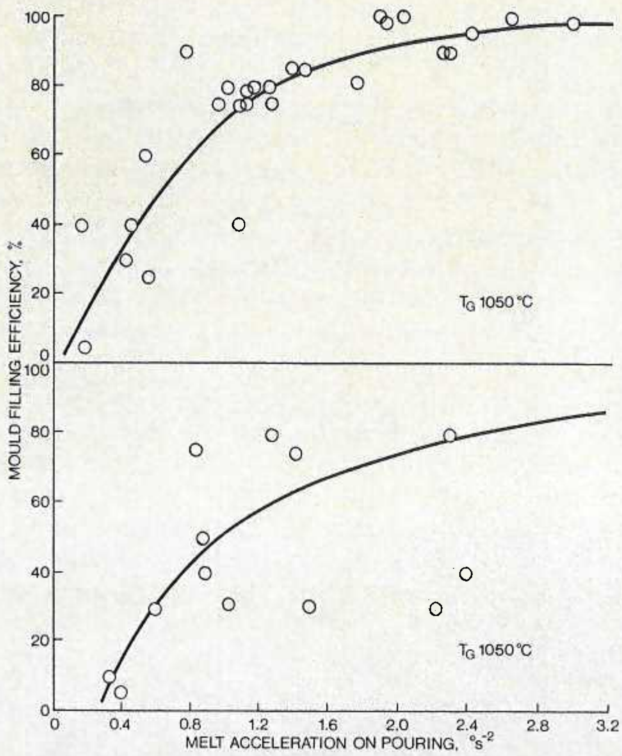



**Fig. 10** Effect of acceleration during pouring on the filling of retention lattice moulds in centrifugal casting (as for Fig. 11). Casting arm angle 20°, casting temperature ($T_G$) 1 050 °C
(a) Upright crucible, wall slope 15°
(b) Horizontal crucible

that the mould filling power is strongly influenced by fortuitous changes in conditions. These have not been identified. In many instances, they make it difficult to discern a significant effect on the mould filling power of the factor under study. Using an upright crucible, however, mould filling is strongly determined by the acceleration of the melt at entry. Using a low acceleration, which leads to poor mould filling, an effect of the slope of the crucible wall can be seen clearly. The mould filling power using a melt entry acceleration of about 0.8 to 1.1° $s^{-2}$, is better with a crucible wall slope of 15° than it is when this slope is 8°.

Accelerations of the melt of over 2° $s^{-2}$ bring about only marginal improvements. As is also revealed in Figure 6, there is no systematic dependence of the mould filling power on the position of attachment of the model to the casting tree. A difference in casting temperature of 50K can, however, influence the mould filling power, as can be seen from Figure 9.

For comparison purposes, data in respect of the filling of retention lattice moulds at different melt entry accelerations are given in Figures 10 to 12. The most important conclusions to be drawn from these studies are that, as in the casting of test spirals, the experimental results generally show a wide scatter, but this scatter is less when a horizontal crucible is used. Increases in the melt entry acceleration up to about 1° $s^{-2}$ have a strong influence on mould filling power but increases above 1° $s^{-2}$ result in only small improvements in mould filling. Because of the great scatter in the results, significant effects on mould filling of crucible and casting arm geometry cannot always be discerned. Use of a horizontally positioned crucible, however, always gives better mould filling.

## Summary

Back pressure which develops as a result of occlusion of air militates against good mould filling in the casting of jewellery. If external forces, such as air pressure differences or centrifugal forces, are not introduced to counteract it, then the mould filling power is approximately linearly dependent on the distances between the point of entry of the melt and the position of attachment of the

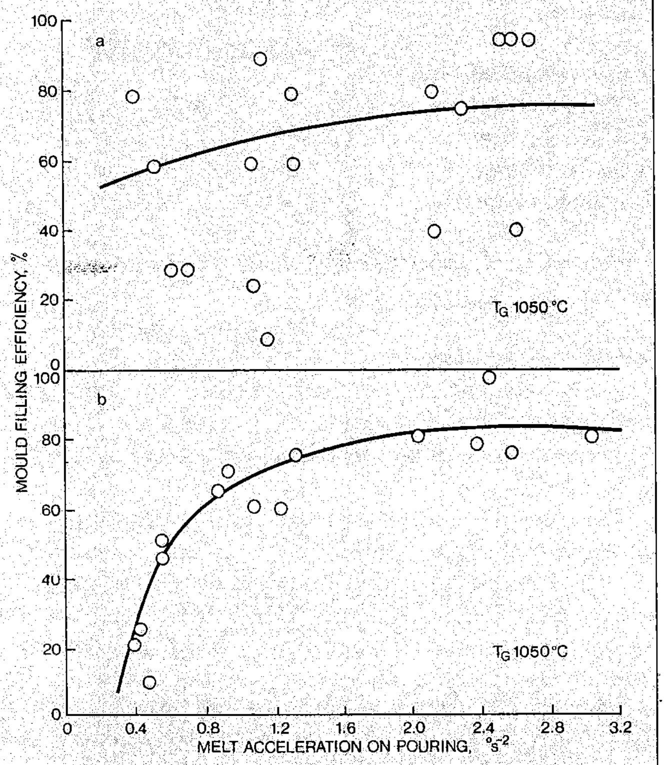



**Fig. 11** Effect on acceleration during pouring on the filling of retention lattice moulds in centrifugal casting. Casting arm angle 10°, upright crucible and casting temperature ($T_G$) 1 050 °C
(a) crucible wall slope 15°
(b) crucible wall slope 8°

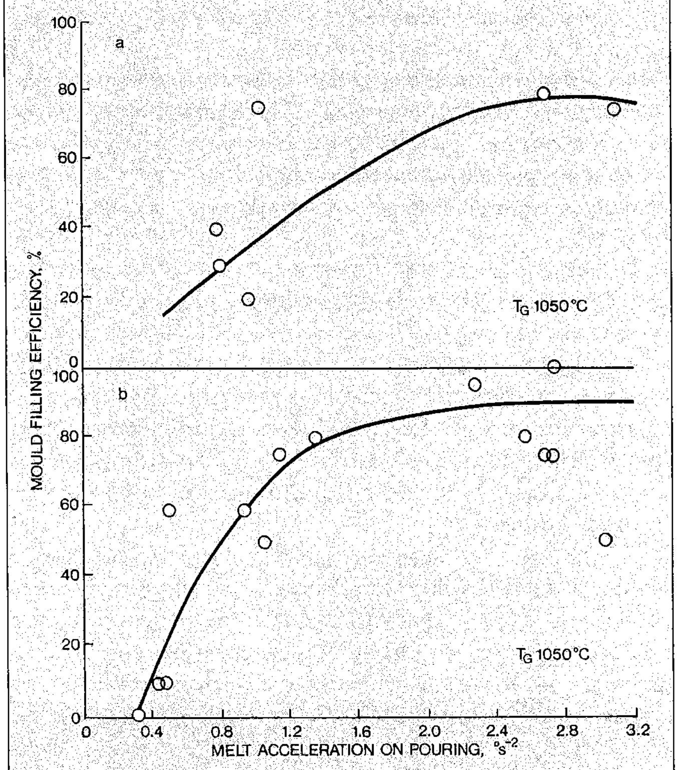



**Fig. 12** Effect of acceleration during pouring on the filling of retention lattice moulds in centrifugal casting. Casting arm angle 10°, upright crucible and casting temperature ($T_G$) 1 050 °C
(a) crucible wall slope 20°
(b) crucible wall slope 15°

model to the casting tree, i.e., upon the head of molten metal in the mould at the end of pouring.

When additional air pressure is applied to this head of molten metal, this dependence of mould filling power on the position of attachment of the model to the casting tree is eliminated or at least greatly weakened. In vacuum assisted casting, however, the pressure differential created by the reduced pressure in the casting chamber promotes good mould filling but does not eliminate its dependence on the position of the model on the casting tree.

In centrifugal casting, the studies have shown that, surprisingly, variation of the mould filling power with the position of the model on the casting tree, which is to be expected in the light of the centrifugal acceleration of the melt, does not occur. Moreover, the effects of geometrical factors, such as the slope of the crucible walls and the angle of the casting arm, are of negligible importance in comparison with a very wide spread in the observed casting powers, the causes of which have not been identified. The angular acceleration of the machine at the time of entry of the melt into the mould does, however, affect mould filling strongly. Very good results are obtained using accelerations of 1.2° s$^{-2}$ to 2.2° s$^{-2}$, but mould filling power decreases rapidly at accelerations below 1.0° s$^{-2}$, and above 2.2° s$^{-2}$ it improves only very little further and, in some instances, may even become worse.

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This article concludes a series on the effects of different process variables on the quality of carat gold jewellery made by casting. The series was also published in *Metall* in German. The first article was published in English in Metall 1981, **35**, (2), 1257 and was not repeated in *Gold Bulletin*. The remaining articles were published in *Gold Bulletin* 1985, **18**, (2); (3); (4) and 1986, **19**, (1). Interested readers should refer to the *Gold Bulletin* 1985, **18**, (2) article which also gives further references to be read in conjunction with this series.