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(54) **CASTABLE ALUMINUM ALLOY**

(76) Inventor: **Herbert William Doty**, Amherst, NH (US)

Correspondence Address:
CHARLES H. ELLERBROCK
General Motors Corporation
Legal Staff, Mail Code 482-C23-B21
P.O. Box 300
Detroit, MI 48265-3000 (US)

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(60) Provisional application No. 60/551,997, filed on Mar. 10, 2004.

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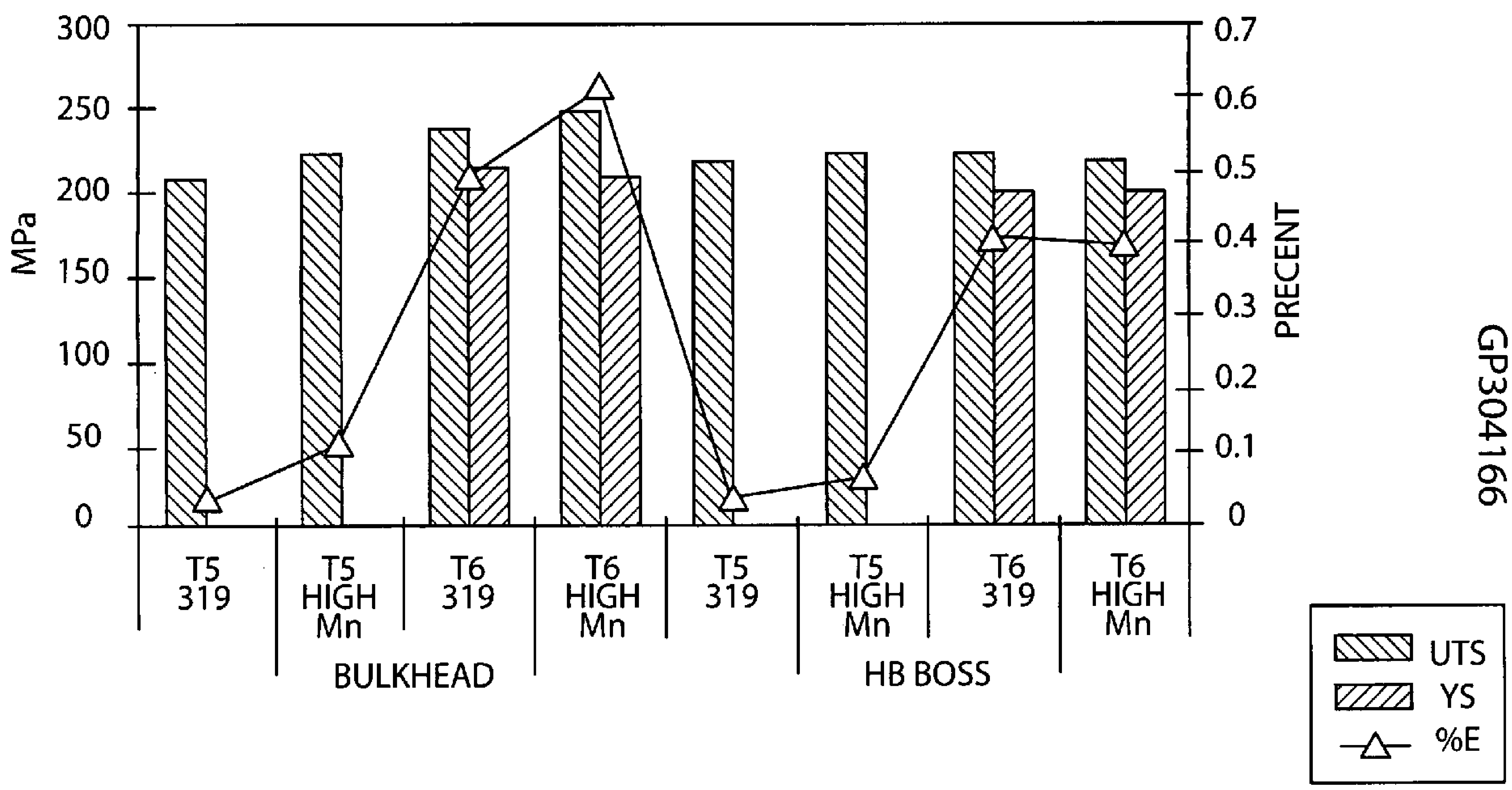
(57) **ABSTRACT**

A castable aluminum alloy includes, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight % to reduce porosity and increase tensile strength of a casting made from the alloy.



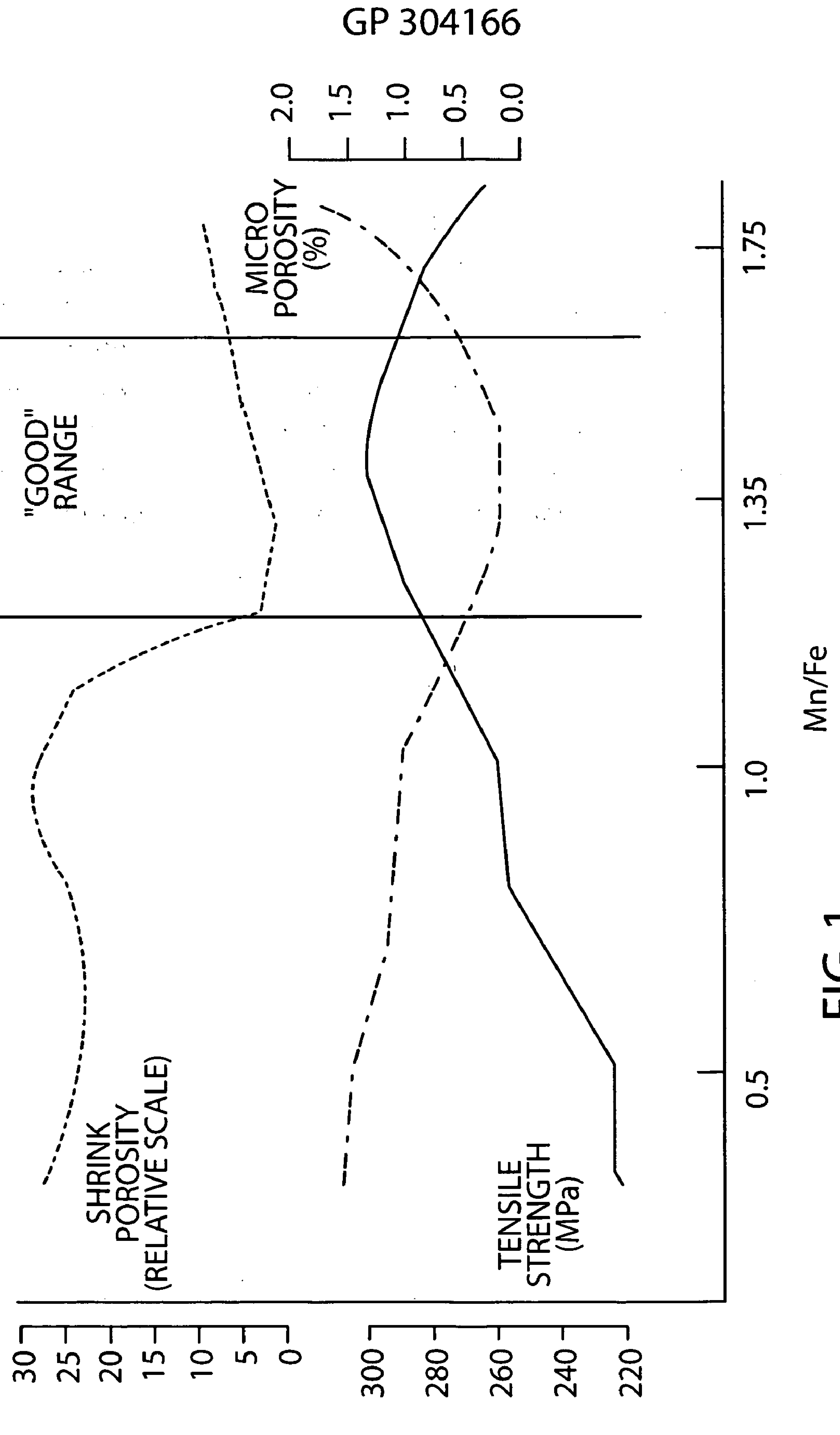

GP 304166
"GOOD" RANGE
SHRINK POROSITY (RELATIVE SCALE)
MICRO POROSITY (%)
TENSILE STRENGTH (MPa)
Mn/Fe
0.5
1.0
1.35
1.75
2.0
1.5
1.0
0.5
0.0
30
25
20
15
10
5
0
300
280
260
240
220

FIG. 1

GP304166

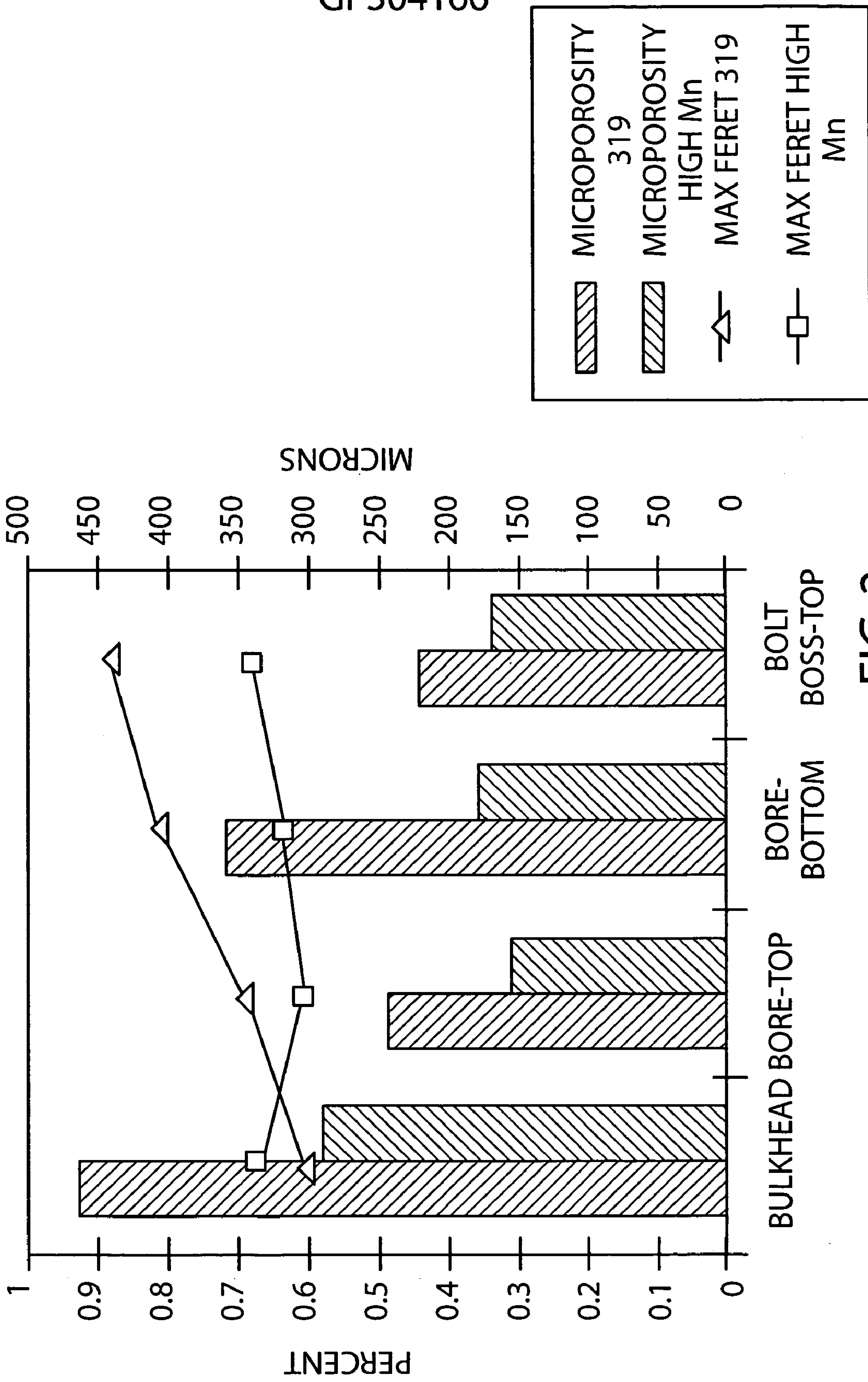


FIG. 2

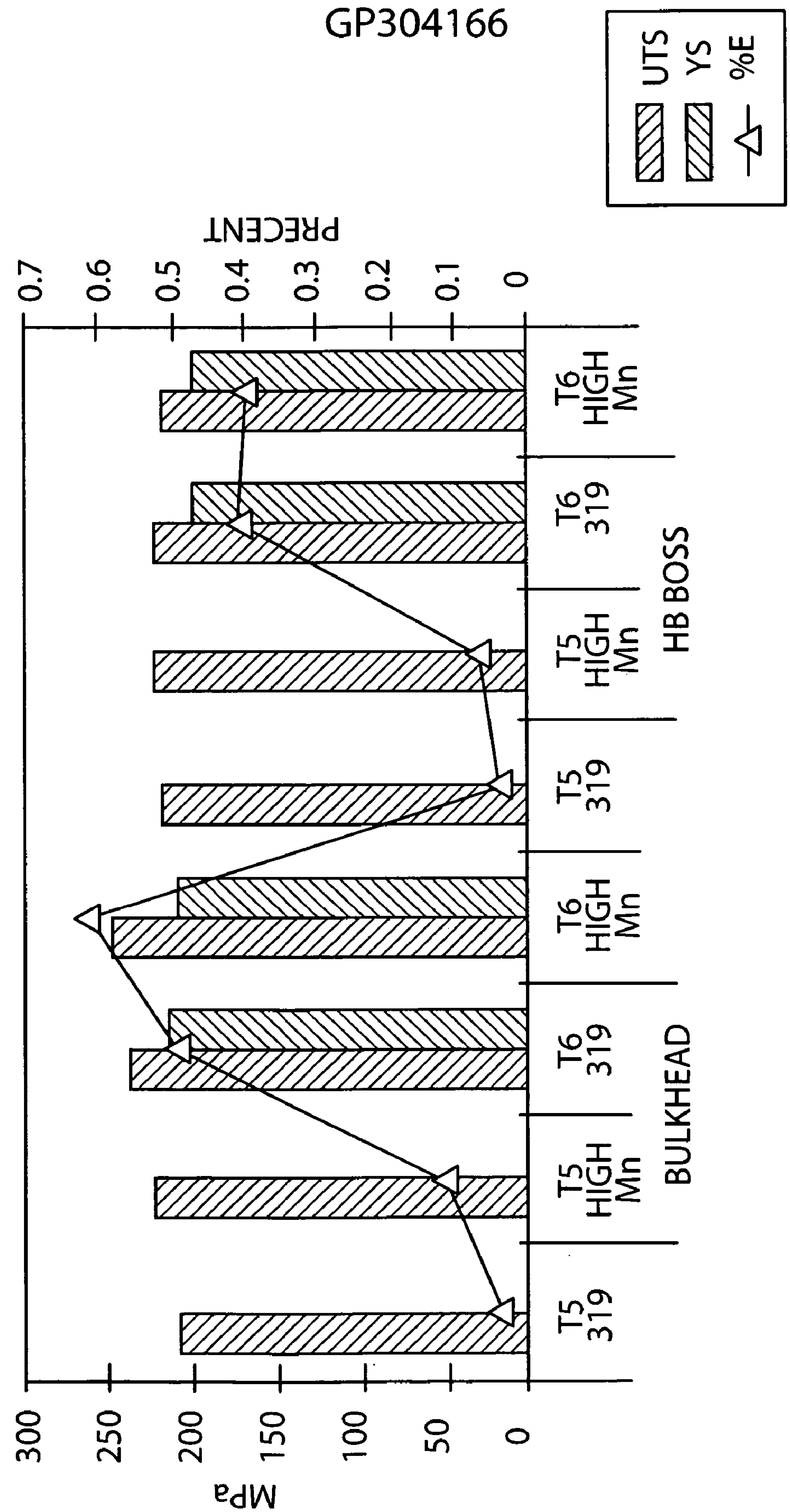

GP304166
UTS
YS
%E
PRECENT
MPa
0
50
100
150
200
250
300
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
T5 319
T5 HIGH Mn
T6 319
T6 HIGH Mn
T5 319
T5 HIGH Mn
T6 319
T6 HIGH Mn
BULKHEAD
HB BOSS

FIG. 3

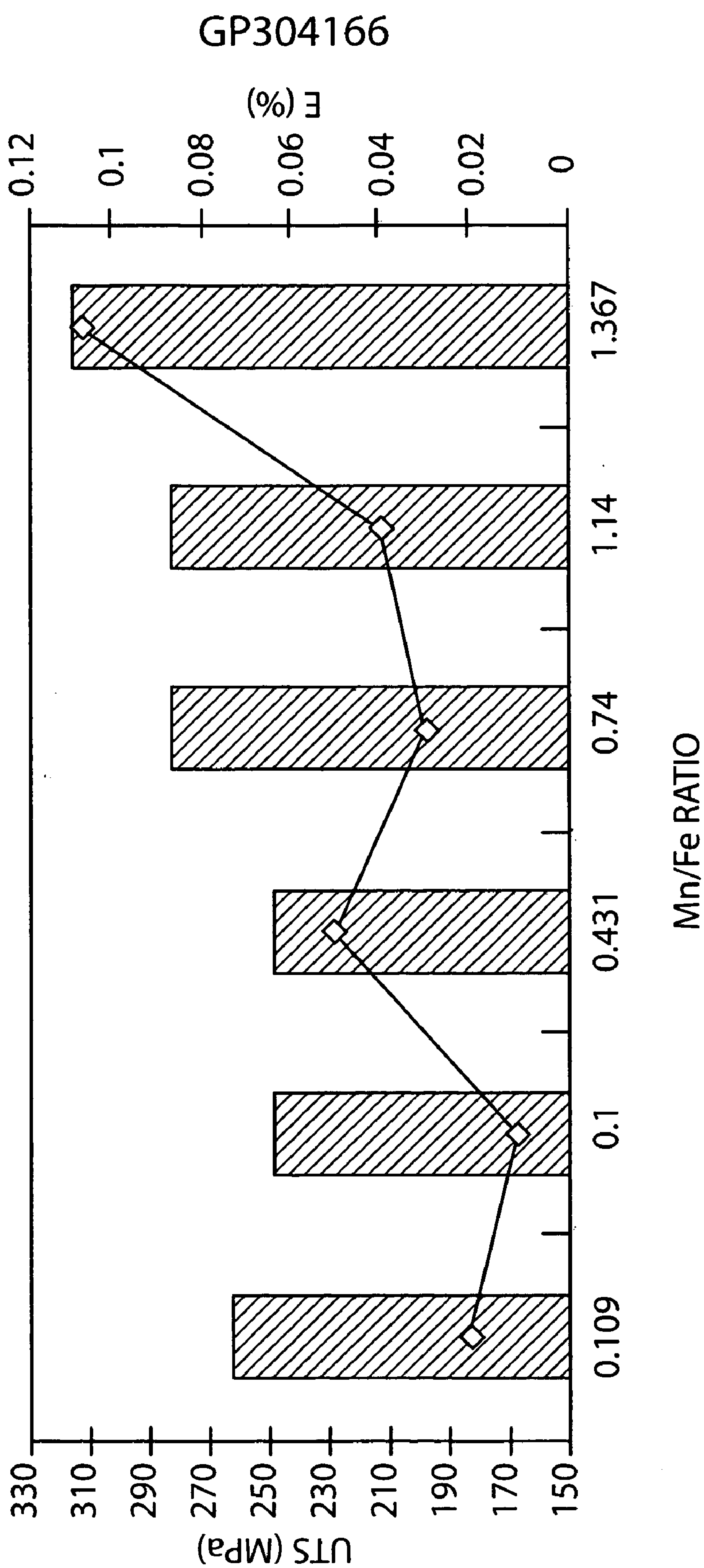

GP304166
E (%)
0.12
0.1
0.08
0.06
0.04
0.02
0
UTS (MPa)
330
310
290
270
250
230
210
190
170
150
0.109
0.1
0.431
0.74
1.14
1.367
Mn/Fe RATIO

FIG. 4

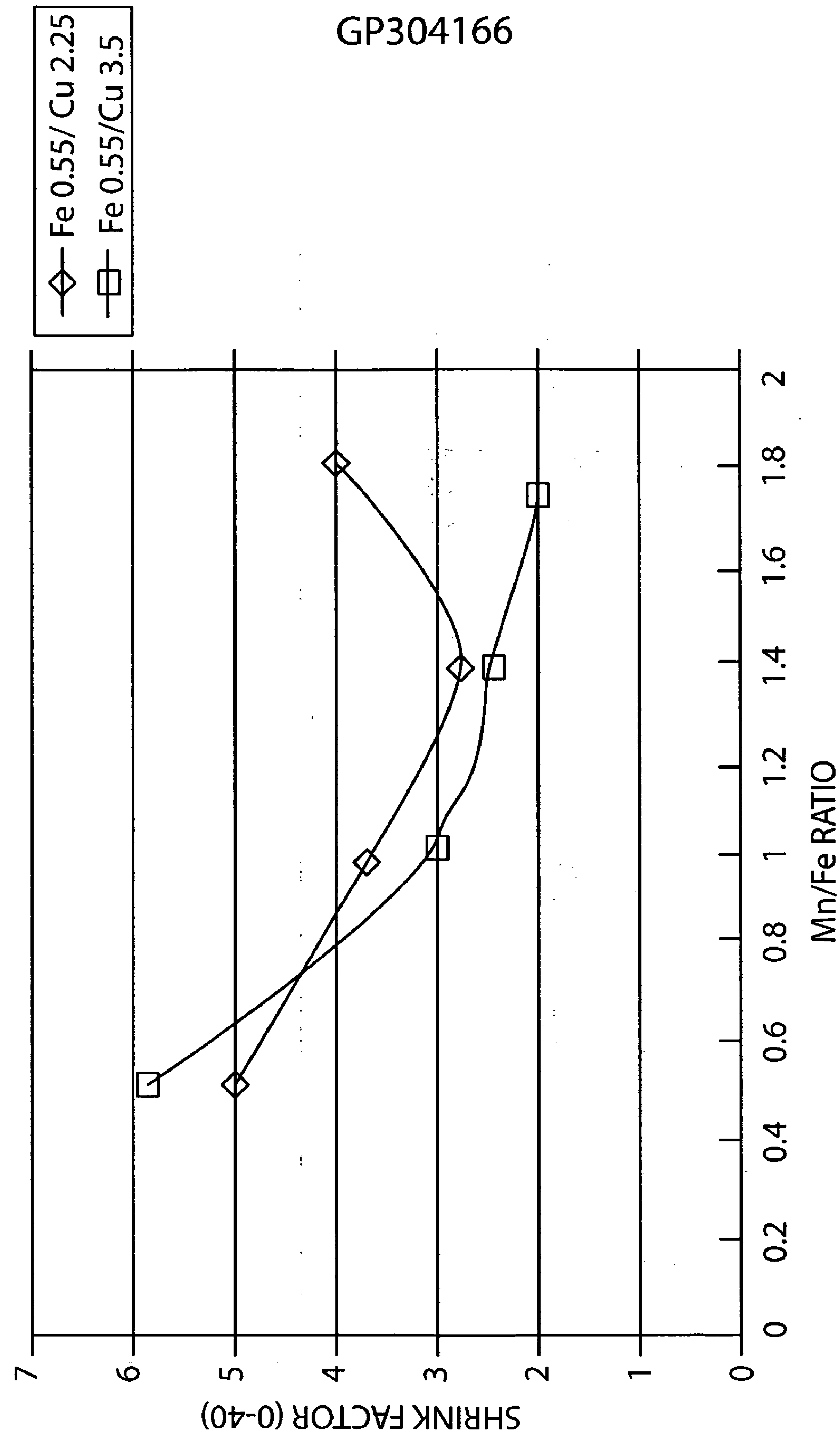
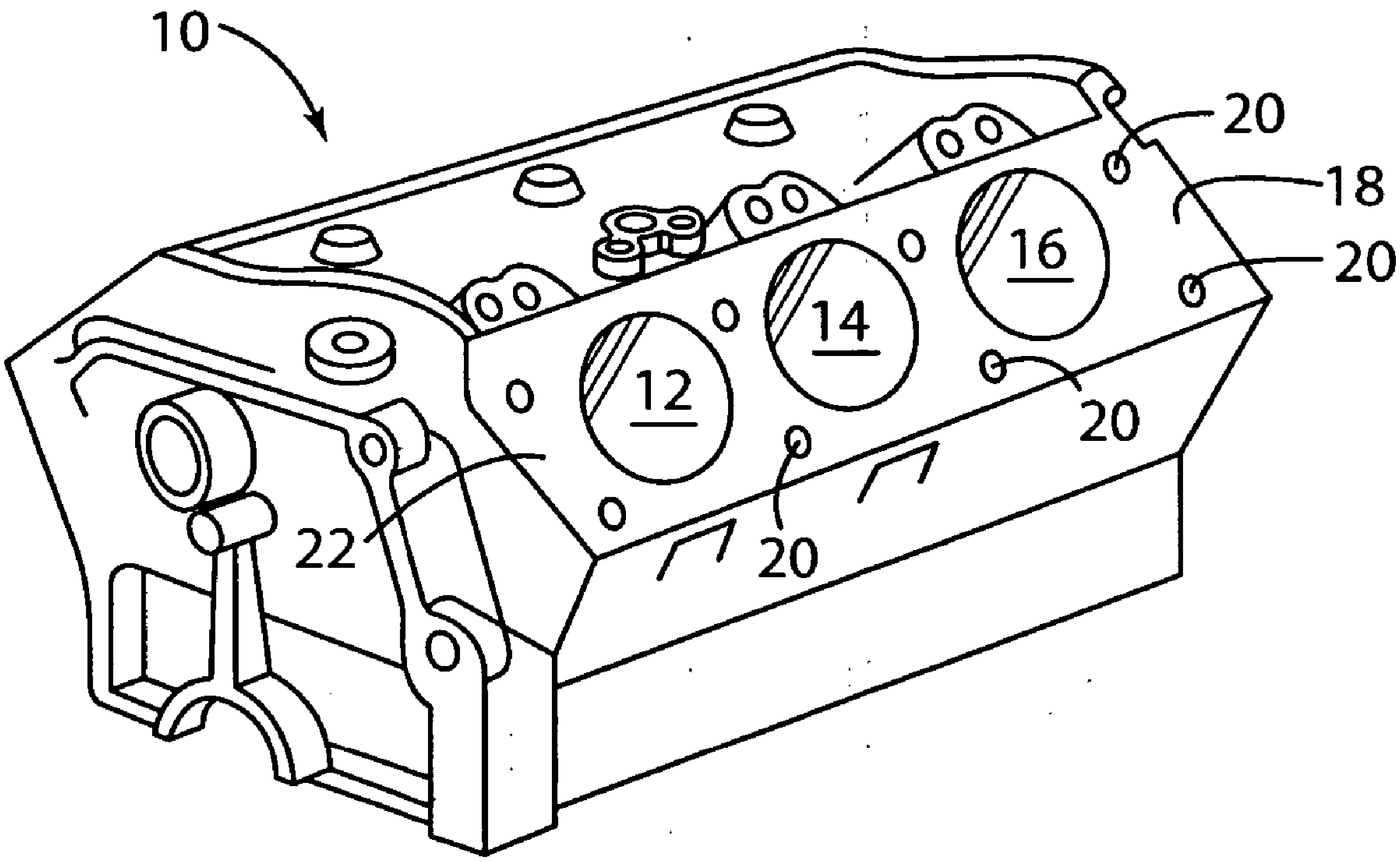

GP304166
Fe 0.55/ Cu 2.25
Fe 0.55/Cu 3.5
SHRINK FACTOR (0-40)
0
1
2
3
4
5
6
7
Mn/Fe RATIO
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

FIG. 5

GP304166

FIG. 6



CASTABLE ALUMINUM ALLOY

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of copending U.S. application Ser. No. 10/603,086 entitled "ALUMINUM ALLOY FOR ENGINE BLOCKS" and filed Jun. 24, 2003. This application also claims benefits and priority of U.S. provisional application Ser. No. 60/551,997 filed Mar. 10, 2004. All of the above non-provisional and provisional applications are hereby incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to castable aluminum alloys and, in particular, to aluminum casting alloys having a relatively high ratio of manganese to iron in the alloy composition to reduce porosity and improve mechanical properties of castings made therefrom.

BACKGROUND OF THE INVENTION

[0003] Many commercial grade castable aluminum-silicon alloys traditionally have included iron (Fe) as an unavoidable tramp alloying element present when aluminum is produced from bauxite containing ferric oxide. Manganese (Mn) has been included in such alloys as an intentional alloying element as a result of its powerful beneficial effect on the morphology of iron-bearing intermetallic phases present in the cast microstructure. In particular, the formation of plate-like beta Al_5FeSi intermetallic phase has been reported to be closely associated with the presence of objectionable dispersed (unconnected) larger microporosity in the cast microstructure. As a result, the Mn concentration of many castable aluminum alloys traditionally has been controlled to be equal to about one-half of the Fe concentration of the alloy. Control of the Mn concentration to this end has been found to promote formation of a co-eutectic alpha phase in the as-cast microstructure commonly referred to as Chinese Script morphology due its appearance under a microscope and resultant reduction in larger micropores in the cast microstructure and moderate increase in tensile strength. However, the alloy melts in which the Mn has been added to improve the shape of the alpha phase to Chinese Script morphology still contain both porosity and shrinkage defects (shrink porosity), although at a lower level.

[0004] There is a need to provide an improved castable aluminum alloy as well as castings made from the alloy having reduced casting porosity and improved mechanical properties.

SUMMARY OF THE INVENTION

[0005] The invention provides a castable aluminum alloy having a relatively high controlled weight ratio of Mn to Fe to satisfy this need.

[0006] In an illustrative embodiment of the invention, a castable aluminum alloy comprises, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is at least 0.6 when Fe is less than 0.4 weight % and weight ratio of Mn/Fe is at least 1.0 when Fe is equal to or greater than 0.4 weight % to reduce porosity and improve tensile strength of castings made from the alloy. The alloy optionally may include an appropriate amount of at least one of strontium or a rare earth metal.

[0007] Pursuant to a preferred embodiment of the invention, a castable aluminum alloy comprises, in weight %, 0 to 9.0% Si, 0 to about 5.0% Cu, about 0.15% to about 0.6% Mg, up to about 1.0% Zn, up to about 0.3% Ti, about 0.2% to about 0.8% Fe, about 0.3% to about 1.2% Mn, and balance Al, wherein the weight ratio of Mn/Fe is controlled to reduce porosity and increase tensile strength of castings made from the alloy.

[0008] Control of the Mn/Fe weight ratio pursuant to the invention can provide significantly less costly higher Fe-containing aluminum alloys (e.g. Fe content of about 0.4 weight % or greater) and/or higher Cu-containing aluminum alloys (e.g. Cu content of about 2.5 weight % or greater) for high strength while obtaining reduced microporosity and shrink porosity (macroporosity) and improved mechanical properties in castings made from the alloys.

[0009] The invention can be practiced to provide improved castable copper-containing aluminum alloys as well as improved castable aluminum alloys wherein copper is present only as an unavoidable tramp or impurity element. Moreover, the invention can be practiced to provide improved castable aluminum alloys having a relatively low or relatively high silicon concentration.

[0010] The invention also envisions improved castings made from the above castable aluminum alloys as well as improved methods of casting same wherein both microporosity and shrinkage porosity (macroporosity) can be reduced in castings. The invention is further advantageous in that mechanical properties can be improved while achieving a reduction in casting porosity. Other advantages and features of the present invention will become apparent from the following description.

DESCRIPTION OF THE DRAWINGS

[0011] **FIG. 1** is a representation of the effect of the Mn/Fe weight ratios on shrink porosity, microporosity, and tensile strength of a Cu-containing aluminum alloy having a composition, in weight %, 6.5% Si, 3.5% Cu, 0.4% Mg, 0.5% Fe, Mn as specified, and balance Al. Microporosity and shrink porosity are expressed as average volume percentage of the samples. Tensile strength is expressed as MPa.

[0012] **FIG. 2** is a graph showing the effect of Mn/Fe ratio on casting porosity at four different indicated locations on a cylinder block cast using the lost foam casting process and using a Cu-containing aluminum alloy having composition, in weight %, 7% Si, 3.5% Cu, 0.55 Fe, 0.75% Mn, and balance Al providing a Mn/Fe weight ratio of 1.33 designated "HIGH Mn" in **FIG. 2** pursuant to the invention and, for comparison, the same Cu-containing alloy with Mn of only 0.35 weight % providing a Mn/Fe weight ratio of only 0.64 designated "319". Each data point is an average value from 10 specimens taken from cast cylinder blocks.

[0013] **FIG. 3** is a graph of showing the effect of the Mn/Fe weight ratio on mechanical properties of tensile specimens cut from the cylinder blocks cast using the lost foam process and using a Cu-containing aluminum alloy having composition, in weight %, 7% Si, 3.5% Cu, 0.55 Fe, 0.75% Mn, and balance Al (Mn/Fe ratio of 1.33) designated

"HIGH Mn" in **FIG. 3** pursuant to the invention and, for comparison, the same Cu-containing alloy with Mn of only 0.35 weight % (Mn/Fe ratio of 0.64) designated "319". The cylinders blocks were heat treated to either the T5 or T6 condition and 10 tensile bar specimens were cut out for each heat treat condition from the bulkhead region (Bulkhead) of the block and from the head bolt bosses (HB Boss) of the block. In **FIG. 3**, UTS is ultimate tensile strength, YS is yield stress at 0.2% offset, and % E is percent elongation.

[**0014**] **FIG. 4** is a graph showing the effect of the Mn/Fe ratio on ultimate tensile strength (UTS) as shown by bars and percent elongation [E(%)] as shown by the line of tensile specimens cut from sand cast bar castings using an aluminum-silicon alloy having a composition, in weight %, 11.75% Si, 0.4% Fe, 3.6% Cu, 0.15% Mg, 0.03% Sr, Mn as specified and balance Al. The castings were heat treated to the T6 condition. Each data-point is an average value from 5 tensile specimens.

[**0015**] **FIG. 5** is a graph showing the effect of the Mn/Fe ratio on shrink factor (shrink porosity) of specimens on a relative scale of 0-40 cut from sand cast bar castings using an aluminum-silicon alloy having a composition, in weight %, 11.0% Si, 0.44% Mg, 0.018% Sr, and Mn, Fe and Cu as specified, and balance Al. Each data point is an average volume percentage value from 8 test castings, each casting being rated from 0 to 5 percentage to arrive at the average value on the scale.

[**0016**] **FIG. 6** is a perspective view of a V-type engine cylinder block which can be cast from aluminum alloys of the invention.

DESCRIPTION OF THE INVENTION

[**0017**] The invention provides castable aluminum alloys having a relatively high Mn/Fe weight ratio and alloy compositional features to reduce casting porosity while at the same time improving mechanical properties of castings made from the alloys. An aluminum casting alloy pursuant to an embodiment of the invention for achieving the dual benefits of reduced casting porosity and improved mechanical properties comprises, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight % to reduce porosity and improve mechanical properties, such as tensile strength, of castings made from the alloy as compared to a like alloy composition in which the Mn/Fe weight ratio is not controlled to such values. The weight ratio of Mn/Fe preferably is 0.6 or greater when Fe is less than 0.3 weight %, the Mn/Fe ratio is 1.0 or greater when Fe is 0.3 weight % to less than 0.4 weight %, and the Mn/Fe ratio is 1.2 or greater when Fe is equal to or greater than 0.4 weight % of the alloy, although the Mn/Fe ratio typically does not exceed 1.75. For most casting applications, it is preferred that the iron content of the alloy not exceed about 0.8 weight %. However, in die casting applications, the iron content of the alloy may be up to 1.5 weight %.

[**0018**] The alloy optionally may include strontium (Sr) up to about 0.05 weight % of the alloy and/or a rare earth metal, or combination of rare earth metals, up to 5 weight % of the alloy wherein rare earth elements include elements having an atomic number of 58 to 64 of the Periodic Table. These alloying elements modify the eutectic aluminum-silicon phase to avoid formation of primary silicon phase and/or modify intermetallic phases. Preferred rare earth elements for optional inclusion in the alloys of the invention include, but are not limited to, Ce, La, Pr, Nd, and/or Pm.

[**0019**] Control of the Mn/Fe weight ratio pursuant to the invention can provide significantly less costly higher Fe-containing aluminum alloys (e.g. Fe content of about 0.4 weight % or greater) and/or higher Cu-containing aluminum alloys (e.g. Cu content of about 2.5 weight % or greater) for high strength while obtaining reduced microporosity and macroporosity and improved mechanical properties for castings made from the alloys.

[**0020**] A castable melt of the aluminum alloy can be prepared by melting aluminum ingot with suitable aluminum based master alloys such as Al—25% Fe, Al—50% Cu, Al—20% Mn, Al—50% Si (where % is weight %) and pure magnesium metal to a desired composition as described above. Rare earth metal additions can be made via a mischmetal-master alloy or as pure metals or as rare earth aluminum master alloys. Such additions can be made to the initial melted charge. However, it is preferred that they are made after the melted charge has been treated with a flux and/or degassed, if such processing is used.

[**0021**] The melt is prepared in a suitable furnace, such as a coreless induction furnace, electric resistance furnace, reverberatory furnace, or a gas-fired crucible furnace of clay-graphite or silicon carbide. A flux is required only with dirty or drossy charge materials. Usually, no special furnace atmosphere is necessary. The charge can be melted in ambient air. Once molten, the melt is degassed using common aluminum foundry practice, such as purging the melt with dry argon or nitrogen through a rotary degasser. The degassing operation can also contain a halogen gas, such as chlorine or fluorine, or halogen salts to facilitate impurity removal. Preferably, the melt is handled in a quiescent manner so as to minimize turbulence and hydrogen gas pick-up.

[**0022**] Once degassed and cleaned, the melt is treated with an agent to effect eutectic aluminum-silicon phase and/or intermetallic phase modification. A preferred agent to this end comprises Sr and/or one or more rare earth metals. The preferred method is to use Al—10% Sr or Al—90% Sr (% is weight %) master alloys, plunged into the melt during the last stages of degassing, provided no halogen material is used. The gas level of the melt is assessed via any of the common commercially available methods, such as the reduced pressure test or an AISCAN.TM. instrument.

[**0023**] Finally, just prior to pouring, the melt optionally may be grain refined to reduce grain size using a titanium-boron master alloy with a typical addition of titanium being about 0.02 to 0.1 weight % of the alloy. Some applications may not require grain refining, however.

[**0024**] Melt superheat can be varied from less than 50 degrees F. to well over 500 degrees F. Lower levels of superheat are recommended to minimize micro-porosity. However, higher levels of superheat have resulted in a refinement of the intermetallics in the cast microstructure such that this method may be preferred in some circumstances. The Examples below provide illustrative melt pouring temperatures. The melt is poured into a suitable mold that can be made by a number of known mold making practices. Such molds include, but are not limited to, bonded sand molds, metal molds, die casting molds, permanent molds, or investment molds. Sand molds can contain metal chills to facilitate directional solidification or to refine cast microstructures locally in certain critical regions of the casting. In the case of sand molds, post-cast operations typically include removing excess sand from the casting by shot blasting. Post-cast operation also typically include removal of gating portions of the casting. Castings can be evaluated by commonly used nondestructive tests, such as X-ray inspection, dye penetrant inspection, or ultrasonic inspection. These tests are typically conducted to determine whether the casting has formed porosity due to shrinkage during solidification. Such shrinkage can be due to the composition of the cast alloy and/or to the shape of the casting.

[0025] Castings made from the aluminum alloys of the invention can be heat treated to enhance the mechanical properties by known precipitation hardening mechanisms for aluminum alloys. Such precipitation hardening heat treatments include, but are not limited to, the T5 temper, T6 temper, and T7 temper. The T5 temper involves artificially aging the casting at an intermediate temperature typically from 300 to 450 degrees F. for up to 12 hours or more. More demanding casting applications may require the peak strength of the T6 temper which involves a solution heat treatment at a temperature near, but less than, the alloy solidus temperature, for times typically ranging from 4 to 12 hours. The casting is quenched from the solution temperature in a suitable quenchant such as water, oil, or polymer or rapidly moving air. Such quenching rapidly cools the heat treated casting through the critical temperature regime, usually 850 degrees F. to 450 degrees F. Once cooled, the casting usually resides at room temperature for 1 hour to 24 hours and is then reheated to an intermediate temperature, similar to the T5 temper. In applications where dimensional stability is of importance, the T7 temper may be specified. This temper is similar to the T6 temper except that the artificial aging cycle is either conducted at higher temperatures or longer times, or both, to achieve a somewhat softer condition with greater dimensional stability.

[0026] Castable aluminum alloys pursuant to the invention are especially useful for making engine cylinder block castings and cylinder head castings which are machinable and which exhibit reduced casting porosity and improved mechanical properties in the as-cast condition as well as in the heat treated (precipitation hardened) condition. For example, cylinder block castings and cylinder head castings for use in gasoline fueled, reciprocating piston internal combustion engines can be made of an alloy pursuant to the invention.

[0027] **FIG. 6** illustrates a typical V-type engine cylinder block casting of the type that can be cast, although the alloy may be used to cast any form of engine cylinder block casting. In **FIG. 6**, the cylinder block casting is shown as a V-6 engine block having three cylinders **12**, **14**, and **16** of one side **18** of the V-block. The walls of the cylinders are machine finished. A large number of bolt holes **20** such as for attaching two cylinder heads (not shown) are drilled and threaded in the block. A machined plane head deckface (bulkhead) surface **22** is provided against which the associated cylinder head resides in known manner. As is known, such engine cylinder block has many intricate sections for coolant and oil flow such that a very fluid molten alloy is required to fill out the mold cavity during the pouring and solidification of the alloy in the mold.

[0028] A castable aluminum alloy useful for making an engine cylinder block consists essentially of, in weight %, 0 to 9.0% Si, 0 to about 5.0% Cu, about 0.15% to about 0.6% Mg, up to about 1.0% Zn, up to about 0.3% Ti, about 0.2% to about 0.8% Fe, about 0.3% to about 1.2% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight %, although the Mn/Fe ratio typically does not exceed 1.75. The Fe content of the alloy is 0.4 weight % or greater to reduce alloy cost.

[0029] A particular preferred Cu-containing castable aluminum alloy for making an engine cylinder block consists essentially of, in weight %, about 5.0 to about 7.0% Si, about 2.5% to about 4.0% Cu, about 0.15% to about 0.35% Mg, up to about 0.5% Zn, up to about 0.3% Ti, about 0.35% to about 0.65% Fe, about 0.4% to about 0.9% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight %.

[0030] Still another particular preferred Cu-containing, low Si castable aluminum alloy for making an engine block comprises, in weight %, 0 to about 0.25% Si, about 3 to about 5% Cu, about 0.1% to about 0.3% Mg, up to about 0.5% Zn, up to about 0.3% Ti, greater than 0 to about 0.5% Fe, about 0.2% to about 0.8% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight %.

[0031] The above Cu-containing aluminum alloys may include Sr in an amount of about 0.005 to 0.03 weight % of the alloy.

[0032] As mentioned above, the invention also envisions castable aluminum alloys that include copper only as an unavoidable impurity element or an unavoidable alloying element as a result of particular refining practices and/or starting materials employed to make the alloy.

[0033] For example, a preferred castable aluminum alloy having copper at impurity levels pursuant to the invention consists essentially of, in weight %, about 6.0 to about 9.0% Si, 0 to about 0.75% Cu, about 0.2% to about 0.4% Mg, up to about 1.0% Zn, 0 to about 1.5% Ni, up to about 0.3% Ti, about 0.35% to about 0.65% Fe, about 0.4% to about 0.9% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is 0.4 weight % or more. This alloy optionally may include strontium (Sr) up to about 0.05 weight % of the alloy and/or a rare earth metal, or combination of rare earth metals, up to 5 weight % of the alloy.

[0034] The aluminum alloys described above can be cast by conventional casting processes such as precision sand casting, permanent mold casting, semi-permanent mold casting, bonded sand casting, lost foam casting, investment casting, die casting, centrifugal casting, and other casting processes to make cast components of myriad types. For certain cast components, the casting is heat treated to develop mechanical properties appropriate for the intended service application. The invention is advantageous in that unexpectedly both microporosity and macroporosity can be reduced in cast components made from the above alloys. In addition, the invention unexpectedly can improve mechanical properties of the cast component while achieving a reduction in casting porosity.

[0035] The following Examples are offered to further illustrate the invention. Although the Examples relate to certain Cu-containing aluminum alloys for purposes of illustration, the invention is not so limited as is apparent from the description above. The castable aluminum alloys described in the Examples are especially useful for making engine cylinder block castings which are machinable and which exhibit reduced casting porosity and improved mechanical properties in the as-cast condition as well as in the heat treated condition.

EXAMPLE 1

[0036] **FIG. 1** is a schematic representation of the effect of the Mn/Fe weight ratio on shrink porosity, microporosity, and tensile strength of a Cu-containing aluminum alloy having a composition, in weight %, 6.5% Si, 3.5% Cu, 0.4% Mg, 0.5% Fe, Mn as specified, and balance Al. The effect of Mn/Fe was determined by preparing a master heat of the base composition and cast into 30 pound ingots. For each value of Mn/Fe weight ratio tested in a series of Mn/Fe ratios from 0.1 to 2.0, a separate heat was prepared and Mn added in the form of Al—25 weight % Mn master alloys. In addition, pure Al was added to each of the heats except to the heat with the highest Mn/Fe ratio. This procedure was used to insure the total addition (Al—25Mn master alloy+pure Al) was a constant to dilute all of the other alloying elements by a constant amount. After melting in a clay-graphite crucible in air, each heat was degassed using a commercial rotary degasser with argon. Two sand molds were made for each heat; one mold being an 8-casting castablity test mold wherein the castings have a shape similar to the cross-section of an automotive cylinder head with rail and bolt boss sections as well as a heave section to simulate the head deckface the second mold being a 10 bar mold used to make stock for machining tensile bars. Both molds were cast from each heat and allowed to cool. The castings were shaken out of the sand, cleaned and sectioned for testing. The bar castings were heat treated to the T6 condition and then machined to tensile bars that were tested using ASTM 557 and 557M test procedure to provide average tensile strength values. The castablity mold castings were first Xrayed, and then microstructure samples were sectioned and mounted in metallographic mountings and polished. The microporosity was determined by computer image analysis of the mounted samples using commercially available software and expressed as average percent porosity by volume as also described in Example 2. The shrink porosity (corresponding to macroporosity attributable to solidification shrinkage) expressed as average volume percentage value was determined by comparison of the Xray images with visual scales.

[0037] **FIG. 1** summarizes the data and reveals that there is an unexpected "Good Range" in the Mn/Fe ratio around a Mn/Fe weight ratio of about 1.35 to 1.45 for the above castable Cu-containing aluminum alloy where unexpectedly microporosity and shrink porosity (macroporosisty) are minimized while tensile strength is increased to a maximum. The mechanical properties in the "Good Range" are improved well above mechanical properties achieved by lower Mn/Fe weight ratios practiced by the prior art. The addition of Mn pursuant to the invention will allow use of significantly less costly higher Fe alloys while obtaining reduced microporosity and macroporosity and improved mechanical properties.

[0038] The width or extent of the "Good Range" depends on a several factors including the iron concentration, silicon concentration, eutectic silicon modification agent of the alloy as well as the cooling rate of the molten alloy after casting into the mold while it solidifies therein. In particular, with higher iron and silicon concentrations in the above alloy, the "Good Range" is decreased, without eutectic modification the "Good Range" is lower, and with higher cooling rates of the molten alloy in the mold, the "Good Range" is increased. Mechanical property curves like that of **FIG. 1** can be generated for other families of castable aluminum alloys to determine the "Good Range" of the Mn/Fe ratio to achieve benefits of practice of the invention.

EXAMPLE 2

[0039] **FIGS. 2 and 3** illustrate practice of the invention with respect to an illustrative castable Cu-containing aluminum alloy.

[0040] In particular, **FIG. 2** is a graph of showing the effect of Mn/Fe weight ratio on casting porosity at four different locations of cylinder blocks cast using the lost foam casting process. A Cu-containing aluminum alloy (319 alloy) having a composition, in weight %, 7% Si, 3.5% Cu, 0.55 Fe, 0.75% Mn, and balance Al providing a Mn/Fe weight ratio of 1.33 pursuant to the invention was cast at a melt temperature of 1430 degrees F. into a lost foam mold. The alloy was solidified in the mold at a cooling rate of about 10 degrees F/minute. For comparison, the same Cu-containing alloy with Mn of only 0.35 weight % providing a Mn/Fe weight ratio of only 0.64 was similarly cast and solidified in a lost foam mold. The Mn/Fe ratio of 0.64 is in excess of usually recommended levels but nevertheless practiced at certain commercial foundries for such alloy.

[0041] The cast cylinder blocks were heat treated to either the T5 or T6 condition and 6 specimens (½ inch by ½ inch) were cut out for each heat treat condition from the bulkhead region (designated BULKHEAD), the top bore region (designated BORE-TOP), bottom bore region (designate BORE-BOTTOM), and the top head bolt boss region (designated BOLT BOSS-TOP) of the cylinder block.

[0042] The microporosity shown by the sectioned bars in **FIG. 2** was determined by computer image analysis and expressed as an average percent porosity by volume based on a total of 30 fields measured at 50× magnification on each microstructure sample. The maximum pore size (designated Max Feret) was determined by computer image analysis measuring 32 equi-angular diameters on each pore and reporting the largest value for each pore. The value reported is the largest of the group of 6 samples at each location and is expressed in microns.

[0043] **FIG. 2** shows the significant beneficial effect of a Mn/Fe weight ratio of 1.33 on the microporosity and maximum pore size at the four indicated locations of the cast cylinder blocks. In particular, the cylinder blocks cast using the alloy having the Mn/Fe ratio of 1.33 pursuant to the invention exhibited reduced microporosity and reduced maximum pore size as compared to the alloy with the Mn/Fe ratio of only 0.64.

[0044] Referring to **FIG. 3**, the effect of the Mn/Fe weight ratio on mechanical properties of tensile specimens cut from the cast cylinder blocks is shown. The cylinder blocks were heat treated to either the T5 or T6 condition and 6 tensile bar specimens were cut out for each heat treat condition from the bulkhead region (BULKHEAD) of the cylinder blocks and from the head bolt bosses (HB BOSS) of the block. In the T5 condition, the casting is quenched from the mold at an elevated temperature into water and subsequently artificially aged by placing the casting in a furnace at about 350 degrees F. for 8 to 10 hours. In the T6 condition, the casting is cooled to room temperature after the mold has been poured and then placed in a furnace at a high solution temperature that is determined by the composition of the alloy. The casting is held at the solution temperature for 4 to 10 hours and then quenched into hot water or using a similar method to rapidly cool the casting. Finally, the casting is artificially aged at an intermediate temperature similar to that used for the T5 condition. The tensile testing was conducted in accordance with ASTM tensile test B 557.

[0045] **FIG. 3** reveals that both the ultimate tensile strength (UTS) and tensile elongation (% E) were increased in the T5 and T6 tempers for the BULKHEAD regions. Both the UTS and % E were improved in the T5 temper condition for the HB BOSS regions. These improvements in mechanical properties were achieved while microporosity and maximum pore size were reduced as shown in **FIG. 2**. There was no effect on mechanical properties in the T6 temper condition for the HB BOSS regions.

EXAMPLE 3

[0046] This example involves beneficial effects achieved by controlling the Mn/Fe weight ratio for aluminum alloys having silicon contents in the range of 11 to 12 weight % of the alloy. For example, **FIG. 4** illustrates effects achieved with respect to castable Cu-containing aluminum alloys having a composition, in weight %, 11.75% Si, 0.4% Fe, 3.6% Cu, 0.15% Mg, 0.03% Sr, Mn as specified, and balance Al. The alloys were cast at a melt temperature of 1320 degrees F. into bonded sand molds. The alloys were solidified in the molds at a cooling rate of about 10 degrees F./minute to produce cast bars that were heat treated to the T6 condition and then cut to make round tensile bars for testing.

[0047] **FIG. 4** illustrates a significant increase in UTS of the heat treated specimens achieved by controlling the Mn/Fe weight ratio above 0.74, especially at a ratio of 1.367. The tensile elongation decreased somewhat at Mn/Fe ratios of 0.74 and 1.14 and then increased significantly at a Mn/Fe ratio of 1.367.

[0048] **FIG. 5** illustrates beneficial effects achieved with respect to castable Cu-containing aluminum alloys having a composition, in weight %, 11.00% Si, 0.44% Mg, 0.018% Sr, Mn, Fe and Cu as specified, and balance Al. The alloys were cast at a melt temperature of 1320 degrees F. into bonded sand molds. The alloys were solidified in the molds at a cooling rate of about 10 degrees F./minute to produce cast bars that were heat treated to the T6 condition and then cut to make round tensile bars for testing.

[0049] **FIG. 5** illustrates a significant reduction in the shrink factor, which corresponds to shrink porosity discussed above, by increasing the Mn/Fe weight ratio above about 1.0. When the Mn/Fe ratio is so increased, the shrinkage is decreased, and it is decreased to a greater extent for the higher Cu alloys.

[0050] The addition of Cu to aluminum-silicon alloys improves tensile strength. However, in the past, addition of Cu to this end resulted in an increase in shrinkage porosity and sometimes microporosity when the Mn/Fe weight ratio was around the typical 0.5 value. It is apparent from **FIG. 5** that control of the Mn/Fe ratio pursuant to the invention unexpectedly allows the casting of higher strength Cu-containing aluminum alloys at better quality levels (having reduced shrinkage porosity defects) than previously achievable.

[0051] It should be understood that the invention is not limited to the specific embodiments or constructions described above but that various changes may be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.

1. A castable aluminum alloy comprising, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is at least 0.6 when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is at least 1.0 when Fe is equal to or greater than 0.4 weight % to reduce porosity and improve tensile strength of a casting made from the alloy.

2. The alloy of claim 1 wherein the Fe concentration is about 0.4 weight % or greater.

3. The alloy of claim 1 wherein the Cu concentration is about 2.5 weight % or greater.

4. The alloy of claim 1 which further comprises at least one of Sr or a rare earth metal.

5. A castable aluminum alloy comprising, in weight %, 0 to 9.0% Si, 0 to about 5.0% Cu, about 0.15% to about 0.6% Mg, up to about 1.0% Zn, up to about 0.3% Ti, about 0.2% to about 0.8% Fe, about 0.3% to about 1.2% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio is 1.0 or greater when Fe is equal to or greater than 0.4 weight %.

6. The alloy of claim 5 wherein the Fe concentration is about 0.4 weight % to about 0.8 weight %.

7. The alloy of claim 5 consisting essentially of, in weight %, about 5.0 to about 7.0% Si, about 2.5% to about 4.0% Cu, about 0.15% to about 0.35% Mg, up to about 0.5% Zn, up to about 0.3% Ti, about 0.35% to about 0.65% Fe, about 0.4% to about 0.9% Mn, and balance Al, wherein the weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and is 1.0 or greater when Fe is equal to or greater than 0.4 weight %.

8. The alloy of claim 7 which further comprises about 0.01% to about 0.025% Sr.

9. The alloy of claim 5 consisting essentially of, in weight %, 0 to about 0.25% Si, about 3 to about 5% Cu, about 0.1% to about 0.3% Mg, up to about 0.5% Zn, up to about 0.3% Ti, greater than 0 to about 0.5% Fe, about 0.2% to about

0.8% Mn, and balance Al, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight %.

10. The alloy of claim 9 which further comprises at least one of Sr up to about 0.05 weight % or a rare earth metal up to 5 weight.

11. The alloy of claim 5 consisting essentially of, in weight %, about 6.0 to 9.0% Si, 0 to about 0.75% Cu, about 0.2% to about 0.4% Mg, up to about 1.0% Zn, 0 to about 1.5% Ni, up to 0.3% Ti, about 0.35% to about 0.65% Fe, about 0.4% to about 0.9% Mn, and balance Al, wherein the weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and is 1.0 or greater when Fe is 0.4 weight % or more.

12. The alloy of claim 11 which further comprises about 0.005% to about 0.025% Sr.

13. A casting, comprising, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight % to reduce porosity and improve tensile strength of the casting.

14. The casting of claim 13 which comprises an engine cylinder block or engine cylinder head.

15. The casting of claim 13 which is precipitation hardened.

16. A method of casting, comprising melting a castable aluminum alloy comprising, in weight %, 0 to about 19% Si, 0 to about 5.0% Cu, 0 to about 1.5% Mg, up to about 3.0% Zn, up to about 2.0% Ni, up to about 0.3% Ti, greater than 0 to about 1.5 weight % Fe, about 0.2% to about 3.0% Mn, wherein a weight ratio of Mn/Fe is 0.6 or greater when Fe is less than 0.4 weight % and the weight ratio of Mn/Fe is 1.0 or greater when Fe is equal to or greater than 0.4 weight %, introducing the melted alloy into a mold, and solidifying the melted alloy in the mold to form a casting wherein said ratio reduces porosity and increases tensile strength of the casting.

17. The method of claim 16 wherein a cast engine cylinder block or cylinder head is formed in the mold.

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