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(71) Applicant:
**Mazda Motor Corporation
Aki-gun, Hiroshima-ken 730-8670 (JP)**

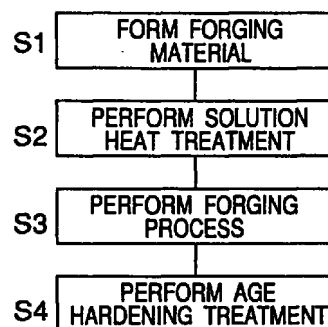
(72) Inventors:
• **Sakamoto, Kazuo,
c/o Mazda Motor Corporation
Aki-gun, Hiroshima 730-8670 (JP)**
• **Yamamoto, Yukio,
c/o Mazda Motor Corporation
Aki-gun, Hiroshima 730-8670 (JP)**

(74) Representative:
**Zinnecker, Armin, Dipl.-Ing. et al
Lorenz-Seidler-Gossel,
Widenmayerstrasse 23
80538 München (DE)**

(54) **Light metal forging material manufacturing method and forged member manufacturing method using the material**

(57) This invention relates to a method for manufacturing a light metal forging material provided as a material to be subjected to a forging process for obtaining a light metal forged member, by charging a light metal molten material into the molding cavity of a specified molding die so as to form a forging material and subjecting the forging material to a specified heat treatment before the forging process, there is generated a blister attributed to internal gas expansion in the material, thereby, in obtaining a finished product made of light metal by forming a forging material and forging the material, a blister associated with heat treatment is reliably prevented from being generated in a product (forged member) through this forging process.

Fig.6



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a method for manufacturing a light metal forging material provided as a material to be subjected to a forging process for obtaining a light metal forged member and to a method for manufacturing a forged member obtained through the forging process using the material.

[0002] Conventionally, as a method for manufacturing a light metal member made of a light metal such as magnesium (occasionally represented by the symbol Mg for the element hereinafter), magnesium alloys, aluminum (occasionally represented by the symbol Al for the element hereinafter) and aluminum alloys, a method based on the casting method is most general. As a kind of this casting method, there has conventionally been well known the so-called die casting method for achieving an increase in speed of the casting process by injecting and charging a light metal molten material into a casting die at high pressure so as to allow the productivity to be remarkably improved.

[0003] There has also been known a semi-solid casting method for injecting and charging a light metal molten material in a semi-solid state (basically at a temperature lower than its melting point) into a casting die in contrast to the normal melt-casting method for injecting and charging a light metal molten material in a completely molten state at a temperature higher than its melting point into a casting die.

[0004] Furthermore, in recent years, a light metal member manufacturing method using an injection molding method is being put into practical use particularly for Mg and its alloys or the like. This method uses an injection molding apparatus and injects and charges a light metal molten material in the molten state from its injection nozzle into the molding cavity of a molding die. This method can efficiently manufacture a molded product (light metal member) in a cycle time shorter than that of the casting method. This injection molding method is also known as a process that is relatively clean and has a higher safety in terms of the working environment as compared with the casting method such as the die casting method while enabling the obtainment of a light metal molded product with high accuracy, homogeneity and little deficiency of shrinkage cavity or the like in terms of quality.

[0005] In connection with this injection molding method, there has also been known the so-called semi-solid injection molding method for injecting and charging a light metal molten material in a semi-solid state (basically at a temperature lower than its melting point) from an injection nozzle into a molding cavity (refer to, for example, the prior art reference of Japanese Patent Publication No. 2-15620).

[0006] Not only in the casting method but also in the injection molding method, since the molten material temperature (the term of "molten material" hereinafter also includes the semi-solid material that is not in the completely molten state) is relatively low when a semi-solid metal molten material is used, the so-called "burr" scarcely appears and being appropriate for injection at high speed and/or high pressure, also providing advantages for improving the productivity.

[0007] Furthermore, by putting the metal molten material into the semi-solid state and charging the same into the molding cavity, the molten material in which the unmolten solid phase portion is mixed in the completely molten liquid phase portion is charged as it is. Therefore, the metal molten material is charged in a state close to a laminar flow, as a consequence of which the involvement of gas is allowed to be relatively little for the obtainment of a structure of a relatively uniform quality. This can improve the mechanical characteristics of the obtained member as a whole.

[0008] It is to be noted that the term of "solid phase" means "the portion that is not molten but maintained in the solid state when the light metal molten material is in the semi-solid state", while the term of "liquid phase" means "the portion that is completely molten and put in the liquid state" in the present specification. The aforementioned "solid phase" can be easily distinguished as "the portion that has not been molten in the semi-solid metal molten material state but maintained in the solid state" from the portion in the liquid phase "that was completely molten in the semi-solid metal molten material state and put in the liquid state" by observing the solidified structure of the obtained light metal member. The term of "solid phase" used for the obtained member means the "portion that has not been molten in the semi-solid light metal molten material state but maintained in the solid state (has been solid phase)".

[0009] It is to be further noted that the term of "solid phase rate" means "the rate of the solid phase relative to the whole molten material (solid phase + liquid phase) in the semi-solid metal molten material" in the present specification. The above rate can be numerically obtained as the rate (area ratio) of the portion that has been in the "solid phase" relative to the whole observed region by observing the solidified structure of the molded product after the injection.

[0010] It is to be further noted that the term of "semi-solid state" used for the light metal molten material basically means "a state in which the raw material in the solid state (solid phase) and the raw material that is molten and put in the liquid state (liquid phase) are coexisting" in the present specification. That is a state obtained normally by heating the raw material below its melting point. It is to be assumed that the case where the solid phase rate is substantially equal to 0 (zero) percent when the temperature of the light metal molten material is substantially at the melting point or just over the melting point is also included in this "semi-solid state".

[0011] Even if the light metal molten material itself has a substantially zero percent solid phase rate, considering the practical injection molding process of, for example, the semi-solid injection molding method, then a solidified portion

(the so-called cold plug) and a high-solid-phase portion having a high solid phase rate are generated at the nozzle tip side as a consequence of the cooling of the metal molten material inside the molten material feed path of the injection nozzle in an interval from the end of one injection (one shot) from the injection nozzle into the die to the execution of the next injection (next shot). Therefore, the light metal molten material to be actually injected into the molding cavity is to inevitably include the solid phase portion.

[0012] On the other hand, if it is required to obtain a light metal member of a higher strength than that of the aforementioned casting method or the injection molding method, the forging method is most generally adopted. Furthermore, as a kind of manufacturing method for manufacturing a light metal member by this forging method, there is known the so-called casting-forging method for forming a material (forging material) appropriate for the forging process by a casting method prior to the forging process, setting this material to a specified forging die and subjecting the material to a forging process, as disclosed in, for example, the prior art reference of Japanese Patent Laid-Open Publication No. 6-297127.

[0013] According to this casting-forging method, a semi-finished product having a shape relatively resembling the shape of the finished product (forged member) can be formed through the forging process in the casting (material) stage. This allows the forging process to be simplified into only one process of the forging for finishing and also allows a member of a complicated shape to be forged. Furthermore, the material structure can be adjusted so that even a material of an inferior forging property can be subjected to the forging process without a trouble.

[0014] It is to be noted that the forming of the forging material in this casting-forging method can be performed by the injection molding method instead of the casting method.

[0015] However, the casting process (forming process for forging material) of this casting-forging method sometimes involves a gas including air in a molten material charging stage or the like. If the solidification occurs in the state in which the gas is involved and internally existing, then there is remaining a gas defect inside the casting product. Particularly when a casting process capable of performing charging at high speed and high pressure such as die casting method is used for this forging material forming process, then the gas defect more easily occurs, and the problem becomes still more significant.

[0016] As is well known, the so-called T6 treatment for performing age hardening treatment after a solution heat treatment is normally performed as a heat treatment for increasing the strength by improving its mechanical properties. However, if the forged product obtained by the casting-forging method is produced with the gas defect included inside as described above in the casting stage (i.e., in the material stage for forging), then swelling (the so-called blister) occurs, during the T6 treatment to be subsequently performed, due to the expansion of the gas that is existing inside in the solution heat treatment stage in which heating is maintained at a relatively high temperature, and the blister directly appears as a defect in the product (forged member) obtained through the forging process. The above disadvantages lead to the problem that the mechanical characteristics are impaired failing in sufficiently obtaining the effect of increasing the strength through the T6 treatment and further to the problem that a process for removing the impaired appearance is needed.

[0017] Furthermore, for the above reasons, the casting process (for example, die casting) capable of performing charging at high speed and high pressure cannot be used for the casting process (forming process of forging material) of the casting-forging method, and this becomes significantly disadvantageous in improving the productivity.

[0018] Furthermore, the problem of the generation of a blister in the case of the forged product obtained through the subsequent process is similarly observed not only in the case where the forming of the forging material is performed by casting but also in the case where another process is adopted. Particularly when a process for charging the light metal molten material into the molding cavity at high speed and/or high pressure is used (for example, in the case where the forging material is formed by the injection molding method), the problem of the generation of a blister in the forged product emerges more significantly.

[0019] It is to be noted that the "solution heat treatment" means a treatment for maintaining the heating of the material or the member for a specified time within the temperature range of the solid solution and then bringing the same into the room temperature, by which the homogenization of the material structure can be promoted.

[0020] For example, explaining the case of the Mg alloy containing four or more percent by weight of Al taken as an example, the compound (Mg₁₇Al₁₂) formed through the preceding process is dissolved into the material structure to promote the homogenization by performing the aforementioned solution heat treatment. It is to be noted that the aforementioned compound is not generated in the case where the Al content is smaller than four percent by weight. Therefore, the homogenization process through the solution heat treatment is generally not needed.

SUMMARY OF THE INVENTION

[0021] The present invention has been made in view of the aforementioned technical problems that possibly occur when obtaining a light metal forged member by forming a forging material and subjecting the material to a forging process and has the object of reliably preventing the generation of a blister due to the heat treatment of the product (forged

member) obtained through a forging process.

[0022] Accordingly, a first aspect of the present invention provides a method for manufacturing a forging material that is made of a light metal and provided as a material to be subjected to a forging process for obtaining a forged member made of the light metal, comprising the steps of charging a light metal molten material into a molding cavity of a specified molding die so as to form a forging material and subjecting the forging material to a specified heat treatment before the forging process, thereby generating a blister attributed to internal gas expansion in the material.

[0023] According to the first aspect of the present invention, when manufacturing a light metal forging material provided as a material to be subjected to the forging process for obtaining a light metal forged member, the light metal molten material is charged into the molding cavity of the specified molding die for the formation of a forging material, and this forging material is subjected to the specified heat treatment prior to the forging process, preparatorily causing a blister attributed to the expansion of the internal gas in the material. Therefore, by subjecting this forging material to the forging process in the subsequent process, the blister that has preparatorily been generated on the material surface and/or its vicinities is crushed. That is, the cavity portion that has existed as the blister on the material (surface and/or its vicinities) is crushed by the compression force applied during the forging process, and this portion becomes a sound basis metal. That is, by preparatorily generating the blister in the material stage, this blister can be crushed through the forging process, by which the generation of blister in the forged member obtained in the subsequent process can be infallibly prevented.

[0024] In a second aspect of the present invention, based on the above aspect of the invention, the specified heat treatment is a solution heat treatment.

[0025] According to the second aspect of the present invention, basically an effect similar to that of the above aspect on the invention can be produced. In particular, the aforementioned specified heat treatment is the solution heat treatment, and this can promote the homogenization of the material structure of the forging material, improve the forging property in the subsequent forging process and improve the mechanical characteristics of the forged member to be obtained.

[0026] Also, in a third aspect of the present invention, based on the above aspect of the invention, the heat treatment temperature of the solution heat treatment is not lower than 300°C.

[0027] The reason why the lower limit value of the heat treatment temperature of the solution heat treatment is set to 300°C is that no blister can be generated previously (before the forging process) in the forging material even if the material is subjected to the solution heat treatment at a temperature lower than the above temperature.

[0028] According to the third aspect of the present invention, basically an effect similar to that of the above aspects on the invention can be produced. In particular, by setting the heat treatment temperature of the solution heat treatment to a temperature of not lower than 300°C, a blister can be generated preparatorily (before the forging process) in the forging material through this solution heat treatment.

[0029] Further, in a fourth aspect of the present invention, based on the above aspects of the invention, the heat treatment time of the solution heat treatment is not shorter than one hour.

[0030] The reason why the lower limit value of the heat treatment time of the solution heat treatment is set to one hour is that the homogenization of the material structure cannot be effectively promoted through the solution heat treatment within a time shorter than the above value.

[0031] According to the fourth aspect of the present invention, basically an effect similar to that of the above aspects can be produced. In particular, by setting the heat treatment time of the solution heat treatment to one hour or longer, the homogenization of the material structure can be effectively promoted through this solution heat treatment.

[0032] Furthermore, in a fifth aspect of the present invention, based on the above aspects of the invention, the solution heat treatment is performed under the treatment conditions that the heat treatment temperature be not lower than 350°C and not higher than 450°C and the heat treatment time be not shorter than 10 hours and not longer than 24 hours.

[0033] The reason why the heat treatment temperature of the solution heat treatment is set not lower than 350°C is that a blister can be reliably generated previous to the forging process in the forging material by performing the solution heat treatment at a temperature higher than the above temperature. The reason why the temperature is set not higher than 450°C is that a phenomenon of the growth of a crystal grain occurs in the material structure when the solution heat treatment temperature exceeds this value and the mechanical characteristics of the product obtained through the forging process are reduced.

[0034] The reason why the heat treatment time of the solution heat treatment is set not shorter than 10 hours is that the effect of homogenizing the material structure can be reliably obtained through the solution heat treatment. The reason why the time is set not longer than 24 hours is that the effect is saturated and goes uneconomical when the treatment is continued in excess of this time.

[0035] According to the fifth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, by setting the heat treatment temperature to a temperature that is not lower than 350°C and not higher than 450°C on the solution heat treatment conditions, the reduction in mechanical

characteristics of the forged member attributed to the phenomenon of the crystal grain growth inside the material structure can be effectively prevented and a blister can be reliably preparatorily generated in the forging material. Furthermore, the heat treatment time is set not shorter than 10 hours and not longer than 24 hours. Therefore, the effect of homogenizing the material structure can be reliably obtained through the solution heat treatment, and this prevents the effect from being saturated and going uneconomical.

[0036] Furthermore, in a sixth aspect of the present invention, based on the above aspects of the invention, the relative density of the forging material after the specified heat treatment is set not smaller than 90%.

[0037] The reason why the lower limit value of the relative density of the forging material is set to 90% is that the amount of blisters that have previously been generated in the forging material stage is too large when the relative density is smaller than this value, and the blister cannot be infallibly crushed. As a result, it is difficult to assure the tensile strength that is generally practically needed. Furthermore, a variation between the maximum value and the minimum value becomes large, and this leads to a difficulty in obtaining the stabilized strength.

[0038] According to the sixth aspect of the present invention, basically an effect similar to that of the above aspects can be produced. In particular, the relative density is set not smaller than 90% after the specified heat treatment. This enables the obtainment of a sound forged member by crushing the blister that has preparatorily been generated in the forging material stage and enables the assurance of the tensile strength that is generally practically needed.

[0039] Furthermore, in a seventh aspect of the present invention, based on the above aspects of the invention, the relative density of the forging material after the specified heat treatment is set not smaller than 95%.

[0040] The reason why the lower limit value of the relative density of the forging material is set to 95% is that a sound forged member can be obtained by infallibly crushing the blister that has previously been generated in the forging material stage when the relative density is not smaller than this value. As a result, the tensile strength that is generally practically needed can be sufficiently assured. Furthermore, the variation between the maximum value and the minimum value is very small, and this allows a high tensile strength to be stably obtained.

[0041] According to the seventh aspect of the present invention, basically an effect similar to that of the above aspect of the invention can be produced. In particular, the relative density is set not smaller than 95% after the specified heat treatment. This enables the obtainment of a sound forged member by more reliably crushing the blister that has preparatorily been generated in the forging material stage and consequently enables the assurance of the tensile strength that is generally practically needed. Furthermore, a high tensile strength having a very small variation between the maximum value and the minimum value can be stably obtained.

[0042] Furthermore, in an eighth aspect of the present invention, based on the above aspects of the invention, the formation of the forging material is performed by charging the light metal molten material into the molding cavity of the specified molding die in a semi-solid state.

[0043] According to the eighth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, by using the light metal molten material in the semi-solid state for the formation of the forging material, a high-quality forging material having a smaller number of shrinkage cavities and gas defect can be obtained as compared with the case of the process that uses the molten material in the completely molten state. Furthermore, since the molten material temperature is low, the so-called "burr" scarcely appears and is appropriate for the process of high speed and/or high pressure, also providing advantages for improving the productivity.

[0044] Furthermore, in a ninth aspect of the present invention, based on the above aspects of the invention, the formation of the forging material is performed by injecting and charging the light metal molten material into the molding cavity of a specified molding die.

[0045] According to the ninth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced in the case where the injection molding method that easily generates a blister through the heat treatment is adopted for the formation of the forging material.

[0046] By adopting the injection molding for the formation of the forging material, the forging material can be manufactured in a short cycle time with high efficiency as compared with the case of the casting process. Furthermore, it is enabled to obtain a light metal forging material that is relatively clean and has a higher safety in terms of the working environment as compared with the casting method such as the die casting method and has high accuracy, homogeneity and little deficiency of shrinkage cavity or the like in terms of quality.

[0047] Furthermore, in a tenth aspect of the present invention, based on the above aspects of the invention, the light metal is a magnesium (Mg) alloy containing four or more percent by weight of aluminum (Al).

[0048] The reason why the lower limit value of the Al content is set to four percent by weight is that the homogenization process through the solution heat treatment is generally not needed since a compound (Mg₁₇Al₁₂) that hinders the homogenization of the material structure in the preceding process is not generated when the Al content is smaller than this value.

[0049] According to the tenth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced in the case where the compound (Mg₁₇Al₁₂) that hinders the homogenization of the

material structure in the preceding processes is generated when the Al content is not smaller than four percent by weight and the Mg alloy that needs the homogenization process by the solution heat treatment is used as a material.

[0050] Furthermore, in a eleventh aspect of the present invention, there is provided a forged member manufacturing method comprising the step of subjecting the light metal forging material of any one of the claims 1 through 10 to a forging process, thereby crushing the blister included in the forging material.

[0051] According to the eleventh aspect of the present invention, the light metal forging material according to any one of the first through tenth inventive aspects is subjected to the forging process so as to crush the blister that has been included in the forging material. Through the above processes, the cavity portion that has internally existed as a blister on the material (surface and/or its vicinities) is crushed by the compression force applied during the forging process, and this portion becomes a sound basis metal. That is, by generating the blister in the material stage, this blister can be crushed through the forging process, reliably preventing the generation of a blister in the forged member obtained in the subsequent process. Subsequently, by subjecting the forged member to the age hardening treatment under the specified heat treatment conditions, a sound forged member that has a high strength and is free from the generation of a blister can be obtained. In this case, an effect similar to that of any one of the first through tenth inventive aspects can be produced.

[0052] Furthermore, in a twelfth aspect of the present invention, based on the above aspect of the invention, the light metal forging material is heated through the specified heat treatment and thereafter subjected directly to the forging process without undergoing a cooling process.

[0053] According to the twelfth aspect of the present invention, basically an effect similar to that of the above aspect of the invention can be produced. In particular, the light metal forging material is heated through the specified heat treatment and thereafter directly subjected to the forging process without undergoing the cooling process. Therefore, the heating process to the forging temperature prior to the forging process can be eliminated, allowing the forging process to be remarkably simplified.

[0054] Furthermore, in a thirteenth aspect of the present invention, based on the above aspects of the invention, a second heat treatment is performed after the forging process at a temperature lower than the heating temperature of the specified heat treatment.

[0055] According to the thirteenth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, the second heat treatment is performed at a temperature lower than the heating temperature of the specified heat treatment after the forging process. Therefore, no blister is generated through the heat treatment after the forging process.

[0056] Furthermore, in a fourteenth aspect of the present invention, based on the above aspects of the invention, the second heat treatment is a heat treatment related to the specified heat treatment.

[0057] According to the fourteenth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, by performing the mutually interrelated heat treatment processes (the specified heat treatment and the second heat treatment) separately before and after the forging process, the necessary heat treatment can be performed without generating a blister in the forged member.

[0058] Furthermore, in a fifteenth aspect of the present invention, based on the above aspects of the invention, the specified heat treatment is a solution heat treatment and the second heat treatment is an age hardening treatment.

[0059] According to the fifteenth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, by performing the mutually interrelated solution heat treatment and age hardening treatment separately before and after the forging process, the necessary heat treatment can be performed without generating a blister in the forged member.

[0060] Furthermore, in a sixteenth aspect of the present invention, based on the above aspects of the invention, the heat treatment temperature of the age hardening treatment is not lower than 100°C.

[0061] The reason why the lower limit value of the heat treatment temperature of the age hardening treatment is set to 100°C is that the age hardening cannot effectively be generated in the forging material at a temperature lower than the above temperature.

[0062] According to the sixteenth aspect of the present invention, basically an effect similar to that of the above aspects of the invention can be produced. In particular, the heat treatment temperature of the age hardening treatment is set not lower than 100°C, and therefore, the age hardening effect can be effectively produced on the forged member.

[0063] Furthermore, in a seventeenth aspect of the present invention, based on the above aspects of the invention, the age hardening treatment is performed under the treatment conditions that the heat treatment temperature be not lower than 100°C and not higher than 250°C, and the heat treatment time be not shorter than three hours and not longer than 24 hours.

[0064] The reason why the lower limit value of the heat treatment temperature of the age hardening treatment is set to 100°C is that the age hardening cannot effectively be generated in the forging material at a temperature lower than the above value. The reason why the upper limit value is set to 250°C is that the age hardening is excessively effected when the temperature exceeds this value, as a consequence of which the tensile strength and the extension cannot

compatibly be satisfied within an appropriate range.

[0065] The reason why the lower limit value of the heat treatment time of the age hardening treatment is set to three hours is that the age hardening cannot effectively be generated within a time shorter than the above value. The reason why the upper limit value is set to 24 hours is that the effect is saturated and goes uneconomical when the treatment is continued in excess of this time.

[0066] According to the seventeenth aspect of the present invention, basically an effect similar to that of the above aspect of the invention can be produced. In particular, the heat treatment temperature of the age hardening treatment is set to a temperature that is not lower than 100°C and not higher than 250°C. With this arrangement, the age hardening effect can be effectively produced on the forged member, and the tensile strength and the elongation can be compatibly obtained within an appropriate range while preventing the excessive age hardening. Furthermore, the heat treatment time of the age hardening treatment is set not shorter than three hours and not longer than 24 hours. With this arrangement, the age hardening effect can be effectively generated on the forged member, and the effect is prevented from being saturated and going uneconomical.

BRIEF DESCRIPTION OF THE DRAWINGS

[0067]

Fig. 1 is an explanatory view schematically showing the cross section of part of an injection molding apparatus according to an embodiment of the present invention;

Fig. 2 is a graph showing the effect of improving the tensile strength of a forged member according to the results of Test 1;

Fig. 3 is a graph showing a relation between the hardness of the forged member and a solution heat treatment time according to the results of Test 3;

Fig. 4 is a graph showing a relation between the tensile strength of the forged member manufactured by the method of the present invention and the relative density before the forging of the forging material according to the results of Test 4;

Fig. 5 is a graph showing a relation between the hardness of the forged member manufactured by the method of the present invention and an age hardening treatment temperature according to the results of Test 5;

Fig. 6 is a chart for explaining the processes of a forged member manufacturing method according to an embodiment of the present invention;

Fig. 7 is a chart for explaining the processes of a forged member manufacturing method according to a prior art example.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0068] Preferred embodiments of the present invention will be described in detail below with reference to the accompanying drawings taking the case where the injection molding method is adopted for the formation of a forging material as an example.

[0069] Reference is first made to the formation of a forging material according to the present embodiment. Fig. 1 is an explanatory view schematically showing the cross section of part of an injection molding apparatus for performing injection molding of a light metal forging material according to an embodiment of the present invention.

[0070] As shown in this figure, the injection molding apparatus 1 is the so-called screw type including a cylinder 2 that has a nozzle 3 at its tip portion and is to be heated by a heater 4 provided on its peripheral surface, a screw 6 that is rotatably supported inside the cylinder 2 and a molding machine body 5 connected with the cylinder 2, a rotary driver 7 provided with, for example, a motor mechanism, a speed reducer and so on for rotatively driving the screw 6, a hopper 8 in which a raw material is loaded and stored and a feeder 9 for feeding the raw material into the molding machine body 5 while measuring the raw material inside the hopper 8.

[0071] Although not specifically illustrated, the molding machine body 5 is internally provided with a high-speed injection mechanism for advancing the screw 6 toward the nozzle 3 side. This high-speed injection mechanism is constructed so as to advance the screw 6 in accordance with specified timing, detect the retreat of the screw 6 by a predetermined distance when it occurs, stop the rotation of the screw 6 and concurrently stop the retreating movement of the screw.

[0072] The injection molding apparatus 1 is set in position so that the internal path of the nozzle 3 communicates with a runner portion 12 connected with a molding cavity 11 and used with the leading end side of the cylinder 2 joined with a metallic die 10.

[0073] The raw material loaded and stored in the hopper 8 is measured by a specified amount and fed into the molding machine body 5 by the feeder 9 and then fed by the rotating screw 6 into the cylinder 2 put in a heated state.

The fed raw material is heated to a specified temperature while being sufficiently stirred and kneaded by the rotation of the screw 6 inside the cylinder 2. According to the present embodiment, a light metal molten material put preferably in a semi-solid state at a temperature lower than the melting point is obtained through this process.

[0074] As the thus-obtained light metal molten material in the semi-solid state is squeezed out ahead of the screw 6, the screw 6 is retreated by the pressure. According to another method, the screw may be forcibly retreated at the desired speed.

[0075] If the screw 6 is retreated by the predetermined distance, then the high-speed injection mechanism (not shown) inside the molding machine body 5 detects the above event and stops the rotation of the screw 6 and concurrently stops the retreating movement. The measurement of the raw material may be performed by setting the distance of retreat of the screw 6.

[0076] Then, by advancing the screw 6 that stops rotating and is put in the retreated position by the high-speed injection mechanism (not shown) so as to apply a specified pressure, the light metal molten material in the semi-solid state is injected from the nozzle 3 into the metallic die 10. That is, the light metal molten material is injected from the nozzle 3 and charged into the molding cavity 11 via the runner portion 12.

[0077] In the present embodiment, a magnesium (Mg) alloy that is a kind of light metal is used as the raw material and this is fed in the form of, for example, chip-shaped pellets to the hopper 8 of the injection molding apparatus 1. A passage that extends from the hopper 8 to the inside of the molding machine body 5 is preferably filled with an inert gas (argon, for example) for preventing the oxidation reaction of the raw material (Mg alloy pellets).

[0078] The molding cavity 11 of the metallic die 10 is preferably formed into a shape that resembles the shape of the forming cavity of the forging die (not shown) used for the forging process to be performed after this injection molding, and there can be obtained a half-finished injection molded product (forging material) resembling the forged member that is the product to be obtained in the subsequent process.

[0079] This enables the simplification of the forging process to only one process of the finishing forging and enables the forging of even a member of a complicated shape. Furthermore, even a material of an inferior forging property can be subjected to the forging process without a hitch.

[0080] According to the conventional procedure, as shown in Fig. 7, the forging material injection-molded by the injection molding apparatus 1 and the metallic die 10 is subjected to the forging process (step S52) after undergoing the forming process (step S51) of the forging material, and the obtained forged member is subjected to the T6 treatment comprised of the solution heat treatment (step S53) and the subsequent age hardening treatment (step S54). However, according to this conventional method, as described above, there is a concern about the generation of the so-called blister in the solution heat treatment stage. If this blister appears as a defect in the forged product (forged member) obtained in the subsequent process, then its mechanical characteristics are impaired, consequently failing in sufficiently obtaining the effect of improving the strength through the T6 treatment and also impairing the appearance. Therefore, a process for removing those blisters is needed.

[0081] Accordingly, the present embodiment reliably prevents the generation of the blister associated with the heat treatment of this forged product (forged member) by contriving the order of the forging process and the heat treatment when obtaining the light metal forged product through the formation of a forging material and the forging of the material, allowing a sound forged member (i.e., a high-quality forged member having little deficiency and the specified mechanical characteristics) to be obtained.

[0082] That is, as shown in Fig. 6, the forging material is formed by semi-solid injection molding by means of the injection molding apparatus 1 and the metallic die 10 (step S1), and thereafter the above forging material is subjected to the solution heat treatment on specified heat treatment conditions (step S2) prior to the forging process. Through the above processes, a blister is preparatorily generated in the forging material stage. It is to be noted that this blister is normally generated in the form of a blister like a skin burn on the material surface and/or its vicinities, and therefore, the blister can be easily detected by visual observation.

[0083] As described above, the forging material in which the blister has preparatorily been generated is subjected to the forging process by means of a specified forging die (step S3). Through this process, the blister that has preparatorily been generated on the material surface and/or its vicinities is crushed. That is, the cavity portion that has existed as the blister on the material (surface and/or its vicinities) is crushed by a compression force applied during the forging process, and this portion becomes a sound basis metal.

[0084] Subsequently, the forged member is subjected to the age hardening treatment on the specified heat treatment conditions (step S4).

(Test 1)

[0085] As a test for confirming the effect of improving the strength of the forged member according to the present invention, the following Test 1 was executed. The test results are shown in Fig. 2. This confirmation test was executed with two types of raw materials of Mg alloys (alloy A and alloy B) listed in the following Table 1.

[0086] The raw materials of Mg alloys each contained four or more percent by weight of Al. The reason why the lower limit value of the Al content was set to four percent by weight is that a compound (Mg₁₇Al₁₂) hindering the homogenization of the material structure was not generated in the preceding processes when the Al content was smaller than this value and therefore the homogenization process by the solution heat treatment was originally not needed.

Table 1

(Unit: percent by weight)							
	Al	Zn	Mn	Fe	Ni	Cu	Mg
Alloy A	7.2	0.2	0.22	0.003	0.0008	0.001	Remainder
Alloy B	9.0	0.7	0.23	0.003	0.0008	0.001	Remainder

[0087] According to this Test 1, the formation of the forging material is performed by the aforementioned semi-solid injection molding in each example. A comparative example 1 shows the case where no heat treatment is performed after the injection molding, while a comparative example 2 shows the case where the T6 treatment is performed after the injection molding according to the conventional process procedure (see Fig. 7). With regard to the comparative example 2 and the embodiment of the present invention, the heat treatment conditions of the solution heat treatment and the age hardening treatment were identical as follows.

• Solution heat treatment

[0088]

Alloy A: The heat treatment temperature was 400°C and the retention time was 10 hours.

Alloy B: The heat treatment temperature was 410°C and the retention time was 16 hours.

• Age hardening treatment

[0089]

Alloy A: The heat treatment temperature was 175°C and the retention time was 16 hours.

Alloy B: The heat treatment temperature was 170°C and the retention time was 16 hours.

[0090] The forging process was performed by heating and maintaining the heat treatment temperature of the solution heat treatment and thereafter directly setting the forging material in the forging die without cooling, in the present embodiment. Therefore, the heating process to the forging temperature prior to the forging process could be eliminated and the forging process was remarkably simplified.

[0091] A tension test piece was cut from each forged members of the comparative examples 1 and 2 and the embodiment of the present invention according to specified shape and dimensions, and the tensile strength of each of these test pieces were examined. The results are shown in Fig. 2.

[0092] As is apparent from the graph of Fig. 2, with regard to either of the materials of the alloy A and the alloy B, the comparative example 2 has the effect of improving the tensile strength by about 20% or less, whereas the present invention has the improvement effect of about 50% or more, with respect to the comparative example 1. According to the above, it was able to be confirmed that the forged member of the present embodiment sufficiently obtained the effect of improving the strength through the heat treatment in comparison with that of the comparative example 2. The standard tensile strength of the generic die casting alloy of JIS MDI alloy is 230 [MPa] and this is generally the practically needed strength. In the case of the forged member of the present invention, the tensile strength of either of the materials of the alloy A and the alloy B sufficiently exceeds this strength (230 [MPa]).

[0093] There was observed the generation of blister in part of the forged member of the comparative example 2, whereas the generation of blister was not observed in the forged member of the embodiment of the present invention, with no appearance impairment.

[0094] As described above, according to the embodiment of the present invention, when manufacturing a light metal forging material provided as a material to be subjected to the forging process for obtaining the light metal forged member, preferably the light metal molten material in the semi-solid state is injected and charged into the molding cavity of the specified molding die for the formation of the forging material, and this forging material is subjected to the solution

heat treatment prior to the forging process in order to preparatorily generate a blister attributed to the expansion of the internal gas of the material. Therefore, by subjecting this forging material to the forging process in the subsequent process, the blister that has preparatorily been generated on the material surface and/or its vicinities is crushed. That is, the cavity portion that has existed as the blister on the material (surface and/or its vicinities) is crushed by the compression force applied during the forging process, and this portion becomes a sound basis metal. Subsequently, by subjecting the forged member to the age hardening treatment on the specified heat treatment conditions, a sound forged member having a high strength free from the generation of a blister can be obtained.

[0095] In the present embodiment, the forging process is performed by heating and maintaining the heat treatment temperature of the solution heat treatment and thereafter directly setting the forging material in the forging die without cooling. However, it is acceptable to perform the forging process by once cooling the forging material and thereafter heat the material to the forging temperature.

[0096] In this case, it is also acceptable to subject the once cooled forging material to machining or the like, scrape off the blister that has preparatorily been generated on the material surface and/or its vicinities through the solution heat treatment and thereafter perform the forging process; By thus removing the blister prior to the forging process, a sound forged member can be reliably obtained regardless of the extent of the generation of blisters.

(Test 2)

[0097] Next, there was performed Test 2 for examining a relation between the heat treatment temperature of the solution heat treatment and the generation of a blister. This Test 2 subjected the forging material obtained by the aforementioned semi-solid injection molding to the solution heat treatment at various heat treatment temperatures (200°C, 250°C, 300°C, 350°C and 400°C) and examined the presence or absence of the generation of a blister in each case. The blister generating test was performed by means of the alloy A of the aforementioned Table 1. The test results are shown in Table 2.

Table 2

Heat treatment temperature	Blister generated
200 °C	Absent
250 °C	Absent
300 °C	Absent
350 °C	Present
400 °C	Present

[0098] According to the results of Test 2, it was discovered that no blister was generated when the heat treatment temperature of the solution heat treatment was not higher than 300°C (200°C, 250°C and 300°C) and the blister was generated when the temperature exceeds 300°C (350°C and 400°C).

[0099] Therefore, in order to preparatorily generate a blister in this material (prior to the forging process) after the formation of the forging material, it is proper to perform the solution heat treatment at a heat treatment temperature of not lower than 300°C and preferably not lower than 350°C in order to more reliably generate a blister.

(Test 3)

[0100] Next, there was performed Test 3 for examining an influence of the heat treatment time of the solution heat treatment on the hardness of the forged member, or the finished product. The test results are shown in Fig. 3. According to Test 3, the alloy A of Table 1 was used as a material to be subjected to the semi-solid injection molding. With regard to the forging material obtained through this process, the comparative example (the curve J1 and the curve J2 in the graph of Fig. 3) that has undergone the forging process and thereafter the T6 treatment (solution heat treatment + age hardening treatment) as in the conventional procedure, and the embodiment of the present invention (the curve K1 and the curve K2 in the graph of Fig. 3) that has been first subjected to the solution heat treatment and thereafter to the forging process, then has undergone the age hardening treatment, according to the method of the present invention, were subjected to the measurement of hardness (Vickers hardness: Hv) of the surface and/or its vicinities by varying the solution heat treatment time.

[0101] The heat treatment temperature of the solution heat treatment of Test 3 was set in two ways as follows.

- The curve J1 and the curve K1 in the graph of Fig. 3:

heat treatment temperature of 400°C

- The curve J2 and the curve K2 in the graph of Fig. 3:

heat treatment temperature of 450°C

[0102] The age hardening treatment was performed on the conditions that the material was maintained at a temperature of 175°C for 15 hours and thereafter be cooled in air.

[0103] The graph of Fig. 3 shows the fact that the hardness of the forged product (forged member) is reduced in correspondence with the duration of the solution heat treatment time according to the curve J2 of the comparative example in the case where the heat treatment temperature is 450°C, thereby, it is discovered that the phenomenon of crystal grain growth occurs inside the material structure. Therefore, in this case, the mechanical characteristics of the product obtained through the forging process are degraded. In contrast to this, according to the curve K2 of the embodiment of the present invention, there is observed no reduction in hardness of the forged product even in the case where the heat treatment temperature is 450°C, similarly to the case where the temperature is 400°C (the curve K1), and it is discovered that no crystal grain growth phenomenon occurs inside the material structure even when the solution heat treatment is performed at a high temperature. Accordingly, in this case, it is enabled to reduce the time necessary for the solution heat treatment by increasing the heat treatment temperature within a temperature range of not higher than 450°C.

[0104] Furthermore, according to the graph of Fig. 3, the reduction in hardness is insufficient and unstable in each case of the curves so long as the heat treatment duration of the solution heat treatment is not longer than one hour. In order to effectively obtain the effect of homogenizing the material structure through the solution heat treatment, the heat treatment time of the solution heat treatment is required to be not shorter than one hour. It was discovered that the heat treatment time should more preferably be not shorter than 10 hours in order to more reliably obtain the effect. If the heat treatment is performed in excess of 24 hours, then the effect is saturated and goes uneconomical.

(Test 4)

[0105] Next, there was performed Test 4 for examining the influence of the relative density of the material prior to the forging (i.e., the forging material obtained after the solution heat treatment) on the tensile strength of the forged member.

[0106] This test is to examine the influence of the degree of the generation of a blister on the mechanical characteristics of the product (forged member) that has undergone the forging process and the age hardening treatment with regard to the case in which the blister has preparatorily been generated through the solution heat treatment before the forging process according to the present invention. The test results are shown in Fig. 4.

[0107] According to Test 4, the material of the alloy A of Table 1 was used as a material to be subjected to the semi-solid injection molding. Tension test pieces of specified shape and dimensions were cut from each product (forged member) obtained by subjecting the thus obtained forging material first to the solution heat treatment, then to the forging process and thereafter to the age hardening treatment according to the method of the present invention, and the tensile strengths of these test pieces were examined.

[0108] The relative density of the material (forging material) prior to the forging was varied within a range of about 84% to 97% by variously changing the solution heat treatment conditions.

[0109] The graph of Fig. 4 shows the fact that a sound forged member can be obtained by reliably crushing the blister that has previously been generated in the forging material stage when the relative density of the forging material prior to the forging is not smaller than 95% (corresponding to case where the amount of generated blister is smaller than 5%). As a result, it was discovered that the tensile strength of 260 [MPa] could be assured at minimum and a high tensile strength could be stably obtained with a very small variation between the maximum value and the minimum value. If the relative density is not smaller than 90%, then the strength (230 [MPa]) that is generally practically needed can be assured at and around the maximum value although a certain degree of variation exists.

[0110] In contrast to this, if the relative density is smaller than 90%, then the strength (230 [MPa]) that is generally practically needed cannot be assured and the variation between the maximum value and the minimum value becomes very large, resulting in a difficulty in obtaining a stabilized strength. This may presumably be attributed to the fact that the amount of blisters preparatorily generated in the forging material stage is too large to be reliably crushed.

[0111] According to the above, it is required to set the relative density of the forging material prior to the forging to a density of not smaller than 90% in order to assure the tensile strength (230 [MPa]) that is generally practically needed, and more preferably set the relative density to a density of not smaller than 95% in order to stably obtain a higher tensile

strength.

(Test 5)

5 [0112] Next, there was performed Test 5 for examining the influence of the heat treatment temperature of the age hardening treatment on the hardness of the forged product (forged member). The test results are shown in Fig. 5. According to Test 5, the alloy B of Table 1 was used as a material to be subjected to the semi-solid injection molding, and the thus obtained forging material was subjected first to the solution heat treatment, then to the forging process and thereafter to the age hardening treatment with the heat treatment temperature variously changed according to the method of the present invention. The hardness (Vickers hardness: Hv) of the surface and/or its vicinities of the obtained product was measured.

[0113] The solution heat treatment of Test 5 was performed under the conditions that the heat treatment temperature was 410°C and the retention time was 16 hours. The age hardening treatment was performed under the conditions that the material was maintained at each temperature for 16 hours and thereafter cooled in air.

15 [0114] According to the graph of Fig. 5, it was discovered that the age hardening could not be effected on the forged member when the age hardening treatment temperature was lower than 100°C and the excessive age hardening resulted to excessively increase the hardness when the temperature exceeded 250°C. It is known that the forged member comes to have a reduced elongation although the tensile strength can be sufficiently obtained if this excessive age hardening is effected on the forging material, consequently failing in compatibly obtaining both the factors within an appropriate range.

[0115] Therefore, it is required to maintain the age hardening treatment temperature at 100°C or higher and it is preferable to set the upper limit of the temperature to 250°C or lower. Furthermore, in regard to the age hardening treatment time, at least three hours are necessary for causing the effective age hardening in the forged member, however, the effect is saturated and goes uneconomical when the treatment is performed in excess of 24 hours.

25 [0116] It is to be noted that the aforementioned embodiment is based on the case where the semi-solid injection molding is adopted for the formation of the forging material. However, the present invention is not limited to this case and is able to be effectively applied to the case where a variety of other processes such as a semi-solid casting method, an injection molding method or a casting method using a light metal molten material in a completely molten state is adopted for the formation of the forging material. The aforementioned embodiment is based on the case where the Mg alloy is used as an injection material. However, the present invention can be effectively applied to the case where a light metal of another kind is used as a material.

[0117] As described above, the present invention is not limited to the aforementioned embodiment and is, of course, able to be subjected to various modifications, improvement in design and so on within the scope not departing from the essence thereof.

Claims

1. A method for manufacturing a forging material that is made of a light metal and provided as a material to be subjected to a forging process for obtaining a forged member made of the light metal, comprising the steps of:

charging a light metal molten material into a molding cavity of a specified molding die so as to form a forging material; and subjecting the forging material to a specified heat treatment before the forging process, thereby generating a blister attributed to internal gas expansion in the material.

2. A light metal forging material manufacturing method as claimed in claim 1, wherein

the specified heat treatment is a solution heat treatment.

3. A light metal forging material manufacturing method as claimed in claim 2, wherein

a heat treatment temperature of the solution heat treatment is not lower than 300°C.

4. A light metal forging material manufacturing method as claimed in claim 2 or 3, wherein

a heat treatment time of the solution heat treatment is not shorter than one hour.

5. A light metal forging material manufacturing method as claimed in any one of claims 2 through 4, wherein the solution heat treatment is performed under the treatment conditions that the heat treatment temperature be not lower

than 350°C and not higher than 450°C and the heat treatment time be not shorter than 10 hours and not longer than 24 hours.

- 5 6. A light metal forging material manufacturing method as claimed in any one of claims 1 through 5, wherein a relative density after the specified heat treatment is set not smaller than 90%.
7. A light metal forging material manufacturing method as claimed in claim 6, wherein a relative density after the specified heat treatment is set not smaller than 95%.
- 10 8. A light metal forging material manufacturing method as claimed in any one of claims 1 through 7, wherein the formation of the forging material is performed by charging a light metal molten material in a semi-solid state into the molding cavity of the specified molding die.
- 15 9. A light metal forging material manufacturing method as claimed in any one of claims 1 through 8, wherein the formation of the forging material is performed by injecting and charging a light metal molten material into the molding cavity of the specified molding die.
- 20 10. A light metal forging material manufacturing method as claimed in any one of claims 1 through 9, wherein the light metal is a magnesium alloy containing four or more percent by weight of aluminum.
- 25 11. A forged member manufacturing method comprising the step of subjecting the light metal forging material claimed in any one of claims 1 through 10 to a forging process, thereby crushing the blister included in the forging material.
- 30 12. A forged member manufacturing method as claimed in claim 11, wherein the light metal forging material is heated through the specified heat treatment and thereafter subjected directly to the forging process without undergoing a cooling process.
- 35 13. A forged member manufacturing method as claimed in claim 11 or 12, wherein a second heat treatment is performed at a temperature lower than the heating temperature of the specified heat treatment after the forging process.
- 40 14. A forged member manufacturing method as claimed in claim 13, wherein the second heat treatment is a heat treatment related to the specified heat treatment.
- 45 15. A forged member manufacturing method as claimed in claim 14, wherein the specified heat treatment is a solution heat treatment and the second heat treatment is an age hardening treatment.
- 50 16. A forged member manufacturing method as claimed in claim 15, wherein the heat treatment temperature of the age hardening treatment is not lower than 100°C.
- 55 17. A forged member manufacturing method as claimed in claim 16, wherein the age hardening treatment is performed under the treatment conditions that the heat treatment temperature be not lower than 100°C and not higher than 250°C and the heat treatment time be not shorter than three hours and not longer than 24 hours.

Fig. 1

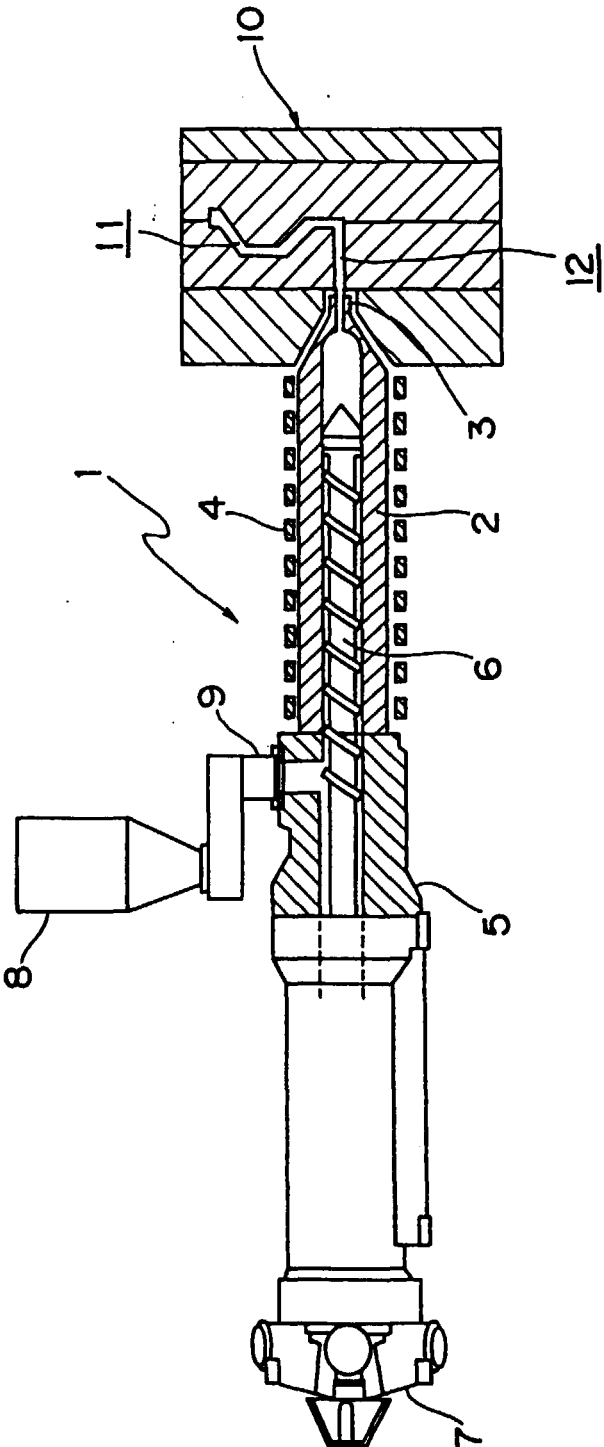


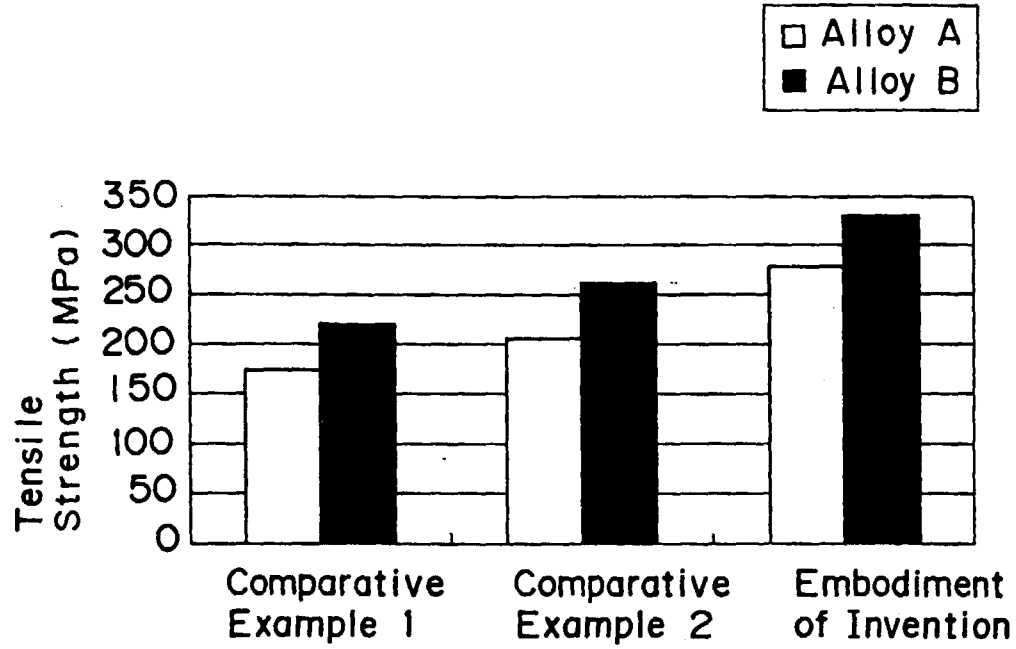
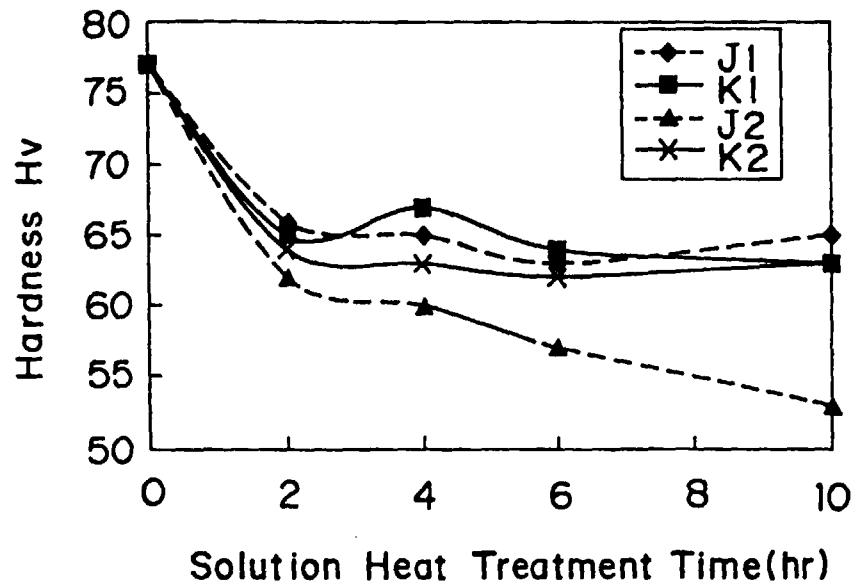
Fig. 2*Fig. 3*

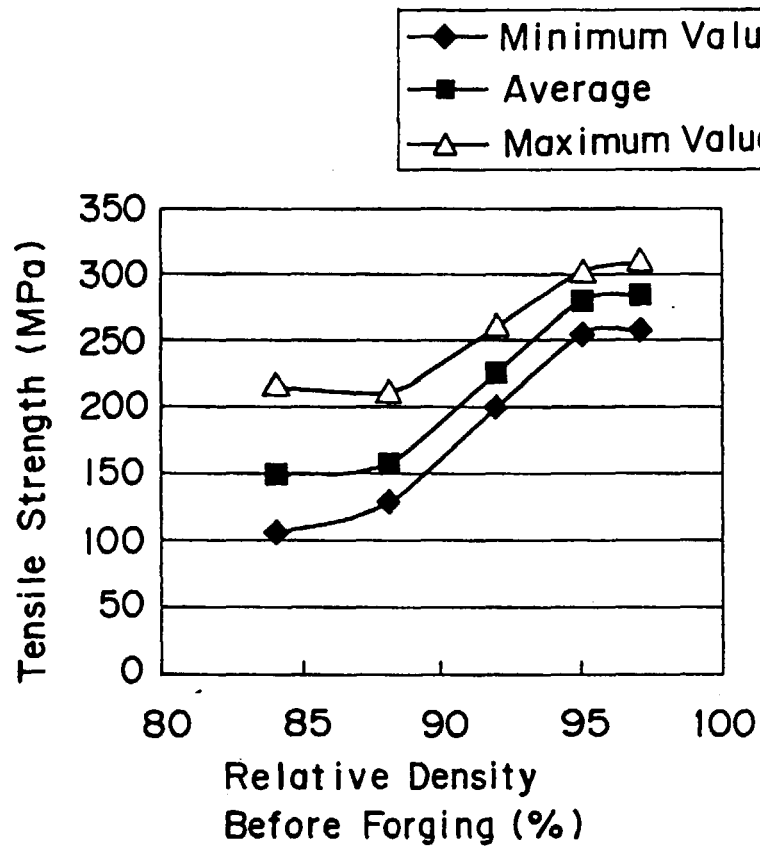
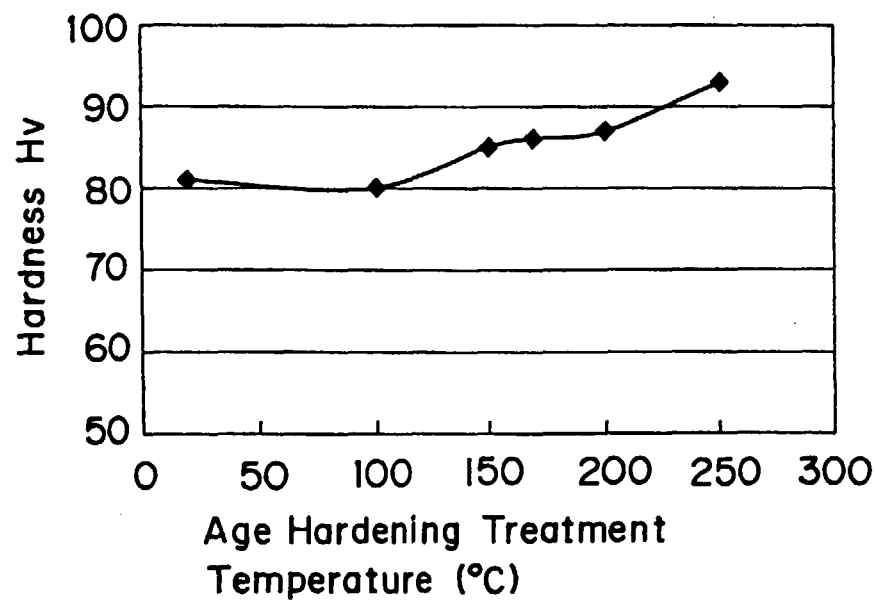
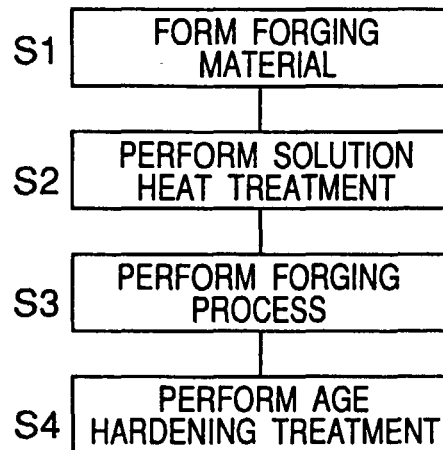
Fig. 4*Fig. 5*

Fig.6*Fig.7*