A method of casting a metal core for plastic injection having a faster solidification rate than an eutectic alloy. The fusible alloy used for the metal core composition allows reduced production rates. The metal core composition has increased thermal conductivity and contains about 45% to 70% by weight tin and the remainder being primarily bismuth. The method includes fitting a mold with the molten metal alloy composition at a higher fill rate than eutectic alloys, the rate preventing contraction of the metal alloy away from mold surfaces when cooling.
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FUSIBLE ALLOY FOR PRODUCTION OF MELT OUT CORE CASTINGS AND METHOD OF CASTING

Technical Field

The present invention relates to melt out fusible alloy cores for subsequent molding in components made of plastic material. More specifically the present invention relates to a specific fusible alloy that provides improved production rates of melt out cores and an improved method of casting melt out cores.

Background Art

Melt out metal parts of complex shapes made of low melting temperature metals such as a combination of lead and tin have been used extensively for plastic component production by what is referred to as the "lost core molding technique". This technique involves plastic injection molding over a low melting point metal alloy core. In a subsequent operation the metal alloy core is removed by melting either by magnetic induction heating or by immersion in a heated oil bath. The net result makes possible the manufacture of hollow plastic components with complex internal geometry. One example of the use of this system is the production of automotive air intake manifolds which have a complex internal shape.
In practice the low melting temperature metal alloy typically used by the industry is a tin and bismuth eutectic alloy (42% Sn/58% Bi). This alloy has been chosen because of its good mechanical properties, low melting point, relative castability and low toxicity compared for example to lead based alloys or alloys which contain cadmium.

One problem of the lost core molding technology, however, is the slowness of the core molding operation in comparison to the plastic injection molding operation. The time for solidification of the alloy core is generally far higher than the time for solidification of the plastic component primarily because of the high latent heat of fusion of the alloy core and the typically large cross-sections of the core geometry. In some cases the alloy core must be completely or nearly completely solid when extracted from the core mold, otherwise it does not retain its shape.

One example of casting metal alloys with low melting temperatures is disclosed in U.S. Patent 4,958,675 to Kidd. In this process the molten alloy is allowed to flow into the mold. It is preferred that substantially no pressure build up during the mold filling step, however, once the mold has been filled then pressure is applied during the solidification of the core.
Thus the prior art discloses a method of making an alloy core by filling a mold at a controlled rate so that there is no substantial pressure build up in the die during the injection and then allowing the core to solidify. If the alloy core has a substantially large cross-section, then the time for these two steps generally becomes the rate limiting operation in a manufacturing production line. The alternative is to invest more capital to increase the number of core molds and casting machines to match the output of the plastic molding operation.

It is an aim of the present invention to provide a fusible alloy that solidifies at a higher rate than the existing material, namely the tin bismuth eutectic alloy presently used, and also it is a further aim to increase the production rate by reducing the time to fill the mold. This is achieved by having a faster alloy flow rate into the mold.

An eutectic alloy is one whose composition has the lowest possible constant melting point. However, one critical alloy property which governs the rate of solidification in the mold is thermal conductivity. The thermal conductivity of pure tin is relatively high (approximately 64 W/(m.k) at room temperature) compared to pure bismuth (approximately 8 W/(m.k) at room temperature). The conductivity of the eutectic alloy
presently used has been reported as approximately 18 W/(m.k).

Disclosure of Invention

Thus, increasing the proportion of tin while decreasing the proportion of bismuth increases the thermal conductivity of the alloy and also increases the melting point of the alloy.

The present invention provides a melt out metal core for plastic injection molding wherein the metal core comprises a composition having increased thermal conductivity over an eutectic alloy and contains about 45% to 70% by weight tin and the remainder being primarily bismuth.

The present invention also provides a method of casting a metal core for plastic injection molding having a faster solidification rate than an eutectic alloy, comprising the steps of forming a metal alloy composition containing in the range of about 45% to 70% by weight tin, the remainder being primarily bismuth, filling a mold of molten alloy composition at an increased rate over an eutectic alloy composition, the rate being sufficient to prevent contraction of the metal alloy away from mold surfaces when cooling.
Brief Description of Drawings

In drawings which illustrate embodiments of the present invention,

Figure 1 is a composite phase diagram showing different alloy ratios of tin and bismuth,

Figure 2 is a diagrammatic view showing the position of an alloy casting against a mold wall surface for a fast filling rate and illustrating the micro-structure of the surface of the alloy casting,

Figure 3 is a diagrammatic view similar to that shown in Figure 2 but showing a space formed between the alloy casting and the mold wall surface for a slow filling rate and illustrating the micro-structure of the surface of the alloy casting,

Figure 4 is a profile temperature curve showing cooling rate of a conventional casting alloy in a mold,

Figure 5 is a profile temperature curve showing the cooling rate of an alloy according to the present invention in a mold, wherein the mold has been filled at fast rate,
Figure 6 is a profile temperature curve similar to that of Figures 4 and 5 showing the cooling rate of an alloy according to the present invention in a mold, wherein the mold has been filled at a slow rate.

Modes For Carrying Out the Invention

By increasing the tin in a tin/bismuth alloy, the thermal conductivity remains high while maintaining most of the benefits of the conventional eutectic alloy. Reference is made to Figure 1 which shows a phase diagram or a composition map of the alloy structure. As the amount of tin increases, from the eutectic composition the alloy becomes hypoeutectic and castability is slightly affected depending on the actual composition ratio used. This occurs because a hypoeutectic alloy has a freezing range instead of a single freezing point.

This potential adverse condition is compensated for by increasing the casting injection pressure to ensure proper filling of cavity details. As the quantity of tin increases in the composition, there is an increase in the quantity of primary $\alpha$ phase formed during solidification making it harder to avoid segregation in the casting process. The $\alpha$ phase may be seen in Figure 1. It has been found that an upper limit of about 70% by weight tin provides a practical composition. The melting range for this composition is about 200°C which is the practical temperature limit for a melt out system. Above 70% tin
would likely result in higher temperature limits which are unacceptable and segregation of the metals may occur during the casting process. This segregation would make it more likely for the metals to contract away from the mold wall as the casting cools which would in turn lead to longer cycle times and therefore not acceptable.

A lower limit is about 45% by weight tin. This lower tin content is a small improvement to the existing eutectic composition which is 42% tin but the ideal preferred range is on or about 60% tin. The segregation and contraction has been successfully controlled for this alloy and the freezing range is manageable. A further advantage is the overall low casting shrinkage of this alloy. Tin contracts on solidification while bismuth expands. At the 60% tin composition, the volume change is well balanced. This makes it easier to control the as-cast final part dimension.

In experiments a 60% tin alloy composition was cast into a rectangular water cooled copper mold having a 2" (5cm) minimum cross-section at one location. Complete solidification was achieved in approximately 66 seconds. The conventional eutectic alloy with a 42% tin content cast under the same conditions required 100 seconds to achieve solidification. Thus, the use of the hypoeutectic alloy represents a 34% improvement in the rate of solidification.
As the tin content increases it was noted that under some casting conditions the hypoeutectic alloy contracts away from the mold wall surface during solidification causing an air gap to appear. This gap acts as a barrier to heat flow and significantly increases the time for solidification. Metallurgical examinations of the microstructure of contracted cores revealed a degree of microsegregation of the primary α phase to the core surface. This micro-segregation was not evident in the non-contracting cores.

To avoid segregation of the primary α phase when casting the hypoeutectic alloy, it was found necessary to increase the rate of mold filling beyond the rate found to be needed for the conventional eutectic alloy. Under the faster fill conditions, the segregation and subsequent contraction is avoided and the solidification of the core proceeds at faster cooling rates. This increased rate of mold filling also reduces the time of filling and consequently increases the production rate.

Minor additions to the composition such as lead and antimony do not change the general structure and properties.

Under the normal filling of molds, as stated there is substantially no pressure applied to the molten alloy entering the mold until the mold is full. However, when
using a hypoeutectic alloy according to the present invention, the key is allowing the alloy to flow into the mold in a generally non-turbulent fashion. It has been found that increased pressures, such as 100 psi (690 kPa) or higher, can be applied to force the alloy into the mold, provided turbulence causing air to be trapped in the mold is avoided. Increased pressure reduces the fill time and a reduced fill time prevents the alloy from pulling away from the mold wall surfaces when it solidifies.

Figure 2 shows schematically a mold wall surface 10 with the alloy casting 12 substantially against the wall with little or no separation or contraction therein. This diagram represents what is referred to as a "fast fill core" wherein the mold has been filled with molten alloy at a faster rate than normal mold filling. The mold fill time was 8 seconds and the mold fill rate was 140 mL/sec. The micro-structure shows a finely dispersed primary α crystals in the eutectic matrix.

Figure 3 illustrates a separation between the alloy casting 12 and the mold wall surface 10, leaving a gap 14. This gap prevents cooling of the alloy casting as it forms a thermal insulator. This diagram represents what is referred to as a "slow fill rate" wherein the mold was filled at about the same fill rate used with eutectic alloys. The mold fill time was 13 seconds and the mold
fill rate was 86 mL/sec. A hypoeutectic alloy was used with a 60% tin content. The micro-structure can be seen with a concentration of primary α crystals at the surface.

Cooling times for different castings are shown in Figures 4, 5 and 6. The graphs all show the cooling time for the temperature to drop below 281°F (138°C), the solidification temperature, from different thermocouples, T₁, T₂, T₃, and T₄ positioned in the mold. In Figure 4 the alloy was a known type of eutectic alloy with a 42% tin content. As can be seen, the cooling time to reach 200°F (93°C), well below the solidification temperature was approximately 100 seconds as shown by the thermocouple T₁ which projected into the casting centre. Figure 5 represents cooling of a hypoeutectic alloy, namely one which has 60% tin content wherein the mold had a fast fill at a time of 8 seconds, similar to that shown in Figure 2. As can be seen, the cooling time is reduced to approximately 66 seconds.

Figure 6 illustrates the cooling time of a hypoeutectic alloy having a 60% tin content wherein the mold was filled slowly according to the conditions shown in Figure 3. As can be seen, thermocouple T₁, which is located on the mold cavity wall recorded a drop in temperature after about 20 seconds. This drop represents the instant that the alloy casting 12 separates from the
mold wall surface 10 to leave a gap 14 as shown in Figure 3. Following this, the time of cooling is greatly increased and represents approximately 125 seconds which is even greater than the eutectic alloy. Thus, this shows that it is important to provide fast filling of the mold in order to prevent separation of the hypoeutectic alloy from the mold wall surfaces.

Various changes may be made to the embodiments shown herein without departing from the scope of the present invention which is limited only by the following claims.
The embodiments of the present invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of casting a metal core for plastic injection molding having a faster solidification rate than an eutectic alloy, comprising the steps of:

   forming a metal alloy composition containing in the range of about 45% to 70% by weight tin, the remainder being substantially bismuth;

   filling a mold with the metal alloy composition in molten form at an increased rate over an eutectic alloy composition, the rate being sufficient to prevent contraction of the metal alloy away from mold surfaces when cooling.

2. The method of casting a metal core according to claim 1 wherein the filling occurs at a higher pressure than the filling pressure for an eutectic alloy composition of tin and bismuth, the increased pressure being selected so as to be sufficient to compensate for any reduction in castability in the metal alloy composition.
3. The method of casting a metal core according to claim 1 wherein the metal alloy composition is in the range of about 60% by weight tin.

4. The method of casting a metal core according to claim 1 wherein the mold is filled at a rate of at least about 86 mL/sec.

5. The method of casting a metal core according to claim 2 wherein the increased pressure is 100 psi (690 kPa) or higher.
FIG. 1
FIG. 4

FIG. 5
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B22C9/10 B29C45/44

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B22C B29C B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>WO,A,92 04999 (ALLIED-SIGNAL INC.) 2 April 1992 see claims 1,3-5</td>
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Date of the actual completion of the international search
26 March 1996

Date of mailing of the international search report
17.04.96

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