Title: METHOD OF REINFORCING LOW MELTING TEMPERATURE CAST METAL PARTS

Abstract: A method of reinforcing a low melting temperature cast metal part comprising preparing a molten metal material having a melting temperature, mixing a reinforcing material having a melting temperature greater than the melting temperature of the molten metal material into the molten metal material, pouring the molten metal material into the mold, applying a force to the reinforcing material causing the reinforcing material to occupy a predetermined portion of the mold and thereby a predetermined portion of the cast metal part, and solidifying the molten metal material.
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,
FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,
NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— with international search report
— before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments
Title
Method of Reinforcing Low Melting Temperature Cast Metal Parts

Field of the Invention
The invention relates to a process and a part made using the process, namely, reinforcing low melting temperature cast metal parts using high melting point fibers or powders applied or dispersed to predetermined portions of the mold casting.

Background of the Invention
Aluminum and magnesium alloys are used commonly in manufacturing industrial products. Although there are many uses for these alloys, they cannot be used for high strength and high wear applications except if there are made of two parts joint together, an aluminum core and a case made of a higher strength material, e.g. steel. A good example is aluminum block engines require a steel sleeve. To improve pure metal properties, alloys are made by adding different metals to the base metal and creating intermetallic compositions and phases in the atomic scale. However, for aluminum and magnesium even their alloys do not have sufficient strength and wear resistance for many applications, even though their low densities and relatively low melting points are very attractive features. A known art to strengthen aluminum and magnesium alloys is addition of ceramics to these alloys. Ceramics do not mix with alloys in the atomic scale; rather, they reinforce these alloys in a macro scale. The problem with ceramic added alloys is the fact that they are extremely difficult to machine. And since castings
are almost never net-shape, they are only suited for certain applications that do not need finish machining.

The addition of ceramics to molten aluminum and magnesium to increase mechanical properties and wear resistance is also known in the art. The problem with ceramic reinforced aluminum is that it is extremely difficult to machine the part after casting. In addition, ceramic reinforced alloys do not have a good ductility.

Representative of the art is U.S. 4586554 which discloses a process is provided for the production of fibre-reinforced light-metal castings by die casting. A fibre moulding is introduced into an auxiliary mould and the auxiliary mould is heated to an optimum temperature above the melting point of the light metal. The auxiliary mould is then inserted with positive fit into a die casting mould corresponding to the outer contour of the auxiliary mould and filled with light metal under pressure. The fibre moulding can optionally be stabilized by means of a temporary organic binder which decomposes when the auxiliary mould is heated.

What is needed is a method of reinforcing low melting temperature cast metal parts using high melting point fibers or powders applied or dispersed to predetermined portions of the mold casting.

**Summary of the Invention**

The primary aspect of the invention is to provide a method of reinforcing low melting temperature cast metal parts using high melting point fibers or powders applied or dispersed to predetermined portions of the mold casting.
Other aspects of the invention will be pointed out or made obvious by the following description of the invention and the accompanying drawings.

The invention comprises a method of reinforcing a low melting temperature cast metal part comprising preparing a molten metal material having a melting temperature, mixing a reinforcing material having a melting temperature greater than the melting temperature of the molten metal material into the molten metal material, pouring the molten metal material into the mold, applying a force to the reinforcing material causing the reinforcing material to occupy a predetermined portion of the mold and thereby a predetermined portion of the cast metal part, and solidifying the molten metal material.

**Brief Description of the Drawings**

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate preferred embodiments of the present invention, and together with a description, serve to explain the principles of the invention.

- Fig. 1 is a perspective view of a first method.
- Fig. 2 is a perspective view of a magnetic mold.
- Fig. 3 is a perspective view of the magnetic mold.
- Fig. 4 is a perspective view of the finished part.
- Fig. 5 is a perspective view of the centrifugal mold.
- Fig. 6 is a perspective view of an armature machine.
- Fig. 7 is a perspective view of a finished part.
- Fig. 8 is a side view of a part formed using gravity separation.
Fig. 9 is a perspective view showing application of powder or fiber to a mold.

Fig. 10 is a perspective view of the mold with poured metal.

Fig. 11 is a perspective view of a finished part.

Fig. 12 is a perspective view of the magnetic mold with the fibers or powder applied before pouring.

Fig. 13 is a perspective view of the filled mold.

Fig. 14 is a perspective view of the finished part.

Fig. 15 is a perspective view of the two step mold.

Fig. 16 is a perspective view of the two step mold with the core removed.

Fig. 17 is a perspective view of the two step mold.

Fig. 18 is a perspective view of the dam mold.

Fig. 19 is a perspective view of the mold with the dam.

Fig. 20 is a perspective view of the finished part.

**Detailed Description of the Preferred Embodiment**

The invention provides a method, and a product using the method, for reinforcing for durability and/or strength enhancement of aluminum, magnesium, zinc or tin castings or any other low melting point metal casting using stainless steel fiber or powder or other high melting point alloy fibers and/or powders mixed within the host metal material. It also comprises a method of reinforcing low melting temperature alloys by mixing a reinforcing powder or material into the molten metal, and subsequently separating the fiber/powder from the molten metal by external forces such as magnetism, centrifugal or gravitational.

The method comprises use of a metal host alloy into which the reinforcing fibers or powders are added to form a metal matrix mix. The metal matrix mix comprises a...
mechanically reinforced alloy. When the mix is cast into a product it will have enhanced mechanical strength (for example, tensile, compressive, fatigue, bending, and so on) and higher wear resistance.

This process disclosed herein can be used in making high strength, wear resistant aluminum sprockets, without the need of hard chrome plating or ceramic coating. In general, the disclosed process is superior to coatings because coatings generally consist of mechanical or chemical bonds which are not as strong as a part manufactured using the inventive process since there is no need for "bonding" between layers and so the part is essentially one piece.

The inventive process comprises use of mechanical or other means of separating or segregating the fiber and/or powder in the molten host metal matrix material in a predetermined manner. This can include use of centripetal force, gravitational force, magnetic force or a static electric charge. By use of these means the concentration of fibers and/or powder in the outer layer (or other desired locations) of a part in the molten stage can be manipulated and increased. This improves the mechanical properties for parts in specific predetermined locations giving higher strength and/or higher wear resistance on the surface or other locations, without increasing the fiber usage in the entire part, thereby reducing the cost and weight.

During the process the fibers or powders are not necessarily uniformly distributed through the metal matrix as one might expect in a pure mixing process. Instead, the powders or fibers are selectively concentrated in areas where either durability or strength enhancements are desired. The concentration of the metal
fibers and/or powders is performed during the casting process.

The metal matrix may comprise aluminum, magnesium, zinc or tin or a combination of two or more of the foregoing. The fibers and powders comprise metal materials having a higher melting point than the metal matrix, including stainless steel, alloy steel, low carbon steel, or other materials that have a very high melting point compared to molten aluminum, magnesium, zinc or tin. The melting point of pure iron is 1537°C. The melting point of pure aluminum is 660°C and melting point of pure magnesium is 650°C. The melting point of pure zinc is 420°C and the melting point of pure tin is 232°C.

Due to the difference in the melting points of the materials, the stainless steel fibers or powder do not melt in the molten metal matrix, rather, an intermetallic boundary layer comprising a combination of iron and the host metal is formed at the fiber or powder interface.

Generally, the melt is agitated before and sometimes depending on the part design after casting (in-mold agitation) to prevent the fibers or powder from settling down in the host molten metal matrix as the density of iron is about three times as much as the density of aluminum or magnesium. The agitation can be done simply by mechanical means or by magnetic forces. Casting is generally done in closed molds and sometimes under pressure (i.e. in die casting). This helps to better fill the mold.

The percentage of fibers, size and shape of fibers, and material composition (alloy) of fibers can vary depending on the required performances of the part. A typical mix will have a fiber or powder content in the
range of approximately 5% to 50% by volume, and fiber sizes of approximately one micron to 10 mm long and approximately 1 micron to 1.0 mm (1 to 1000 microns) in cross sectional diameter. The cross section can be any shape, but for simplicity, it has been considered basically round. The range of sizes, although given only as an example, will allow easy die casting of the reinforced alloy.

The powder can also vary in the range of approximately one micron to one millimeter size, but is not limited to this range. For alloys that are not die cast, for example, sand cast, permanent mold cast, and so on, the size of fibers and powder can be larger both in length and diameter. Choosing powder, fiber, or a combination of both is a matter of achieving the desired properties in the finished part. The percentage of fiber/powder in the selected enriched area of parts can be as high as 95%, but not limited to this amount. The enriched layer applied on the mold in the mold coating process can have some aluminum powder mixed with it to assure that it melts and creates the homogeneous enriched layer after casting.

Example fibers include:

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<tr>
<td>Nickel</td>
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<td>nil</td>
</tr>
<tr>
<td>Carbon</td>
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<td>0.02</td>
</tr>
</tbody>
</table>
Fig. 1 is a perspective view of a first method. In order to prevent the host metal matrix 10 from solidifying on the mold surface 21 before magnetic, centrifugal, static electric or gravity separation of the fibers or powder, the mold 20 is preheated and the molten alloy is superheated (hotter than melting point). This allows separation of the stainless steel fiber/powder before the solidification process starts. The superheat applied to the metal matrix material required is approximately 250°C. The poured metal matrix material is then allowed to cool. Once cooled to ambient conditions the cast reinforced part is removed from the mold 20.

Instead of simply mixing the reinforcing powder or fiber as described in Fig. 1, selective dispersion of fiber or powder material to predetermined portions of the metal matrix can be achieved using a variety of processes. These include separation processes wherein the fiber or powder is mixed with the host metal matrix alloy, and then moved to a desired location or concentration by use of magnetic force which causes the fiber or powder to move to the desired location(s) in the part.

It should be noted that in practice casting molds are closed and molten metal fills the mold through gates, usually under pressure. The drawings in this specification show an open top mold for ease of illustration and explanation.

Fig. 2 is a perspective view of a magnetic mold. Mold 20 is surrounded by an electromagnet 22. Prior to pouring the host metal matrix material 10 is mixed with the reinforcing fiber or powder. The host metal matrix
alloy is superheated and the mold 20 preheated to prevent premature solidification of the material 10. The superheat and preheat are approximately 250°C above the melting point of the host alloy. The fiber and powder are then migrated to a desired location in the casting by force of electromagnet or permanent magnet 22.

Fig. 3 is a perspective view of the magnetic mold. After the molten metal matrix material is poured into the mold the magnet is turned on. While under the influence of the electromagnetic field the fibers or powder 11 are drawn toward the surface 21 of the mold 20. This causes the concentration of fibers or powder to significantly increase in the outer regions of the part, for example, at an outer wear (tooth) surface where a belt would engage the sprocket.

Fig. 4 is a perspective view of the finished part. Fibers 11 are concentrated at an outer region of the part at the teeth 102 where enhanced strength and wear characteristics afforded by the fibers are desired. Where the enhanced wear and strength are not required, only the non-reinforce metal material 101 is present.

In an alternative method the fiber or powder may be applied directly to the mold prior to pouring the molten metal. Fig. 12 is a perspective view of the magnetic mold with the fibers or powder applied before pouring. First, the electromagnet 22 is turned on. Fibers or powder 11 are then sprayed on the mold 20 to the desired depth and concentration. The electromagnetic force aligns and holds the fibers or powder in the desired position in the mold. The host alloy is then poured into the mold 20. The host alloy flows around the fibers held in place by the electromagnet.

In an alternate embodiment, a static charge is applied to the mold 20. The static charge then holds the
fibers or powder in place on the mold until the host alloy is poured and solidifies. In this embodiment mold 20 is made of a conductive metal material.

Fig. 13 is a perspective view of the filled mold. In this alternate process there are no fibers or powder mixed into the host alloy 101, the fibers are only combined with the molten metal once in the mold. Fig. 14 is a perspective view of the finished part. The reinforced portion 110 is disposed at the outer region of the part where the desired enhanced wear and strength is required.

In an alternate method, centrifugal force can be used to move the fibers or powder to the desired location(s) in the part. Fig. 5 is a perspective view of the centrifugal mold. Metal matrix material 10 containing fibers or powder are heated to a molten state and poured into a mold 10. Again, during the process the host metal matrix alloy must be superheated and the mold preheated to prevent premature solidification. Once mold 20 is filled a cover 23 is attached using fasteners 24 or clamps. The assembly is then attached to an armature 30. Fig. 6 is a perspective view of an armature machine. The assembly is rotated at a speed sufficient to cause the fibers and/or powder to be moved radially outward to the outer region of the part. To achieve uniform separation around the part the speed is ramped up from one RPM to approximately 3000 RPM over a period of approximately 30 seconds and then kept at the top speed until the part solidifies.

Fig. 7 is a perspective view of a finished part. The reinforcing material 11 is disposed in the area of the teeth 102 thereby enhancing the strength and durability of the part. Non-reinforced material 101 is
radially inwardly displaced by the radially outward movement of the reinforcing material.

Further, based upon differing specific gravities for the fibers or powders and the metal matrix, gravity may be relied upon to move the fiber or powder to the desired location(s) on the part. Fig. 8 is a side view of a part formed using gravity separation. A mixture of metal matrix material is prepared with the desired concentration of fibers or powder. Again, the host metal matrix material is superheated and the mold preheated to prevent premature solidification. During the process the denser powder or fibers sink toward the bottom of the mold, thereby reinforcing the metal matrix material accordingly. Non-reinforced or less densely reinforced material develops as the fibers or powders sink in the mold through the molten metal. It is necessary to keep the mold heated until the desired amount of settling has occurred to prevent improper distribution by rapid solidification. Gravity separation cannot be used for symmetrical parts that require uniform strengthening on all sides, such as sprockets. It is suitable for applications such as pistons and shafts where one end requires higher wear resistance or higher strength.

For coating processes the fiber or powder is placed in a mold using different means and then the host metal alloy is poured in the mold. This can be achieved by covering the mold with the powder and/or fiber and pouring the molten metal into the mold. The molten metal material will penetrate the fiber or powder coating, thereby enriching only on the surface of the finished part.

Fig. 9 is a perspective view showing application of powder or fiber to a mold. Covering or coating of the mold surface with the powder or fiber can be
accomplished by spraying, brushing, or any other suitable method using for example, a spray gun SP. For example, powder and fiber 11 can be mixed with a liquid suspension material such as water, solvents, or any suitably tacky material to make the fibers or powder temporarily adhere to the mold surface until the molten metal is poured. The tacky material should be of a type that burns off easily with little or no gases generated when contacted by molten metal. Any fumes from the suspension and adhesive are vented from the mold. During casting the molten metal fills the porosity/cavity of the fiber or powder material on the mold surface to create a layer of very high concentration of durable material intermixed with host metal material on the part surface. It is important to note that for this method the alloy is not premixed with fibers or powder. It is only during casting that the alloy mixes with the fibers or powder already applied to the mold surface.

Fig. 10 is a perspective view of the mold with poured metal. Fibers or powder 11 are present at the mold surface. The poured metal material 101 (without fibers or powder) mixes among the fibers or powder and then cools in the mold.

Fig. 11 is a perspective view of a finished part. Enriched metal matrix material 110 is present on the outer surface of the part. Non-reinforced material 101 is present in the interior of the part. In this embodiment only the wear surface of the part is reinforced without the need to reinforce the entire part.

In an alternate method, static electricity may be used to hold the sprayed powder or fiber on the mold surface. In this method the fiber or powder is charged in a manner known in the art and the mold is given a
charge opposite that of the powder/fiber so the powder or fiber adheres to the mold surface as it is sprayed in.

An alternate method includes use of a two (or more) step molding or casting process. Fig. 15 is a perspective view of the two step mold. The mold comprises a mold 20 and a core 25. Disposed between mold 20 and core 25 is a cavity 200. Cavity 200 is where the highly reinforced metal matrix material is poured. Core 200 serves as a means of restricting the reinforced material to the portion of the finished part as needed. In the two step process, reinforced metal matrix material containing fibers and/or powder is mixed. The mixed material is then superheated and poured into cavity 200 and allowed to cool, thereby forming reinforced layer 201. Once cooled core 25 is removed.

Fig. 16 is a perspective view of the two step mold with the core removed. Layer 201 has solidified.

Fig. 17 is a perspective view of the two step mold. Superheated and non-reinforced alloy 101 is then poured into the volume created by the withdrawn core 25 and allowed to cool.

In order for the first and second castings to weld together the second casting is performed at a higher temperature than a "normal" casting operation, that is the material for the second casting is super heated. Depending on the mold type (for example, metal, sand, graphite, etc.) the super heating will be anywhere from 100 to 250 degrees Celsius above the melting point of the cast material. The method comprises using the core wherein the bulk of the mold volume is closed to the flow of the molten metal during the first casting leaving only a relatively narrow layer 201 open at the desired finished part surfaces, in most cases these are usually outer surfaces.
For the first casting pour the molten metal matrix material is poured into the mold, with a very high concentration of powder already in it. The concentration can be in the range of up to approximately 95% powder or fiber, or a combination of both, to approximately 5% alloy. After solidification of the first pour, for the second pour the core is removed and a non-reinforced, that is not containing fibers or powder, host metal alloy is poured in the cavity formerly occupied by the now removed core. In order for the second pour to weld completely to the solidified high fiber/powder content outer layer, it is super heated to cause it to partially melt the surface of the first pour layer and thereby solidify the two pours together.

In yet another alternate method, a pre-made temporary separation dam made of the host metal alloy is first placed in the mold so the reinforced areas that need to be rich in powder and/or fiber are segregated from the rest of the part. Fig. 18 is a perspective view of the dam mold. The mold comprises an outer portion 301 and an inner portion 302. Disposed between the inner and outer portion is a cavity 300. To form the dam, non-reinforced metal material 101 is poured into the cavity 300 and allowed to cool forming a dam 150.

Fig. 19 is a perspective view of the mold with the dam. Dam 150 is placed within mold 20. Dam 150 is advantageously sized to create a cavity 200 and cavity 202.

For this method a host metal matrix material having a high concentration of powder and/or fiber, and a non-reinforced host alloy are simultaneously pored in their respective cavities. The high concentration mixture is poured into cavity 200. The non-reinforced alloy is poured into cavity 202. Both are superheated enough to
melt the surface of the temporary separation dam 150 thereby melting and welding the temporary dam to the two poured materials in order to create a one piece part. Fig. 20 is a perspective view of the finished part. Dam 150 is completely subsumed into the reinforced material 201 and the non-reinforced material 101.

Once the cast part is removed from the mold it is usually further processes to create the final part dimensions. A number of methods are available to accomplish this result. In addition to sizing a part to a final dimension using an ironing die after casting, parts with a heavy concentration of powder and/or fiber in a surface layer can be forged, spun, or worked mechanically with known metal working methods to compact the powder and/or fiber area further.

In an alternate method, the reinforced fiber/powder layer can be briefly exposed to very high temperatures (1100° to 1250° Celsius) to sinter the fiber and/or powder particles together. Of course, the low melt temperature host metal material core cannot be exposed to the high sintering temperature, thus induction heating is an acceptable method to heat the outer layer rapidly. The reinforced layer which is in the range of approximately 70% to 95% fiber and/or powder material with the reminder being host metal material will see a rapid sintering of the fiber and/or powder particles. Most of the host alloy in the reinforced layer (approximately 25% to 5% remainder) which is disposed in the interstitial cavities/porosities between the fiber and/or powder particles will melt and solidify rapidly. A slight amount of the trapped host metal material may sweat out of the part in this stage without any problems. The general categories described in this specification, namely, mold coating and separation of the fiber/powder from the
molten metal matrix, can also be combined to achieve higher concentrations of fiber/powder in the desired areas if needed.

The reinforcing process described herein does not have to be only applied symmetrically to a part, it can be localized on a specific portion of a part as well. For example, localized reinforcement or strengthening can be performed on shafts or other parts that have a limited area that needs to be stronger or have more wear resistance, but not otherwise required on the entire part. For instance where a particular area of a shaft is in oscillating contact with another part and as a result requires enhanced wear resistance. Although a non-symmetrical version is shown for only one process, namely, magnetic coating, localized reinforcement can be used for all of the processes explained in this specification.

Although forms of the invention has been described herein, it will be obvious to those skilled in the art that variations may be made in the construction and relation of parts and method without departing from the spirit and scope of the invention described herein.
Claims

We claim:
1. A method of reinforcing a low melting temperature cast metal part comprising:
   preparing a molten metal material having a melting temperature;
   mixing a reinforcing material having a melting temperature greater than the melting temperature of the molten metal material into the molten metal material;
   pouring the molten metal material into the mold;
   applying a force to the reinforcing material causing the reinforcing material to occupy a predetermined portion of the mold and thereby a predetermined portion of the cast metal part; and
   solidifying the molten metal material.

2. The method as in claim 1 comprising applying a magnetic force.

3. The method as in claim 1 comprising applying a centrifugal force.

4. A method of reinforcing a low melting temperature cast metal part comprising:
   preparing a molten metal material having a melting temperature;
   adding a reinforcing material having a melting temperature greater than the melting temperature of the molten metal material to the mold;
   applying a force to the reinforcing material causing the reinforcing material to occupy a predetermined portion of the mold and thereby a predetermined portion of the cast metal part;
pouring the molten metal material into the mold; and
cooling the molten metal material.

5. The method as in claim 4 comprising applying a
magnetic force.

6. The method as in claim 4 comprising applying a
centrifugal force.

7. The method as in claim 4 comprising applying a
static electric charge to a mold surface.

8. A method of reinforcing a low melting temperature
cast metal part comprising:
   preparing a molten metal material having a melting
temperature;
   adding a reinforcing material having a melting
temperature greater than the melting temperature of the
molten metal material to the mold in a predetermined
location;
   pouring the molten metal material into the mold; and
   cooling the molten metal material.

9. The method as in claim 8 comprising retaining the
reinforcing material in a predetermined position in the
mold by application of a magnetic force.

10. A method of reinforcing a low melting temperature
cast metal part comprising:
    preparing a molten metal material having a melting
temperature;
    mixing a predetermined amount of reinforcing
material having a melting temperature greater than the
melting temperature of the molten metal material into the molten metal material;
  pouring the molten metal material into a predetermined portion of the mold, said portion
  constituting less than the total volume of the mold;
  preparing a second molten metal material having a melting temperature;
  pouring the second molten metal material into the mold remainder; and
  solidifying the molten metal material and the second molten metal material.

11. The method as in claim 10 comprising segregating the predetermined portion of the mold from the mold remainder by occupying the mold remainder so as to exclude molten material from the mold remainder during pouring into the predetermined portion of the mold.
A. CLASSIFICATION OF SUBJECT MATTER

INV. B22D19/16

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)

B22D C22C

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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

Date of the actual completion of the international search

25 April 2008

Date of mailing of the international search report

07/05/2008

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epc rt.
Fax: (+31-70) 340 3016

Authorized officer

Lombois, Thierry
C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>EP 0 280 830 A (BATTELLE MEMORIAL INSTITUTE [CH]) 7 September 1988 (1988-09-07) claims 1-14</td>
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