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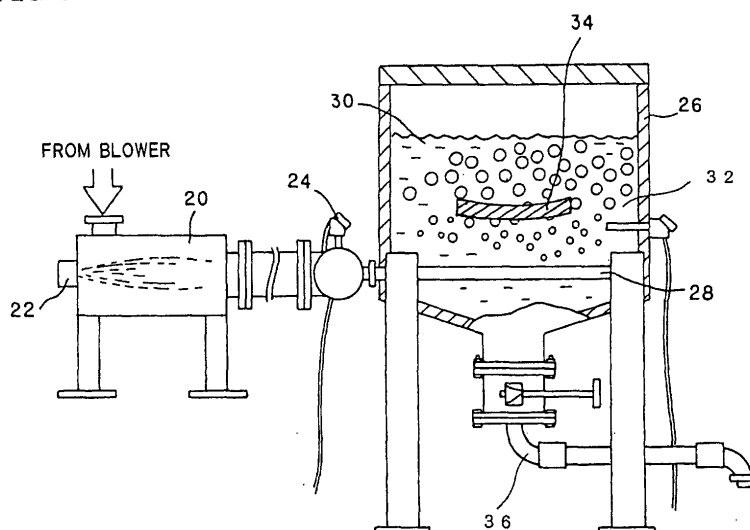
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(54) **ALUMINUM ALLOY FORMED BY PRECIPITATION HARDENING AND METHOD FOR HEAT TREATMENT THEREOF**

(57) There is provided a precipitation hardening Al alloy in which an average area of eutectic structures existing in the Al alloy is less than $4 \mu\text{m}^2$. This Al alloy contains 6.5 to 7.5% by mass of Si, 0.36% by mass or less of Mg and 20 to 70 ppm of Sr, and is preferably used as a vehicle wheel. In heat treatment method of the precipitation hardening Al alloy, a work piece is subjected to solution treatment by being made to exist in a fluidized

bed, and further a rate of solid solutions of Si and/or Mg into α phase is made to be 60% or more in the solution treatment and aging treatment is carried out at temperatures from 150°C or more to less than 200°C . The precipitation hardening Al alloy to be obtained has well-balanced three mechanical properties of tensile strength, yield strength, and elongation, and is also excellent in fatigue strength.

FIG. 2



Description

TECHNICAL FIELD

[0001] The present invention relates to a precipitation hardening Al alloy and a method for heat treatment thereof.

BACKGROUND ART

[0002] As Al alloys for casting products of castings, die castings and the like and for wrought products, Al-Si-based Al alloys that mainly containing Al and several percent by weight of Si have been known, and multinary Al-Si-base alloys that further contain other elements such as Cu and Mg in addition to the Al-Si-based Al alloys as the basic composition have been used. The reasons for this include that these alloys are more excellent in important properties in the casting of casting products of castings, die castings and the like and of wrought products, such as the fluidity and mold filling of molten metal, than other alloys; little cracking occurs in casting; alloys that have higher strength and elongation can be obtained by combining other elements; and these alloys have a small coefficient of thermal expansion and a higher wear resistance.

[0003] Examples of Al-Si-based alloys to which a small quantity of Mg is added include AC4A, AC4C and AC4CH. These alloys have increased strength by the effect of heat treatment with the precipitation of the intermediate phase of Mg_2Si . In particular, AC4C and AC4CH that has increased toughness by limiting the Fe content to 0.20% by mass or less are used as alloys for wheels of vehicles such as motor vehicles.

[0004] Furthermore, Al-Si-based alloys to which small quantities of Mg and Cu are added are also used. The strength of these alloys is improved by precipitation hardening with the intermediate phase of Mg_2Si , solid solution hardening with Cu, precipitation hardening with the intermediate phase of Al_2Cu and the like.

[0005] As described above, the improvement of strength of heat-treated Al alloys is achieved by the addition of other elements, and the aging and precipitation of resultant intermediate phases, and the heat treatment for aging and precipitation consists of the solution treatment and the aging treatment. The solution treatment is a heat treatment for obtaining the solid solution of a uniform composition at the normal temperature by making a solid solution of a non-equilibrium phase crystallized during solidification at a high temperature and then by cooling it with water. The aging treatment carried out following the solution treatment is to precipitate and harden an element, which has been held at relatively low temperatures and been made to a solid solution, as an intermediate precipitation phase. These heat treatments intend to improve the mechanical properties of Al alloys.

[0006] Heretofore, although an atmospheric kiln that uses the air as the heat medium, such as a tunnel kiln, has been used for the solution treatment and the aging treatment of such Al alloys, there are such problems that temperature raising takes a long time, the deviation of temperatures is as large as about $\pm 5^\circ C$, as a result the solution treatment can not be carried out at a higher temperature and others. In addition, the mechanical properties of obtained Al alloys were at levels of about 290 MPa in tensile strength, about 200 MPa in 0.2% yield strength, and about 8% in elongation.

[0007] Furthermore, in the heat treatment method using a conventional atmospheric kiln, the temperature raising speed is too slow to take a long time to reach the solution treatment temperature, and since the solution treatment is carried out by maintaining Al alloys at the solution treatment temperature for more than 3 hours, there is such a problem that the total time for the solution treatment takes about 4 hours or more. Moreover, according to the examination by the present inventor, if Al alloys are maintained at the solution treatment temperature for more than 3 hours as mentioned above, there may be caused such a problem that eutectic structures become coarse to lower the strength and ductility of Al alloys greatly.

[0008] Moreover, it is extremely advantageous to further improve the mechanical properties of tensile strength, 0.2% yield strength and elongation of Al alloys used for the wheels of motor vehicles, because the thickness of the wheels of motor vehicles can be made thinner, thereby reducing the entire weight of a motor vehicle, and because rolling resistance is decreased, resulting in contributing to the improvement of driving stability as well as the elevation of fuel consumption and exhaust gas purification performance.

[0009] Accordingly, the present inventor has studied these subjects from different angles and as a result, paid his attention to fine structures of Al alloys to be obtained and found that the mechanical properties of Al alloys are improved when eutectic structures are not greater than a predetermined size, resulting in reaching the present invention.

[0010] That is, an object of the present invention is to provide Al alloys that have well-balanced three mechanical properties of tensile strength, yield strength and elongation and are also excellent in fatigue strength.

[0011] Further, another object of the present invention is to provide a heat treatment method for precipitation hardening Al alloys in which strength and elongation of obtained Al alloys are improved by increasing a rate of solid solutions of Si and/or Mg to a level higher than predetermined rates through carrying out solution treatment with a fluidized bed.

DISCLOSURE OF THE INVENTION

[0012] According to the present invention, there is provided a precipitation hardening Al alloy characterized in that an average area of eutectic structures existing in the above described Al alloy is less than $4\ \mu\text{m}^2$.

[0013] In this precipitation hardening Al alloy, it is preferable to contain 6.5 to 7.5% by mass of Si and less than 0.36% by mass of Mg as components, and it is more preferable to contain 20 to 70 ppm of Sr. Moreover, the precipitation hardening Al alloy of the present invention is suitably used for the wheels of motor vehicles.

[0014] Furthermore, according to the present invention, there is provided a heat treatment method of a precipitation hardening Al alloy comprising; subjecting a work piece comprising the precipitation hardening Al alloy to solution treatment, and then subjecting the work piece to aging treatment, to improve mechanical properties of the work piece, characterized in that said work piece is subjected to said solution treatment by being made to exist in a fluidized bed, and further a rate of solid solutions of Si and/or Mg into α phase is made to be 60% or more in said solution treatment and said aging treatment is carried out at temperatures from 150°C or more to less than 200°C .

[0015] In the present invention, it is preferable to increase a temperature raising speed so that raising temperature up to the solution treatment temperature is made within 30 minutes and a maintaining time at the solution treatment temperature is between 25 minutes and 3 hours. Furthermore, the solution treatment temperature is desirable to be 540 to 550°C . And, in the present invention, the fluidized bed is preferable to be formed by direct blowing of hot air.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

Figure 1 is a schematic diagram showing an example of hot air direct blowing fluidized beds used in the present invention;

Figure 2 is a schematic diagram showing an example of fluidized bed type solution treatment kilns used in the present invention;

Figure 3 is a perspective view showing an aluminum vehicle wheel used in Embodiment 1;

Figure 4 is a graph showing the heat treatment schedule in Embodiment 1;

Figure 5 is a graph showing the results of tensile tests in Embodiment 1;

Figure 6 is a graph showing the results of impact and hardness tests in Embodiment 1;

Figure 7 is a graph showing the relationship between the average area of eutectic structures and the solution treatment time;

Figure 8 is an explanation drawing showing the shape and size of a test piece used in rotating bending fatigue tests in Embodiment 2;

Figure 9 is a graph showing fatigue strength (inner rim) in Embodiment 2 and Comparative Example 2;

Figure 10 is a graph showing fatigue strength (outer rim) in Embodiment 2 and Comparative Example 2;

Figure 11 is a graph showing the results of tensile tests (tensile strength, 0.2% yield strength and elongation) in Embodiment 3 and Comparative Example 1;

Figure 12 is a graph showing the results of differential calorimetric analyses that measured absorption energy discharged when Si and/or Mg is made as a solid solution into α phase in the solution treatment;

Figure 13 is a graph showing the heat treatment schedule in Embodiment 4;

Figure 14 is a graph showing the results of tensile tests in Embodiment 4 and Comparative Examples 5 and 6;

Figure 15 is a graph showing the results of impact and hardness tests in Embodiment 4;

Figure 16 is a graph showing the results of tensile tests in Comparative Example 3;

Figure 17 is a plan view showing another example of an aluminum vehicle wheel; and

Figure 18 is a graph showing the heat treatment schedule in Comparative Example 3.

BEST MODE FOR CARRYING OUT THE INVENTION

[0017] The present invention will be described below in detail.

[0018] The present invention relates to a precipitation hardening Al alloy in which strength is improved by precipitation hardening with an intermediate phase of Mg_2Si or an intermediate phase of Al_2Cu , and concretely to an Al alloy in which an average area of eutectic structures existing in the Al alloy is less than $4\ \mu\text{m}^2$.

[0019] Precipitation hardening Al alloys related to the present invention are those in which the average area of eutectic structures existing in the alloys is less than $4\ \mu\text{m}^2$, preferably 1 to $3\ \mu\text{m}^2$, and more preferably 1.2 to $3\ \mu\text{m}^2$. Al alloys having such structures have well-balanced three mechanical properties of tensile strength, yield strength and elongation, and present, for example, tensile strength of 310 MPa or more, preferably 320 MPa or more, 0.2% yield strength of 240 MPa or more, preferably 260 MPa or more, and elongation of 10% or more, preferably 12% or more.

[0020] Here, the mechanical properties, such as tensile strength, 0.2% yield strength and elongation, of the Al alloy are measured in accordance with the test methods specified in JIS (Japanese Industrial Standards) Z2241.

[0021] The Al alloy of the present invention that has the specified or better mechanical properties as mentioned above is preferable to have an Al-based composition containing 6.5 to 7.5% by mass of Si and 0.36% by mass or less of Mg, and is more preferable to be the composition further containing 20 to 70 ppm of Sr. That is, the Si content within a range between 6.5 and 7.5% by mass is preferable because the casting properties of the Al alloys are improved in the range, and a range between 6.8 and 7.2% by mass is further preferable.

[0022] It is preferable that the content of Mg is 0.36% by mass or less. On the heat treatment, Mg precipitates an intermediate phase known as an Mg_2Si phase together with Si, thereby causing significant aging hardness to occur. However, although the content of Mg exceeding 0.36% by mass increases tensile strength and the like, a problem of conversely decrease in elongation arises.

[0023] Also, Sr acts as an agent for reducing the size of eutectic structures of the Al alloy, and the content of Sr is preferably 20 to 70 ppm, more preferably in a range between 30 and 60 ppm.

[0024] Accordingly, the Al alloy of the present invention covers alloys based on AC4C and AC4CH in its subjects.

[0025] Since the Al alloy of the present invention has predetermined or better mechanical properties, such as tensile strength, 0.2% yield strength, and elongation, and these three properties are well balanced, it can be used very effectively for the wheels of vehicles such as motor vehicles.

[0026] Next, the precipitation hardening Al alloy of the present invention that has the above described fine eutectic structures can be manufactured by, for example, a heat treatment method described below.

[0027] First, after a casting (work piece) of the Al alloy cast using an ordinary method is subjected to solution treatment, the casting is generally quenched, and then subjected to aging treatment. By subjecting the casting to these treatments, the mechanical properties of the Al alloy can be improved so as to apply to the desired uses such as vehicle wheels.

[0028] In the present invention, a precipitation hardening Al alloy in which the average area of eutectic structures is small like $4\ \mu m^2$ or less as described above can be obtained by maintaining the treatment time (includes the time needed for raising temperature) at the solution treatment temperature of 540 to 550°C for preferably within 4 hours (240 minutes), more preferably within 3 hours and 30 minutes (210 minutes) in the process of the solution treatment.

[0029] In this case, from the viewpoint of preventing the spheroidizing and coarsening of eutectic structures, it is desirable to raise the temperature of the work piece quickly to 540 to 550°C, the solution treatment temperature, within 30 minutes.

[0030] In the solution treatment, as described above, it is preferable to heat the work piece in a short period of time. For example, in case of vehicle wheels, it is preferable to raise the temperature to 540 to 550°C in 3 to 10 minutes. This is especially preferable from the viewpoint of fining eutectic structures.

[0031] In the solution treatment, it is sufficient to heat the work piece quickly, and the method is not limited to a specific method. That is, it is sufficient to enable the work piece to be quickly heated by controlling the ambient temperature, and for example, high-frequency heating, low-frequency heating, and far-infrared heating can also be utilized, but quick heating using a fluidized bed is more preferable from the viewpoint of the simplicity of temperature controlling.

[0032] After the work piece is subjected to the solution treatment, it is quenched to room temperature, and is subjected to the aging treatment. The concrete method of this aging treatment is not especially limited, and a conventional atmospheric kiln using the air as the heat medium (tunnel kiln) can be used. However, the use of a fluidized bed is preferable similarly to the solution treatment. This is because the aging treatment time can be shortened, and further when a fluidized bed is used for the solution treatment, the use of the same fluidized bed is preferable from the points of view of the control and operation of the whole process.

[0033] Next, the heat treatment method of the present invention, which can also be applied to wrought products of Al alloys as well as casting products of Al alloys, will be described.

[0034] First, a casting product or wrought product (work piece) of the Al alloy made using an ordinary method is subjected to the solution treatment, and then subjected to the aging treatment. By subjecting the casting product or wrought product to these treatments, the mechanical properties, including tensile strength, of the Al alloy can be improved so as to be applied to the desired uses such as vehicle wheels. However, it is especially preferable to make the rate of solid solutions of Si and/or Mg into α phase be 60% or more in the solution treatment.

[0035] By making the rate of solid solutions of Si and/or Mg be 60% or more in the solution treatment, the obtained Al alloy is not made coarse, and the ductility (extensional property) as well as the strength of Al alloy are more improved compared to the conventional alloy.

[0036] In this case, it is preferable to raise the temperature quickly to the solution treatment temperature in a short period of time within 30 minutes, more preferably within 20 minutes, and especially preferably in 3 to 10 minutes. And, the maintaining time at the solution treatment temperature is preferable to be 25 minutes to 3 hours, more preferable to be 30 minutes to 2 hours.

[0037] It is preferable to carry out the solution treatment under such conditions as described above in order to make

the rate of solid solutions of Si and/or Mg into α phase be 60% or more. On the other hand, if raising the temperature to the solution treatment temperature is carried out in a time exceeding 30 minutes, eutectic structures in the Al alloy become coarse. Further, if the maintaining time at the solution treatment temperature is short like less than 25 minutes, the rate of solid solutions of Si and/or Mg into α phase become less than 60% as shown in Figure 12, and the mechanical properties of an obtained Al alloy will be lowered. And, if the maintaining time exceeds 3 hours, the rate of solid solutions of Si and/or Mg exceed 60%, but eutectic structures in the Al alloy become coarse and the mechanical properties of the Al alloy will similarly be lowered.

[0038] In this case, the solution treatment temperature of the Al alloy is in a range between 530 and 550°C and preferably in a range between 540 and 550°C.

[0039] As described above, in this heat treatment method, the temperature raising time to the solution treatment temperature is short and the maintaining time at the solution treatment temperature is also decided to be within the prescribed time. As a result, the total time of the solution treatment can be kept within 4 hours (240 minutes), preferably within 3 hours and 30 minutes (210 minutes).

[0040] Then, after the solution treatment, the work piece is generally quenched to ordinary temperature, and then subjected to the aging treatment.

[0041] The aging treatment is preferably carried out by heating the work piece to 150°C to less than 200°C in several minutes, and maintaining the temperature for 30 to 360 minutes. The aging treatment temperature is more preferably 170°C to 190°C. In the case where the aging treatment temperature exceeds 200°C, the ductility of the obtained Al alloy will be lowered. The mechanical properties, including ductility (extensional property) and strength, of the Al alloy can be improved by carrying out the aging treatment at 150°C to less than 200°C for the prescribed time.

[0042] The Al alloy that the present invention is aimed at is a precipitation hardening Al alloy that precipitates an intermediate phase such as Mg_2Si phase and the like by heat treatment, and is not limited as far as it goes. Therefore, the present invention can be applied to any of casting products and wrought products of Al alloys made using an ordinary method.

[0043] Casting products of Al alloys are castings and die-castings, and wrought products indicate plates, foils, shape materials, pipes, rods, wires, forged products, and the like. Each Al alloy is improved in its properties such as strength and the like by being added with various elements, and there are Al-Mg-Si-based alloys, Al-Cu-Mg-based alloys, Al-Cu-Si-based alloys and others. For example, as a casting product, Al alloys of AC4C and AC4CH provided in JIS can be effectively applied. And, as a wrought product, 2000-series alloys, including 2017 that is known by the name of duralumin and improved in strength by containing a relatively high quantity of copper, and other 6000-series and 7000-series alloys can be applied.

[0044] In the solution treatment, the use of a fluidized bed is preferable to raise the temperature of the work piece quickly. Quick heating using a fluidized bed is performed by placing the work piece in the fluidized bed.

[0045] The fluidized bed is formed by granular substances such as powder and granules heated and evenly mixed by blowing gas, and has features of making the temperature in the fluidized bed substantially uniform, as well as a high thermal conductivity.

[0046] By utilizing a fluidized bed in the solution treatment of the work piece, the temperature uniformity (about ± 2 to 3°C) in the fluidized bed can be achieved, the solution treatment can be carried out at a higher temperature, and the high thermal conductivity enables the time for heating the work piece to the solution treatment temperature to be shortened. These features are great advantages over conventional atmospheric kilns using air as the heat medium.

[0047] Now, in the aging treatment, any of the above described fluidized bed system and a publicly known conventional atmospheric kiln can be used.

[0048] As a fluidized bed system, besides indirect heating systems, including the vessel heating system to heat the vessel of the fluidized bed from the outside and the radiant tube system that incorporates radiant tubes in the fluidized bed, a direct heating system by directly blowing hot air has been known, and any system can be applied, but the formation of the fluidized bed using a direct heating system by directly blowing hot air is preferable because the better temperature distribution in the fluidized bed can be achieved.

[0049] Next, the above described heat treatment methods will be described in further detail according to drawings.

[0050] Figure 1 is a schematic diagram showing an example of direct blowing hot air fluidized beds used in the heat treatment methods. The numeral 10 represents a vessel, and in the vessel 10, granular substances 12 such as powder and granules are packed on a perforated plate 16, and these granular substances 12 are fluidized and evenly mixed by hot air 14 blown from the bottom of the perforated plate 16 to form a fluidized bed 18.

[0051] Figure 2 is a schematic diagram showing an example of fluidized bed type solution treatment kilns. In Figure 2, the numeral 20 represents a hot air generator, in which the air sent by a blower that is not shown is heated by flames from a burner 22 to form hot air of a temperature of 700 to 800°C. This hot air is blown to a fluidized bed type solution treatment kiln 26 through a hot air temperature monitor 24. In the fluidized bed type solution treatment kiln 26, the hot air is blown from a perforated pipe 28 into the fluidized bed 30 to fluidize and heat the granular substances 32. Thus, the fluidized bed 30 is heated to 540 to 550°C, and the uniformity of temperature in the kiln, in which the deviation of

the kiln temperature is about 6°C ($\pm 3^\circ\text{C}$) and the deviation at a point is about 3°C, is achieved. Thereby the work piece 34 present in the fluidized bed 30 is rapidly heated. Further, the numeral 36 represents a granular substances discharging valve, adequately discharging the granular substances 32 to the outside.

[0052] Although it is not shown, the fluidized bed as shown in Figure 1 and 2 can be used in the aging treatment.

[0053] In the following, the present invention will be described further concretely according to Embodiments and Comparative

Examples.

(Embodiment 1)

[0054] A heat treatment method was carried out on a cast wheel made of an Al alloy of AC4CH using a fluidized bed type solution treatment kiln, and using an atmospheric kiln as an aging treatment kiln.

[0055] The fluidized bed type solution treatment kiln is constituted of a square tank-shaped fluidized bed vessel that is 1500 mm $\times$ 1500 mm in side area, and has a straight body part of 1800 mm and a trapezoidal bottom. Further, as the aging treatment kiln, a publicly known conventional tunnel kiln (atmospheric kiln) was used. And as the granular substances, silica sand of 50 to 500 μm in average particle diameter was used.

[0056] As a subject of heat treatment, a cast aluminum vehicle wheel (14 kg) shown in Figure 3 was used, and test pieces were cut from three positions of the outer rim flange, the inner rim flange and the spoke. As for the composition of the above described aluminum wheel made of an Al alloy of AC4CH, the wheel contained 7.0% by mass of Si, 0.33% by mass of Mg, and 40 ppm by mass of Sr, and further contained 0.001% by mass of Cu and 0.11% by mass of Fe, and the balance being Al.

[0057] As heat treatment conditions, the heat treatments were carried out with each maintaining time changed according to the schedule shown in Figure 4. Further, the aging treatment was carried out under the condition of maintaining the wheel for 53 minutes at 190°C (the total aging treatment time including the temperature raising time was 85 minutes).

[0058] Test pieces ($n = 4$) were cut from the heat-treated aluminum vehicle wheel, and were subjected to the tensile test (tensile strength, 0.2% yield strength, and elongation), the impact test, and the hardness test. The obtained results are shown in Figure 5 and 6.

[0059] Moreover, as the above described impact test, impacts values were measured with the use of the Charpy test method provided in JIS. And as the hardness test, Rockwell hardness was measured with the use of the method provided in JIS Z2245.

[0060] Further, the relationship between the average area of eutectic structures and the solution treatment time at this time is shown in Figure 7.

[0061] Here, the average area of eutectic structures was measured in the following method.

[0062] After having been mirror-like polished, the surface of a test piece was photographed at a magnification of $\times 1000$, and then the average area of eutectic structures was obtained by calculating the number and the average area of eutectic structures existing in the range of 4768.716 μm^2 in area.

(Embodiment 2)

[0063] Test pieces (Figure 8) were cut from the aluminum vehicle wheel obtained in the same method as Embodiment 1, and were subjected to the rotating bending fatigue test to obtain fatigue strength.

[0064] Here, the rotating bending fatigue test was carried out using Ono rotating bending fatigue tester. In the tester, test piece 1 were subjected to a stress at stress ratio of -1 while being rotated at 3600 rpm in the air at room temperature, and the fatigue strength was measured from the relationship between the stress and the number of flexes when the test piece was broken. The results are shown in Figure 9 and 10.

(Embodiment 3)

[0065] Test pieces were cut from the aluminum vehicle wheel that was obtained when the maintaining time was 60 minutes at the solution treatment temperature of 550°C in Embodiment 1, and the average areas of eutectic structures in the test pieces were measured in the same method as Embodiment 1.

[0066] The results are shown in Table 1. Moreover, the results of the tensile test (tensile strength, 0.2% yield strength, and elongation) at this time are shown in Figure 11.

Table 1

Sample name				The number of measured samples	The average value (μm ²)
1	Comparative Example 1	Outer rim	1	81	5.862
			2	104	5.528
			3	85	4.986
		The average		90	5.459
2		Inner rim	1	77	8.253
			2	75	7.200
			3	103	8.397
		The average		85	7.950
3		Spoke	1	64	8.992
			2	92	7.49
			3	75	8.961
		The average		77	8.481
4	Embodiment 3	Outer rim	1	176	2.285
			2	288	1.636
			3	246	1.924
		The average		237	1.948
5		Inner rim	1	188	3.305
			2	217	3.001
			3	287	1.979
		The average		231	2.762
6		Spoke	1	310	1.841
			2	305	2.122
			3	240	1.799
		The average		285	1.921

(Comparative Example 1)

[0067] As a solution treatment kiln and an aging treatment kiln, a conventional tunnel kiln (atmospheric kiln) was used, and a cast aluminum vehicle wheel was subjected to heat treatment under the following conditions. That is, the solution treatment temperature was set to be 540°C, the aging treatment temperature was set to be 155°C (the total treatment time was 174 minutes), and the temperature raising time to the solution treatment temperature was 1 hour and 12 minutes and the maintaining time at the solution treatment temperature was 4 hours. Other conditions are the same as those in Embodiment 1.

[0068] Test pieces (n = 4) were cut from the heat-treated aluminum vehicle wheel, and were subjected to the tensile test (tensile strength, 0.2% yield strength, and elongation). The obtained results are shown in Figure 11.

(Comparative Example 2)

[0069] Test pieces (Figure 8) were cut from the aluminum vehicle wheel obtained in the same method as Comparative Example 1, and were subjected to the rotating bending fatigue test to obtain fatigue strength. The results are shown in Figures 9 and 10.

(Discussion)

[0070] As clearly seen from Embodiments 1 to 3 and Comparative Examples 1 and 2, the tensile strength, 0.2% yield strength, and elongation of the vehicle aluminum wheel in which the average area of eutectic structures is as minute as less than $4\ \mu\text{m}^2$ are the predetermined levels or higher, and these values satisfy all the required values of the tensile test. As a result, it was ascertained that these values have been greatly improved compared to those for the conventional wheel in which the average area of eutectic structures is over $4\ \mu\text{m}^2$. And, the fatigue strength is also greatly improved compared to the conventional values.

[0071] Further, even in the case where the solution treatment kiln and aging treatment kiln of the fluidized bed type were used, it was found that the coarsening of eutectic structures went ahead when the solution treatment time exceeded 240 minutes.

[0072] Moreover, from the results of Embodiment 2 and Comparative Example 2, it was found that fatigue properties both in the inner rim and the outer rim were improved in the heat treatment using a fluidized bed when compared to those in the heat treatment using a conventional tunnel kiln.

(Embodiment 4)

[0073] A heat treatment method was carried out using a fluidized bed type solution treatment kiln shown in Figure 2 and using an atmospheric kiln as an aging treatment kiln.

[0074] The fluidized bed type solution treatment kiln is constituted of a square tank-shaped fluidized bed vessel that is $1500\ \text{mm} \times 1500\ \text{mm}$ in side area, and has a straight body part of $1800\ \text{mm}$ and a trapezoidal bottom. Further, as the aging treatment kiln, a conventional tunnel kiln (atmospheric kiln) was used. And as the granular substances, silica sand of 50 to $500\ \mu\text{m}$ in average particle diameter was used.

[0075] As a subject of heat treatment, a cast aluminum vehicle wheel ($13\ \text{kg}$) shown in Figure 17 was used, and test pieces were cut from two positions of the outer rim flange and the spoke. As for the composition of the above described aluminum wheel, the wheel contained 7.0% by mass of Si, 0.34% by mass of Mg, and $50\ \text{ppm}$ by mass of Sr, and the balance being Al.

[0076] As the heat treatment conditions, the solution treatment temperatures were set to be 540°C and 550°C , the aging treatment temperatures were set to be 190°C and 220°C , and further the temperature raising time to the solution treatment temperature, the maintaining time at the solution treatment temperature, and the temperature raising time and the maintaining time in the aging treatment were carried out according to the schedule shown in Figure 13 (when the solution treatment temperature is 550°C).

[0077] Figure 12 shows the results of differential calorimetric analysis that measured absorption energy when Si and/or Mg are made as a solid solution into α phase in the solution treatment. As clearly seen from Figure 12, in the solution treatment, making the rate of solid solutions of Si and/or Mg into α phase to be 60% or more is equivalent to the solution treatment time (the total of the temperature raising time and the maintaining time) of 18 minutes or more at the solution treatment temperature of 540°C , and to the solution treatment time of 7 minutes or more at the solution treatment temperature of 550°C .

[0078] Further, it can be seen that the solid solution rate will be 100% when the solution treatment time is 180 minutes at the solution treatment temperature of 540°C and the solution treatment time is 60 minutes at the solution treatment temperature of 550°C .

[0079] Test pieces ($n = 4$) were cut from the aluminum vehicle wheel heat-treated as described above, and were subjected to the tensile test (tensile strength, 0.2% yield strength, and elongation), the impact test, and the hardness test. The obtained results are shown in Figure 14 and 15.

(Comparative Example 3)

[0080] As a solution treatment kiln and an aging treatment kiln, a conventional tunnel kiln (atmospheric kiln) was used, the solution treatment temperature was set to be 540°C and the aging treatment temperature was set to be 155°C , and a cast aluminum vehicle wheel was subjected to heat treatment according to the schedule shown in Figure 18. Other conditions are the same as those in Embodiment 4.

[0081] In this Comparative Example 3, as seen from Figure 12, the rate of solid solutions of Si and/or Mg into α phase was about 50% even though the solution treatment time was 312 minutes.

[0082] Test pieces ($n = 4$) were cut from the aluminum vehicle wheel heat-treated under the above described conditions, and were subjected to the tensile test (tensile strength, 0.2% yield strength, and elongation). The obtained results are shown in Figure 16.

(Comparative Example 4)

[0083] A cast aluminum vehicle wheel was subjected to heat treatment under the same conditions as Comparative Example 3, except for the aging treatment temperature of 190°C and the aging treatment time of 85 minutes.

[0084] Test pieces (n = 4) were cut from the obtained aluminum vehicle wheel, and were subjected to the tensile test (tensile strength, 0.2% yield strength, and elongation), resulting in the tensile strength of 305.7 MPa, the 0.2% yield strength of 244.4 MPa, and the elongation of 11.3% on the outer rim flange.

(Comparative Example 5)

[0085] A cast aluminum vehicle wheel was subjected to heat treatment under the same conditions as Comparative Example 3, except for the aging treatment temperature of 220°C and the aging treatment time of 35 minutes.

[0086] Test pieces (n = 4) were cut from the obtained aluminum vehicle wheel, and were subjected to the tensile test (tensile strength, 0.2 % yield strength, and elongation). The obtained results are shown in Figure 14.

(Comparative Example 6)

[0087] A cast aluminum vehicle wheel was subjected to heat treatment under the same conditions as Embodiment 4, except for the solution treatment temperature of 550°C, the rate of solid solutions of Si and/or Mg into α phase of 50%, the aging treatment temperature of 220°C and the aging treatment time of 35 minutes.

[0088] Test pieces (n = 4) were cut from the obtained aluminum vehicle wheel, and were subjected to the tensile test (tensile strength, 0.2 % yield strength, and elongation). The obtained results are shown in Figure 14.

(Discussion)

[0089] As clearly seen from the results of the tensile tests, the impact tests, and hardness tests in Embodiment 4 and Comparative Example 3 to 6, the aluminum vehicle wheel obtained in Embodiment 4 was found to have the tensile strength of 326.2 MPa or more, the 0.2 % yield strength of 261.3 MPa or more, and the elongation of 12.9 % or more on the outer rim flange.

[0090] On the other hand, it can be seen that the aluminum wheel obtained in the conventional tunnel kiln shown in Comparative Example 3 is inferior in the mechanical properties of tensile strength, yield strength and elongation to that obtained in Embodiment 4, and that when the solid solution rate is as low as 50% in the solution treatment as in Comparative Examples 3 and 4, the wheel is also inferior in tensile strength, 0.2% yield strength and elongation to the wheels in Embodiments.

[0091] Moreover, when the aging treatment temperature is as high as 220°C as in Comparative Examples 5 and 6, it can be seen that the mechanical properties of the obtained aluminum wheels are further inferior.

INDUSTRIAL APPLICABILITY

[0092] As described above, according to the present invention, it is possible to provide an Al alloy that has well-balanced three mechanical properties of tensile strength, yield strength, and elongation, and is also excellent in fatigue strength. Furthermore, according to the heat treatment method of the present invention, because the solution treatment is carried out using a fluidized bed, the rate of solid solutions of Si and/or Mg is raised to the predetermined rate or higher, and the aging treatment temperature is the predetermined temperature or less, the strength and elongation of an obtained precipitation hardening Al alloy can be improved.

Claims

1. A precipitation hardening Al alloy, **characterized in that** an average area of eutectic structures existing in said Al alloy is less than 4 μm^2 .
2. The precipitation hardening Al alloy according to claim 1, wherein said alloy contains 6.5 to 7.5% by mass of Si, 0.36% by mass or less of Mg.
3. The precipitation hardening Al alloy according to claim 1 or 2, wherein said alloy contains 20 to 70 ppm of Sr.
4. The precipitation hardening Al alloy according to any of claims 1 to 3, wherein said alloy is used as a vehicle wheel.

5. A heat treatment method of a precipitation hardening Al alloy comprising;

subjecting a work piece comprising the precipitation hardening Al alloy to solution treatment, and then
subjecting the work piece to aging treatment, to improve mechanical properties of the work piece,

characterized in that said work piece is subjected to said solution treatment by being made to exist in a fluidized bed, and further a rate of solid solutions of Si and/or Mg into α phase is made to be 60% or more in said solution treatment and said aging treatment is carried out at temperatures from 150°C or more to less than 200°C.

6. The heat treatment method according to claim 5, wherein temperature raising to said solution treatment temperature is carried out within 30 minutes, and further a maintaining time at said solution treatment temperature is 25 minutes to 3 hours.

7. The heat treatment method according to claim 6, wherein said solution treatment temperature is 540 to 550°C.

8. The heat treatment method according to any of claims 5 to 7, wherein said fluidized bed is formed by direct blowing of hot air.

Amended claims under Art. 19.1 PCT

1. (Amended) A precipitation hardening Al alloy,
characterized in that an average area of eutectic structures existing in said Al alloy is below 4 μm^2 , and said alloy contains 6.5 to 7.5 by mass % of Si and 0.36 by mass % or less of Mg.

2. (Canceled)

3. (Amended) The precipitation hardening Al alloy according to claim 1, wherein said alloy contains 20 to 70 ppm of Sr.

4. (Amended) The precipitation hardening Al alloy according to claim 1 or 2, wherein said alloy is used as a vehicle wheel.

5. A heat treatment method of a precipitation hardening Al alloy, which comprises;

subjecting the work piece to aging treatment, to improve mechanical properties of the work piece,

characterized in that said work piece is subjected to said solution treatment by being made to exist in a fluidized bed, and further a rate of solid solutions of Si and/or Mg into α phase is made to be 60% or more in said solution treatment and said aging treatment is carried out at temperatures from 150°C or more to less than 200°C.

6. The heat treatment method according to claim 5, wherein temperature raising to said solution treatment temperature is carried out within 30 minutes, and a maintaining time further at said solution treatment temperature is 25 minutes to 3 hours.

7. The heat treatment method according to claim 6, wherein said solution treatment temperature is 540 to 550°C.

8. The heat treatment method according to any one of claims 5 to 7, wherein said fluidized bed is formed by direct blowing of hot air.

FIG.1

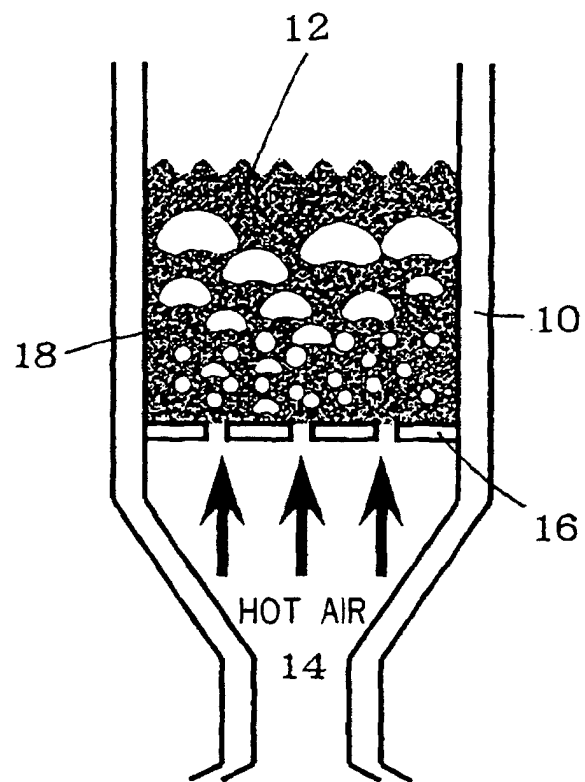


FIG. 2

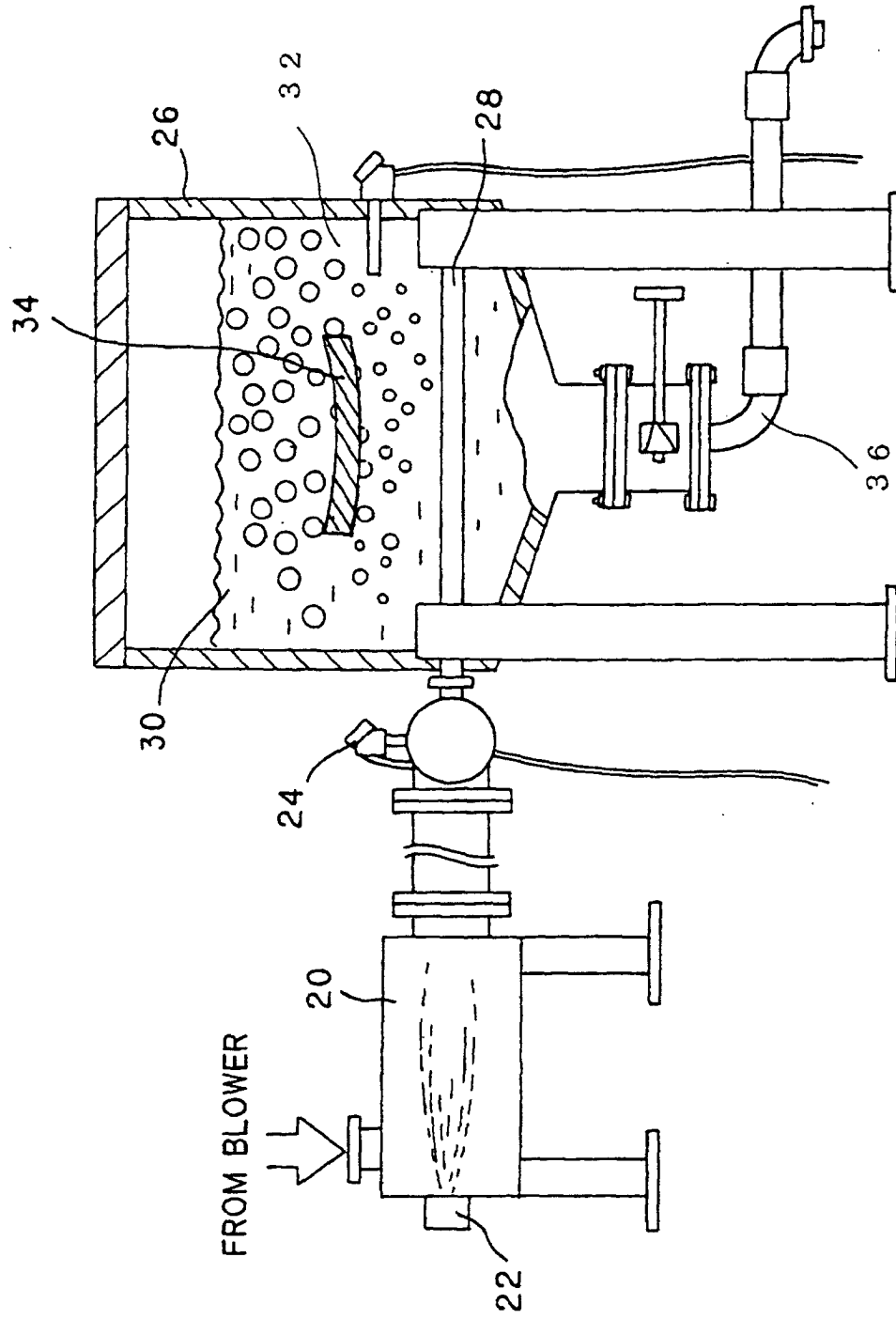


FIG. 3

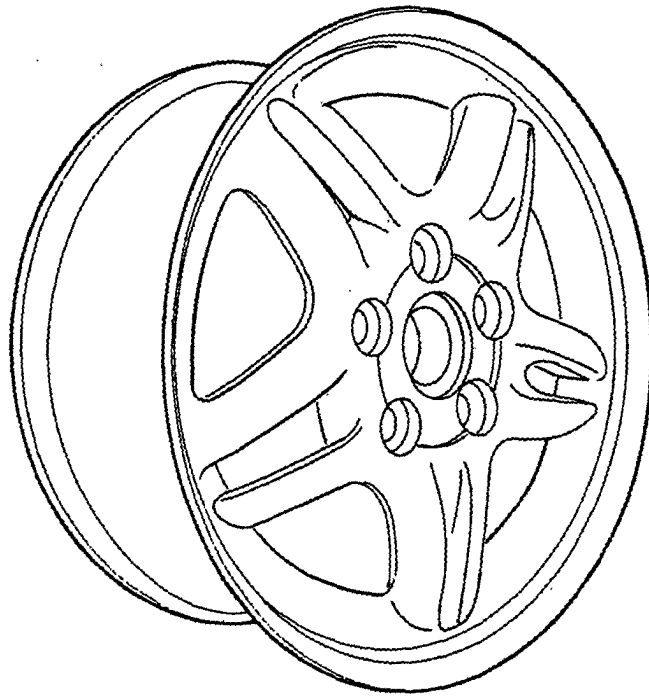
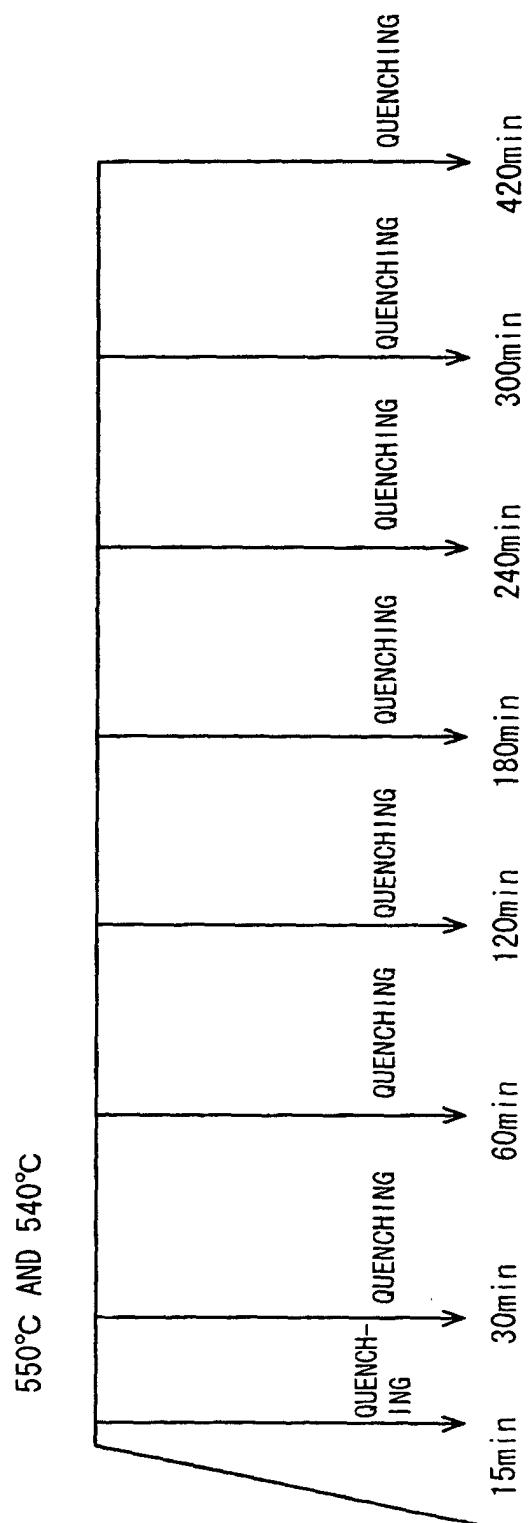
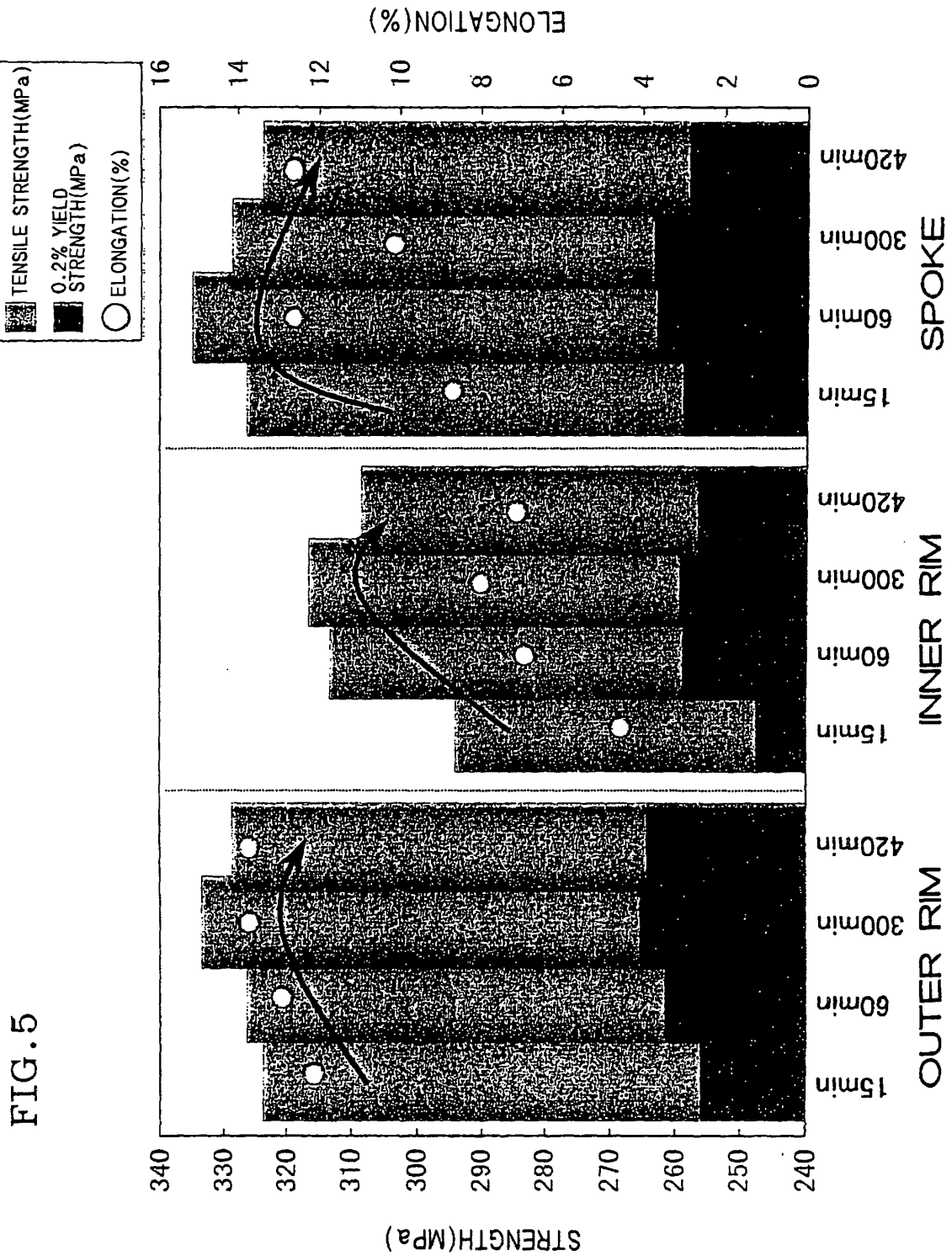


FIG. 4



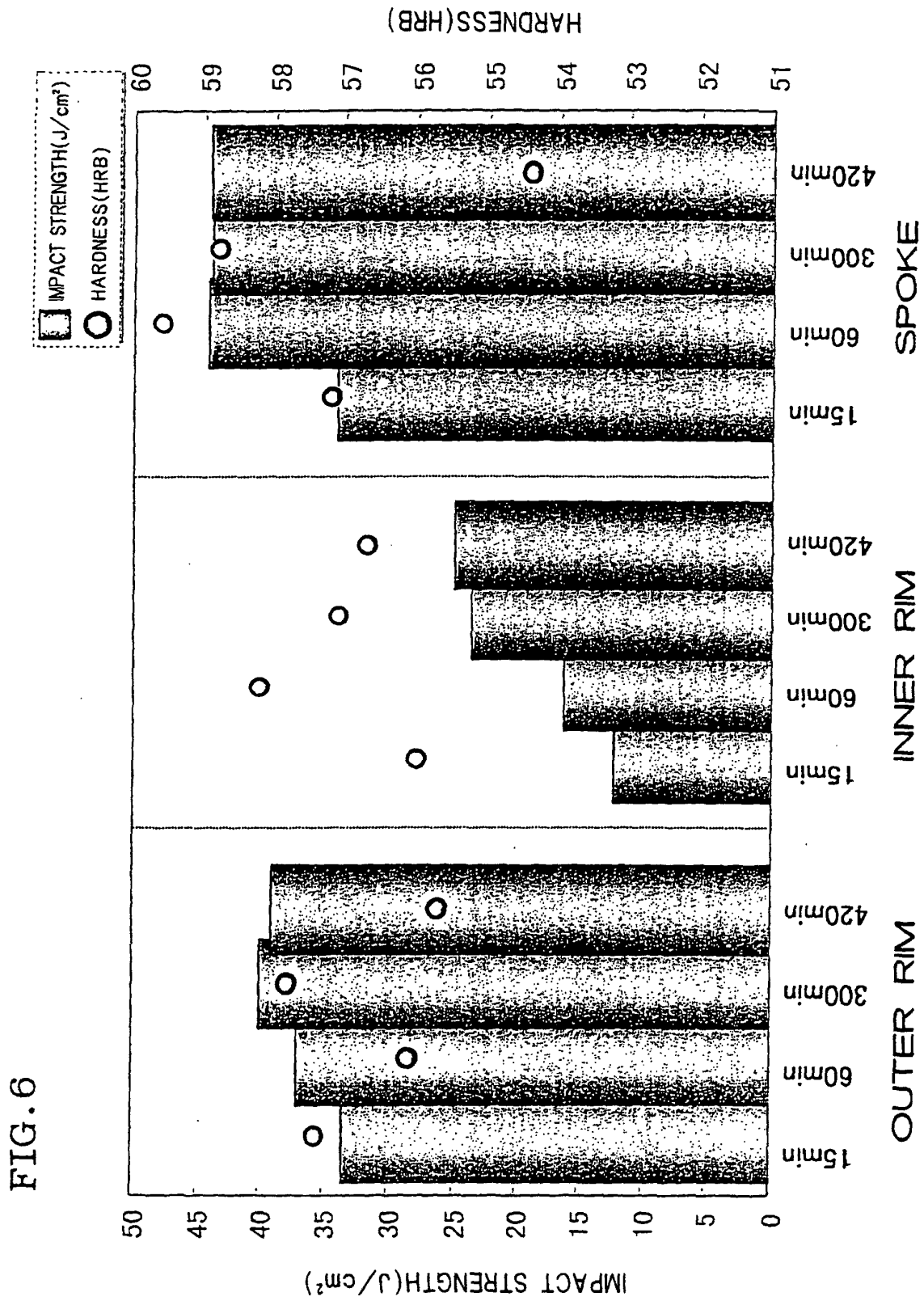


FIG. 7

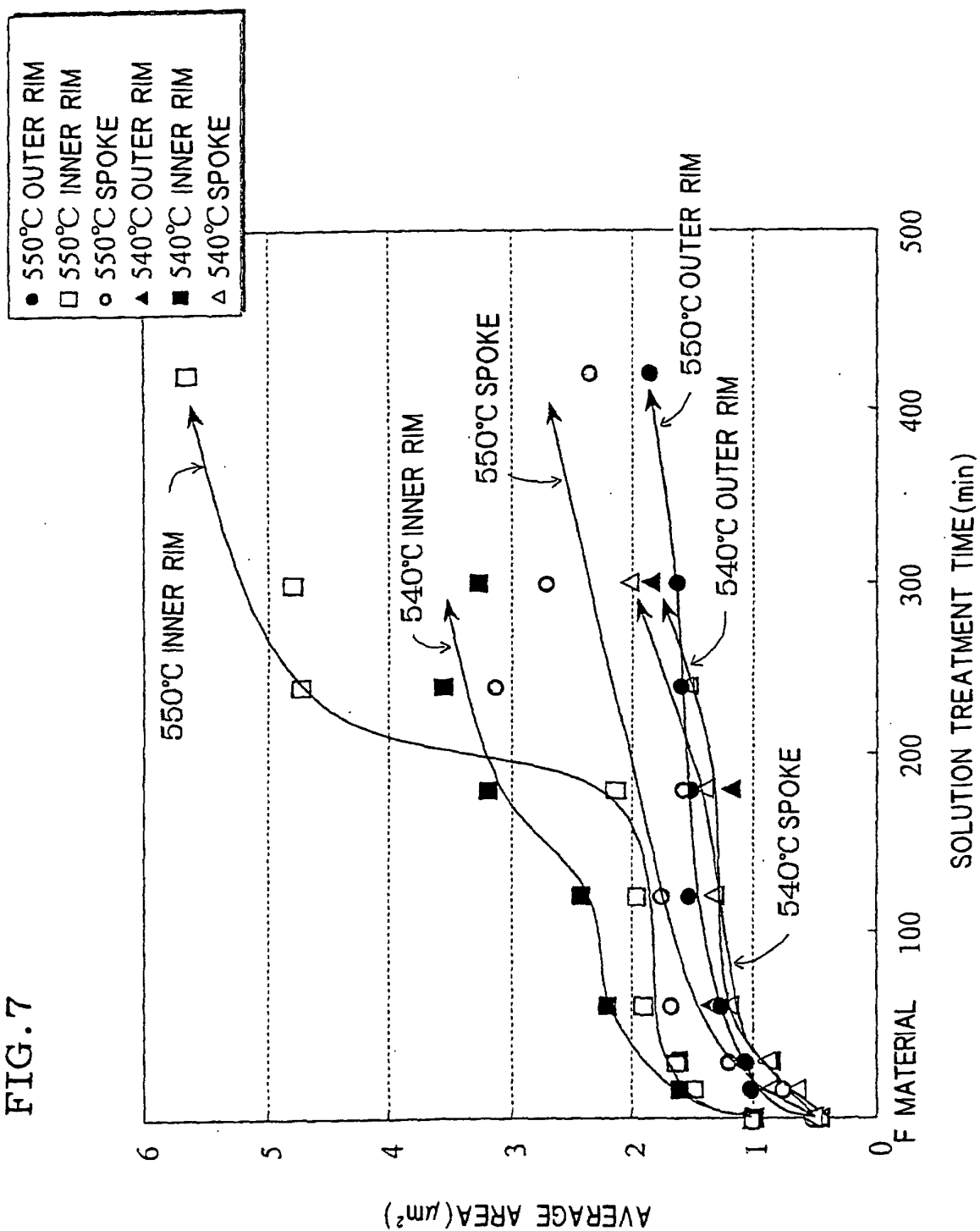


FIG. 8

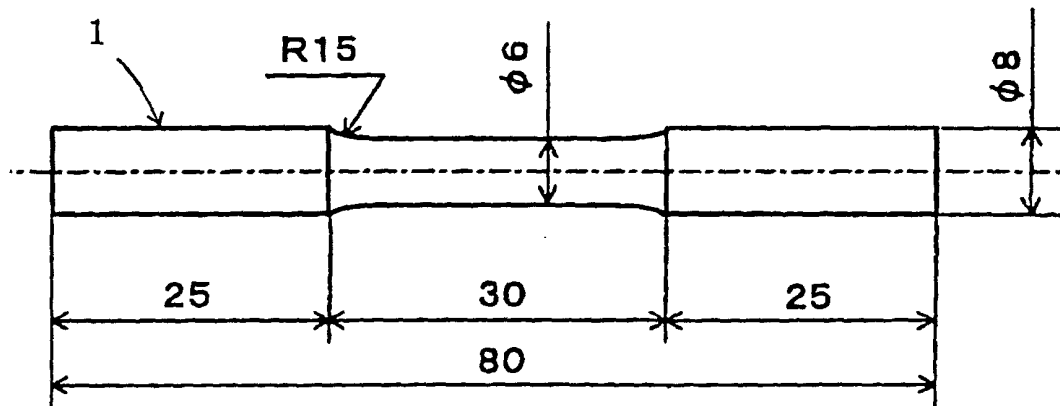


FIG. 9

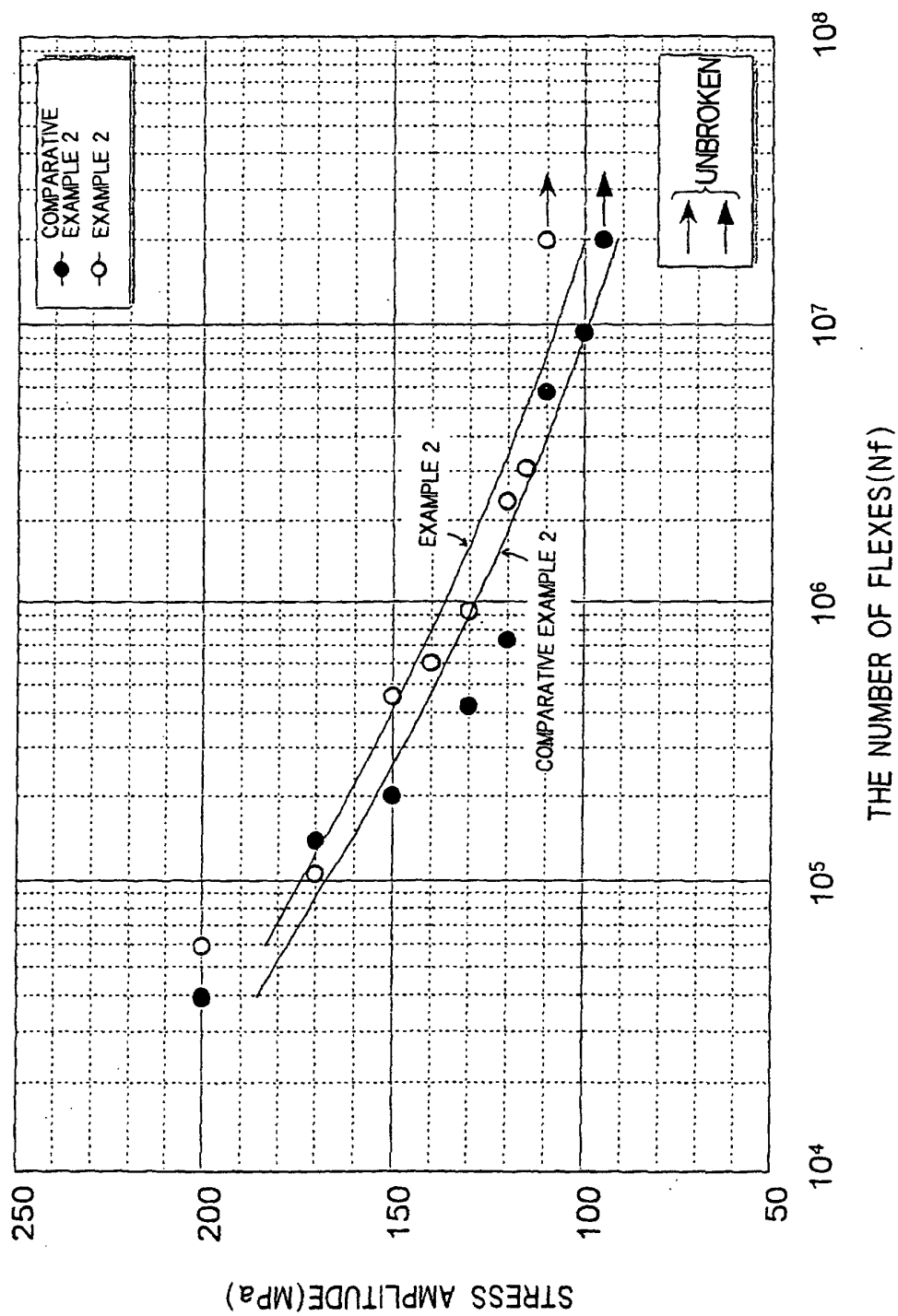


FIG. 10

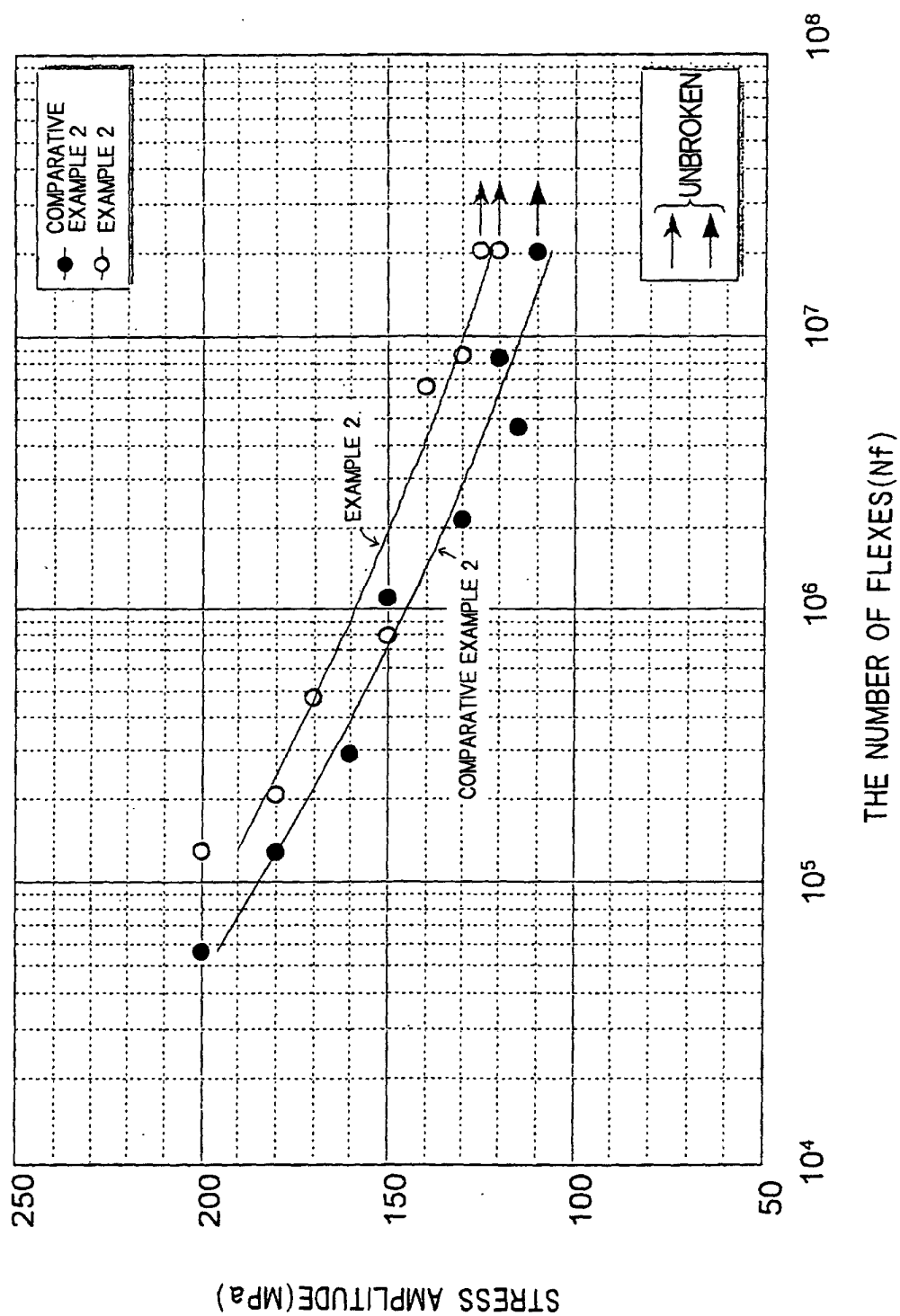


FIG. 11

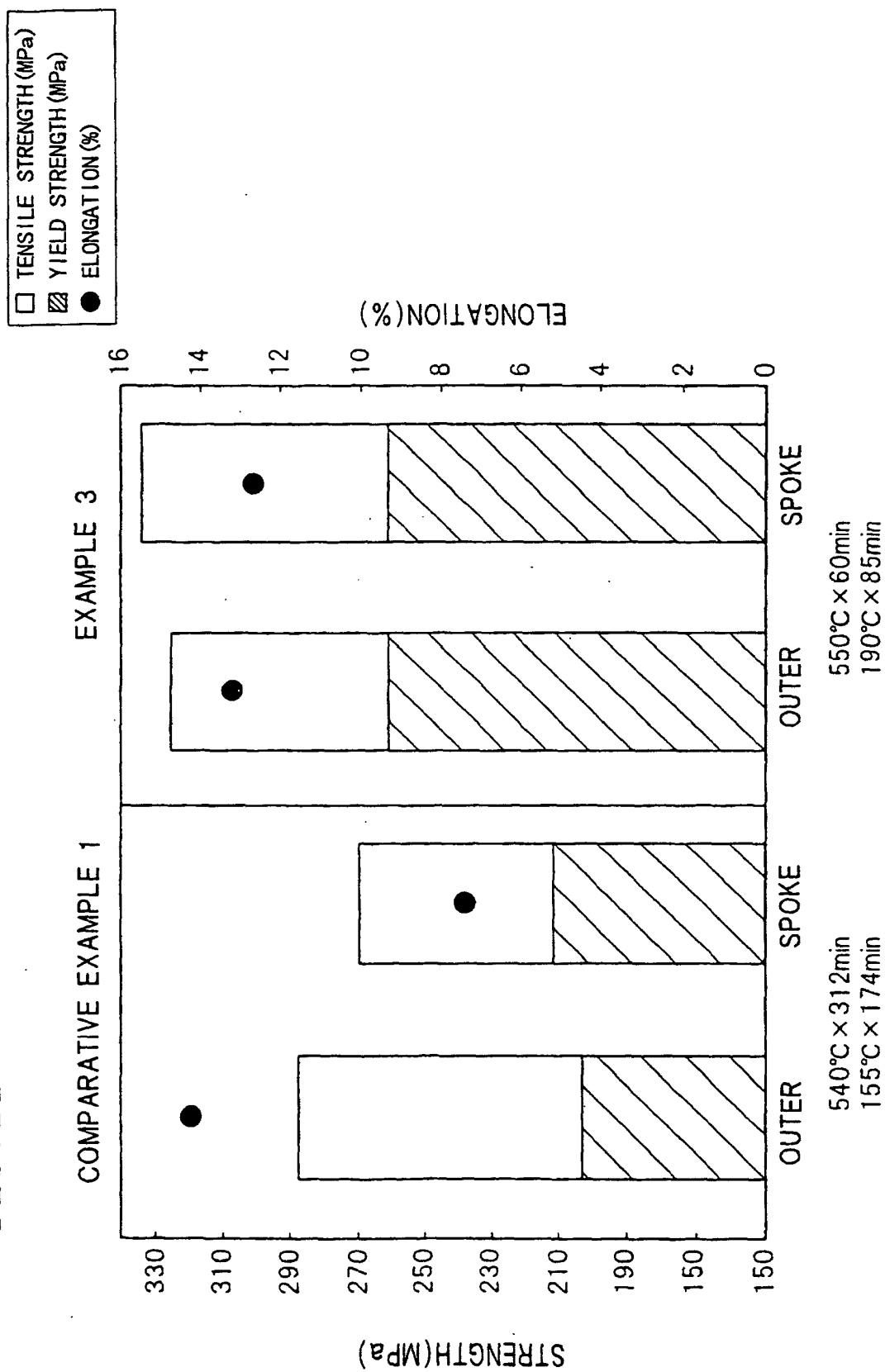


FIG. 12

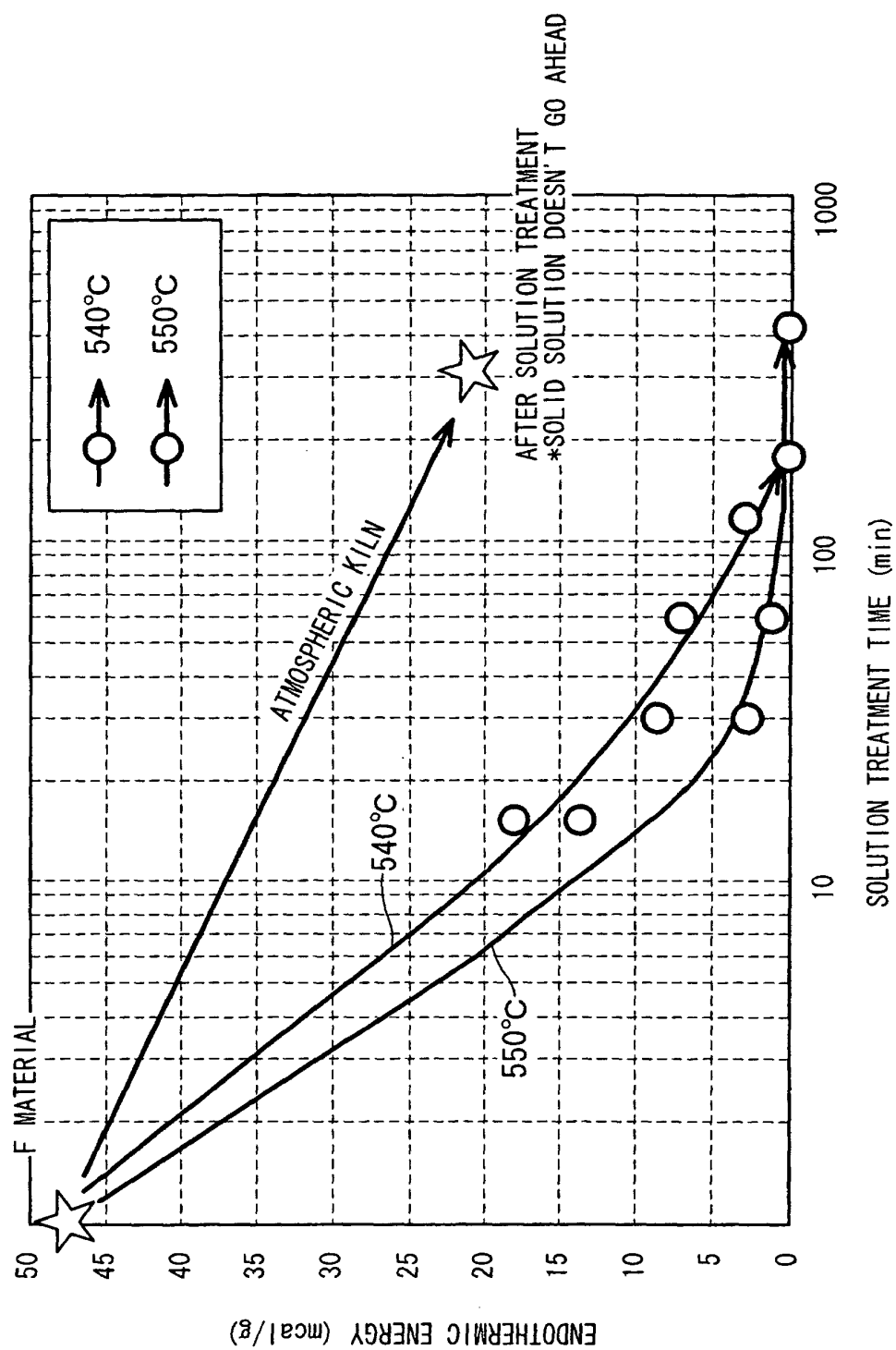


FIG. 13

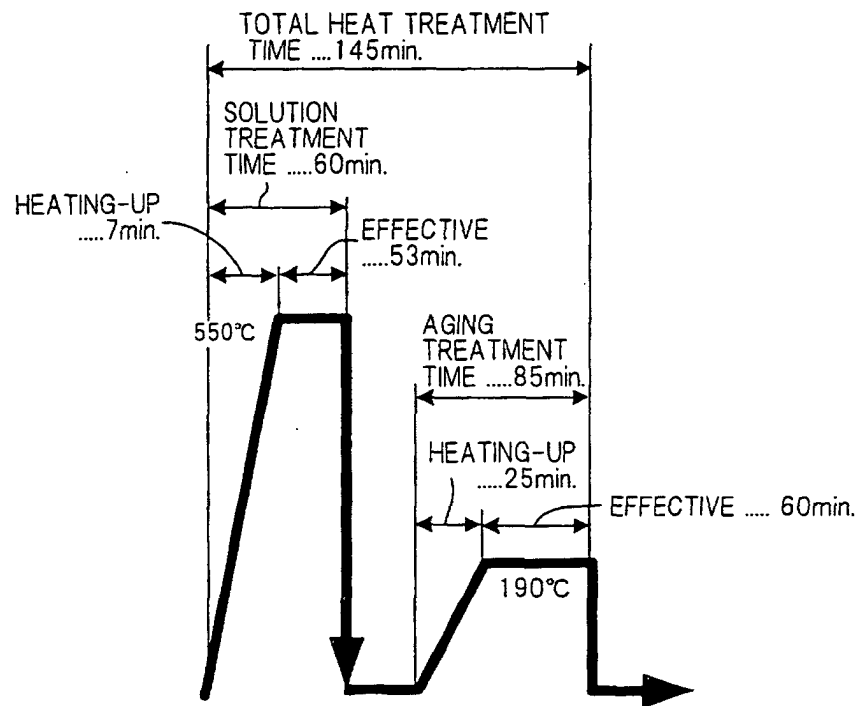


FIG. 14

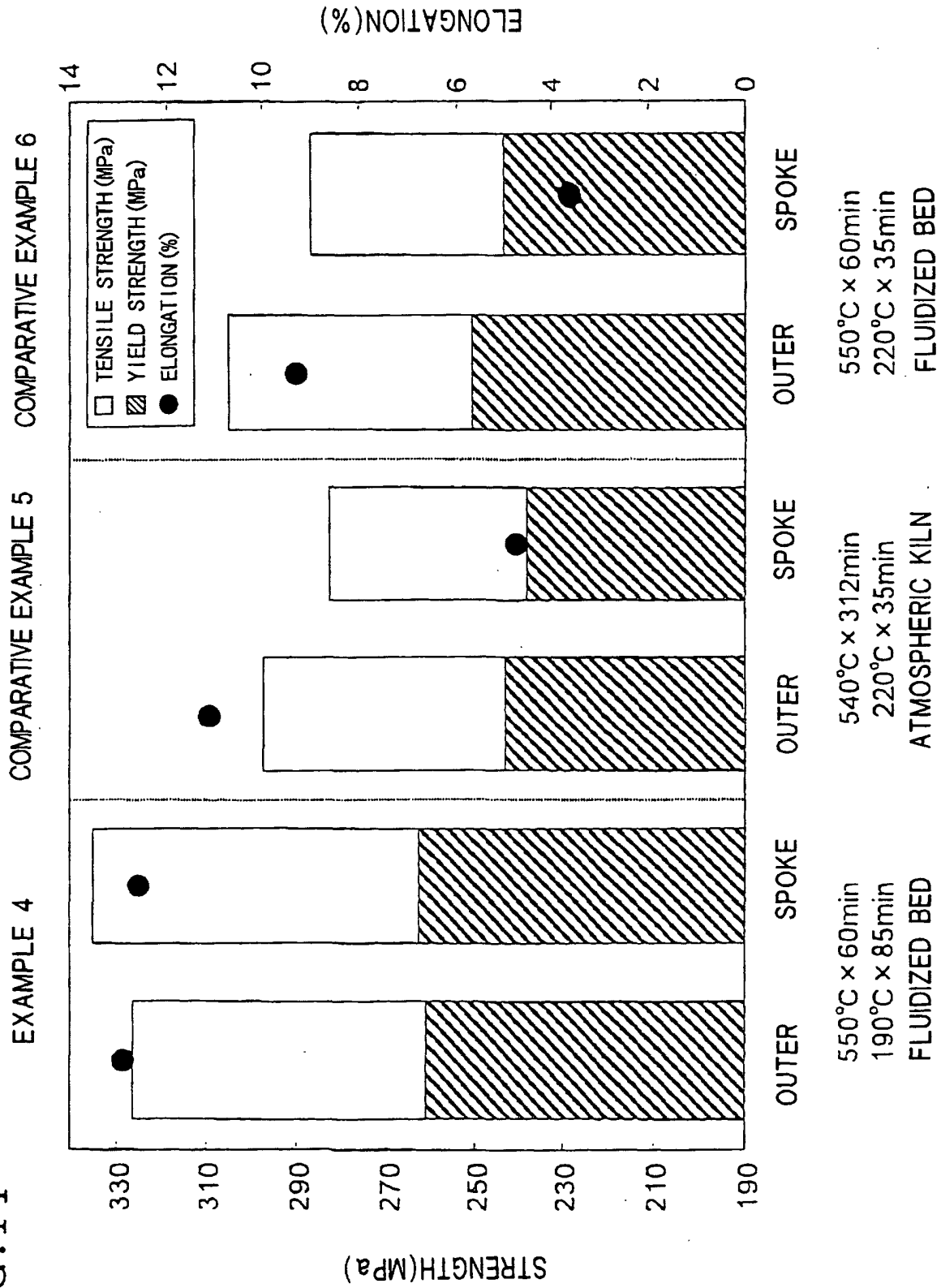


FIG. 15

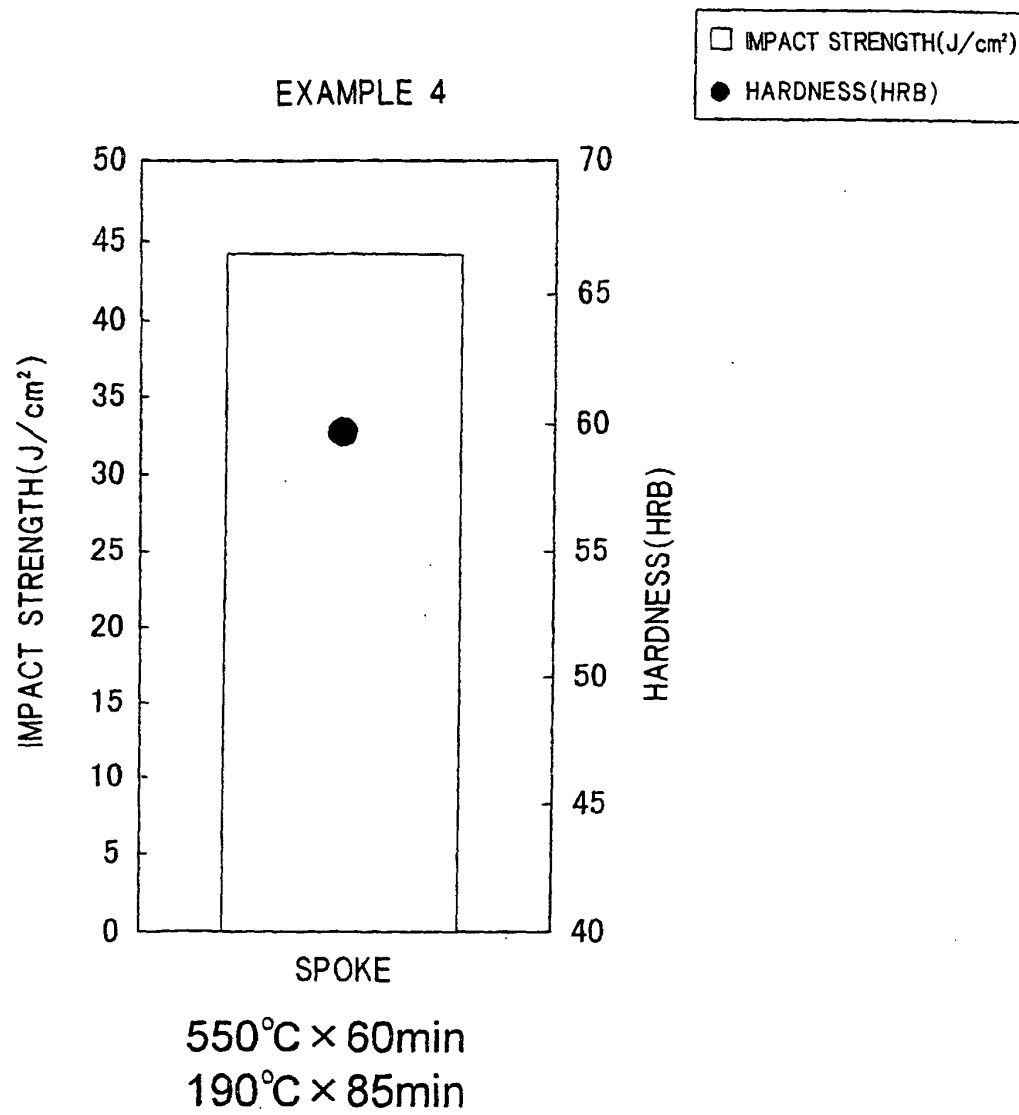


FIG. 16

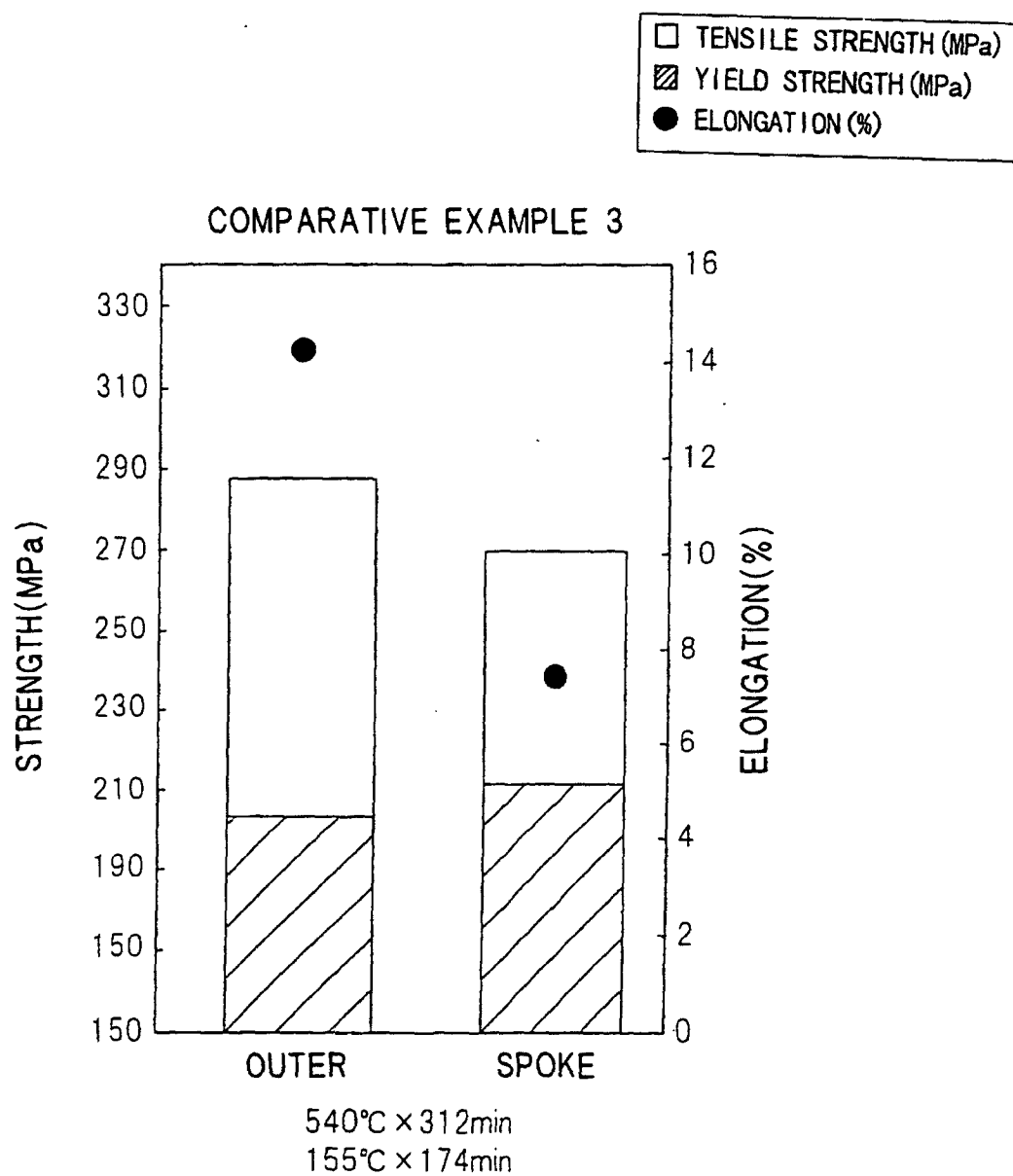


FIG. 17

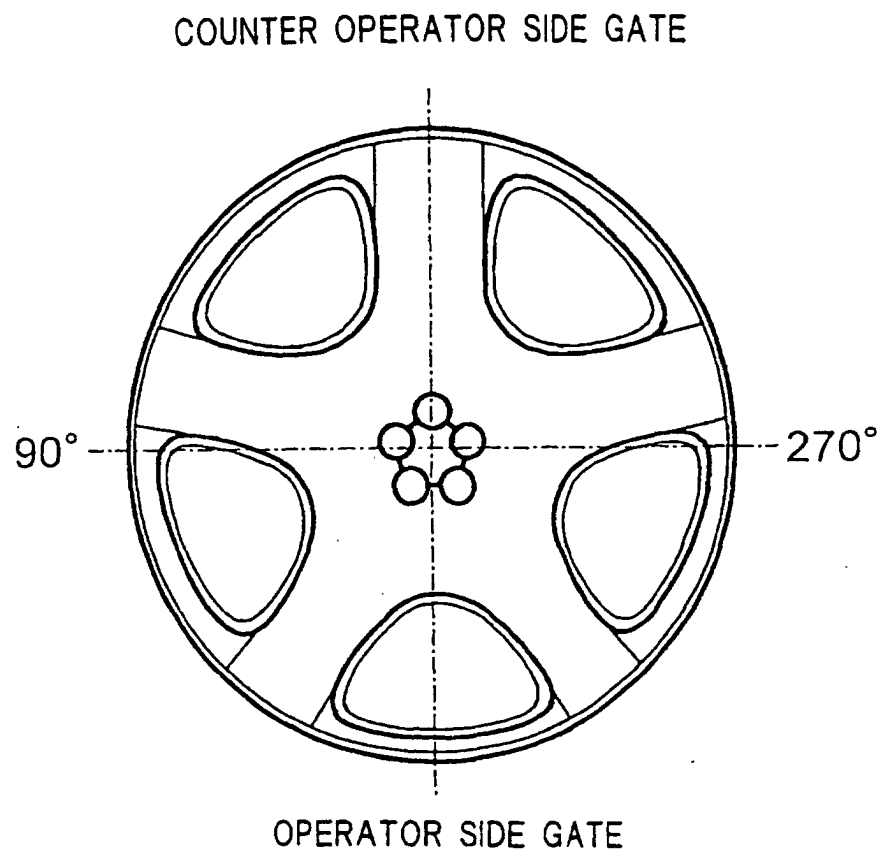
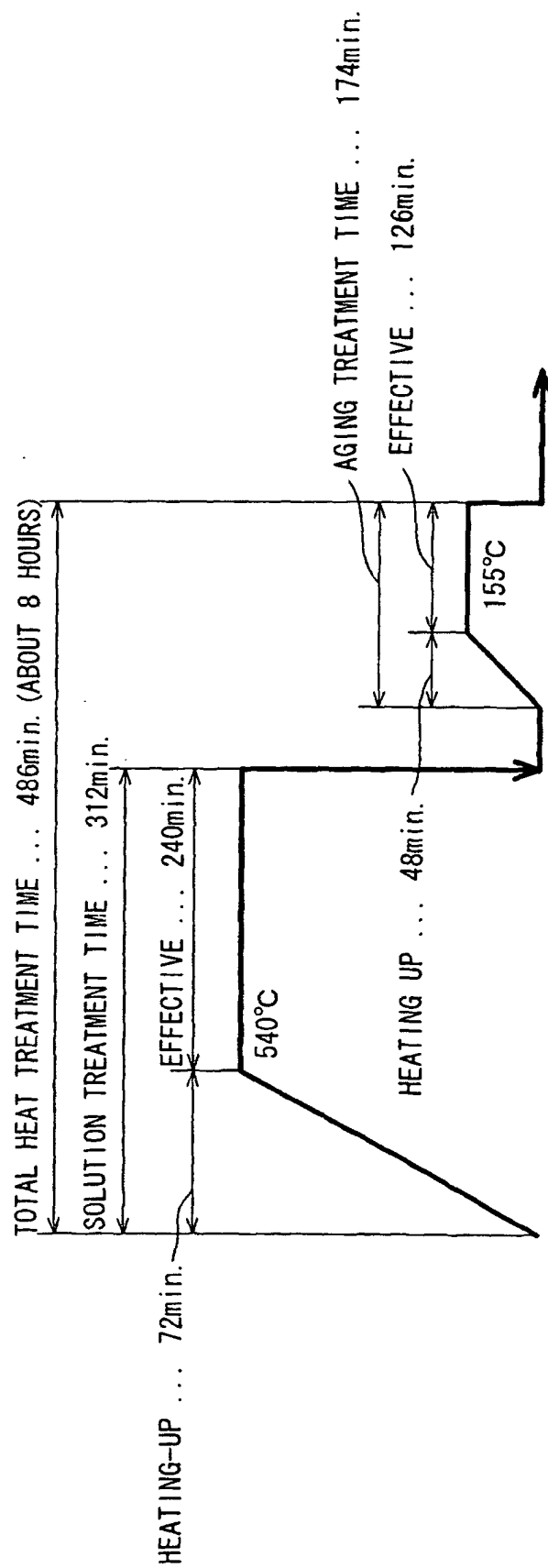


FIG. 18



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP01/06157

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl⁷ C22F 1/043

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl⁷ C22F 1/04-1/057, C21D 1/53, F27B 15/00-15/20

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

Jitsuyo Shinan Koho	1926-1996	Toroku Jitsuyo Shinan Koho	1994-2001
Kokai Jitsuyo Shinan Koho	1971-2001	Jitsuyo Shinan Toroku Koho	1996-2001

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X P,Y	JP 2001-73056 A (Kobe Steel, Ltd.), 21 March, 2001 (21.03.01), Claims 1, 2, 4, 5; page 5, column 7, lines 27 to 39; page 6, column 10, lines 28 to 39 (Family: none)	1,2 3-8
Y	JP 62-56220 B2 (Maeda Keikinzoku Kogyo K.K.), 25 November, 1987 (25.11.87), Claims (Family: none)	1-8
Y	JP 2000-17413 A (Aisin Seiki Co., Ltd.), 18 January, 2000 (18.01.00), Claims; page 2, column 1, lines 17 to 19; page 3, column 3, lines 40 to 45 (Family: none)	1-8
X Y	JP 11-293430 A (Hitachi Metals, Ltd.), 26 October, 1999 (26.10.99), Claims; Figs. 1 to 7 (Family: none)	1 2-8
A	JP 7-310150 A (Hitachi Metals, Ltd.), 28 November, 1995 (28.11.95), Claims; working example (Family: none)	1-8

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
05 October, 2001 (05.10.01)Date of mailing of the international search report
16 October, 2001 (16.10.01)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP01/06157

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 53-16312 A (Hitachi Metals, Ltd.), 15 February, 1978 (15.02.78), Claims (Family: none)	1-8

Form PCT/ISA/210 (continuation of second sheet) (July 1992)