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(54) Heat-resistant spheroidal graphite cast iron.

(57) A heat-resistant spheroidal graphite cast iron consists essentially of not more than 3.4 wt% of C, 3.5 to 5.5 wt% of Si, not more than 0.6 wt% of Mn, 0.1 to 0.7 wt% of Cr, 0.3 to 0.9 wt% of Mo, not more than 0.1 wt% of a spheroidizing agent and the balance of Fe. Compared to conventional high silicon spheroidal graphite cast irons, this cast iron distinctly higher in the resistance to oxidation at high temperatures and is higher in strength too. This cast iron is far lower in production cost than conventional high nickel spheroidal graphite cast irons which are high in the resistance to oxidation at high temperatures.

Preferably the cast iron contains at least 1.7 wt% of C and from 0.25 to 0.7 wt% of Cr. Suitable spherodizing agents are Mg, Ca and Ce.

The cast iron may be made by a conventional process by allowing a molten metal of an appropriate composition and containing a spheroidizing agent to solidify in a mould and then subjecting the solidified casts to a spheroidizing-ferritizing heat treatment.

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HEAT-RESISTANT SPHEROIDAL GRAPHITE CAST IRON

This invention relates to a spheroidal graphite cast iron which has a high resistance to oxidation at high temperatures.

In many fields it is often desired to use a spheroidal graphite cast iron as a structural material in an apparatus or device which is operated at high temperatures. In the automobile industry, for example, the turbine housing of an exhaust gas turbocharger is usually made of a spheroidal graphite cast iron. Sometimes a high silicon spheroidal graphite cast iron having a ferrite matrix is employed as the material of the turbine housing. For example, such a spheroidal graphite cast iron contains 3.0 to 3.4 wt% of C, 3.65 to 4.10 wt% of Si, up to 0.6 wt% of Mn, up to 0.5 wt% of Ni, 0.5 to 0.7 wt% of Mo and up to 0.07 wt% of Cr. Spheroidal graphite cast irons of this class are relatively low in price and are generally satisfactory in mechanical properties, but have an unsatisfactorily low resistance to oxidation at high temperatures.

To meet the high temperature oxidation resistance requirement, it becomes necessary to employ a high nickel-chromium spheroidal graphite cast iron commonly called niresist. For example, a spheroidal graphite cast iron of this class contains up to 3.0 wt% of C, 1.5 to 3.0 wt% of Si,0.70 to 1.25 of Mn, 18.0 to 22.0 wt% of Ni and 1.75 to 2.75 wt% of Cr, and another cast iron of the same class contains up to 2.4 wt% of C, 1.0 to 2.8 wt% of Si, up to 1.0 wt% of Mn, 34.0 to 36.0 wt% of Ni and 2.0 to 3.0 wt% of Cr. However, cast irons of this class are very costly due to their Ni content, and, further such cast irons are relatively low in strength (e.g. about 40 kgf/mm^2 in tensile strength and about 20 kgf/mm^2 in 0.2% proof stress) and also in toughness (e.g. below 10% in elongation).

It is an object of the present invention to provide a spheroidal graphite cast iron which is satisfactory in both mechanical properties and resistance to oxidation at high temperatures and is lower in production costs than the conventional high nickel spheroidal graphite cast irons.

The present invention provides a heat-resistant spheroidal graphite cast iron which consists essentially of not more than 3.4 wt% of C, 3.5 to 5.5 wt% of Si, not more than 0.6 wt% of Mn, 0.1 to 0.7 wt% of Cr, 0.3 to 0.9 wt% of Mo, not more than 0.1 wt% of a spheroidizing agent and the balance of Fe. The matrix of this cast iron is principally ferrite.

Preferably the C content of the cast iron of the invention is not less than 1.7 wt%, and the Cr content is not less than 0.25 wt%.

A spheroidal graphite cast iron according to the invention is comparable to, and sometimes better than, conventional high silicon spheroidal graphite cast irons in mechanical properties and distinctly superior in resistance to oxidation at high temperatures such as 700-1000°C. The favourably balanced properties of the cast iron of the invention are realized by correlatively specifying the contents of Si and Cr within the above indicated ranges. Compared to conventional high nickel spheroidal graphite cast irons, a spheroidal graphite cast iron of the invention is higher in strength and nearly equivalent in the resistance to oxidation at relatively low temperatures and, as an industrially important factor, can be prepared at a far lower cost.

In the following description reference will be made to the accompanying drawings in which:

Figs. 1 and 2 are graphs showing the results of experiments to determine the dependence of the oxidation resistance of a spheroidal graphite cast iron at high temperatures with relation to the Si content of the cast iron;

Fig. 3 is a chart showing the ferritizing heat treatment conditions employed in the preparation of a cast iron as an example of the invention;

Fig. 4 is a graph showing the result of experiments to determine the oxidation resistance of spheroidal graphite cast irons prepared as examples of the invention at high temperatures in comparison with examples of conventional spheroidal graphite cast irons; and

Fig. 5 is a photomicrograph showing the structure of a spheroidal graphite cast iron prepared as an example of the invention.

A heat-resistant spheroidal graphite cast iron according to the invention has the composition specified above. The effects of the respective alloying elements and the reasons for the limitations on the amounts of the respective elements are as follows. Throughout the following description, the amounts of the elements in the cast iron are given in percentages by weight.

(1) Carbon

C is an alloying element indispensable to cast iron. In the cast irons of the present invention the C content is limited to a maximum of 3.4 because the presence of more than 3.4% of C tends to cause crystallization of an excessively large quantity of graphite and a reduction in the strength and toughness of the cast iron. If the C content is too low, the cast iron becomes inferior in its properties mainly because of insufficiency in the crystallization of graphite and a reduction in the fluidity of the molten metal. In most cases this tendency becomes significant if the C content is less than about 1.7%. Therefore, it is preferred that a spheroidal graphite cast iron according to the invention contains at least 1.7% of C.

(2) Silicon

In general Si is added to cast iron for the purpose of achieving graphitization. In the cast irons of the present invention, the Si content is specified to be higher than in ordinary spheroidal cast irons with the additional purpose of enhancing the oxidation resistance of the cast iron.

To examine the general relationship between the content of Si in spheroidal graphite case iorn and the oxidation resistance of the cast iron at high temperatures, an experiment was carried out using a conventional spheroidal graphite cast iron FCD 40 (according to JIS G 5502) containing 2.90% of Si (together with about 3.4% of C, about 0.4% of Mn, about 0.05% of Mg, about 0.02% of P and about 0.01% of S) and by preparing modified samples in which the content of Si was increased to 3.28%, 4.86% and 5.56%, respectively. Test pieces of the four cast iron samples were kept heated in air at either 600°C or 700°C for a total period of 500 hr, and the thickness of an oxidized scale layer on each test piece was measured at suitable time intervals to estimate the oxidation resistance of each cast iron sample on the basis of the maximum thickness of the scale layer in each sample. The results of these experiments at 600°C and at 700°C are shown in Figs. 1 and 2 of the drawings, respectively. From the curves in Figs. 1 and 2 it is apparent that the oxidation resistance of the cast iron can be enhanced by increasing the content of Si.

However, if the content of Si is increased too much the resultant spheroidal graphite cast iron suffers from insufficient elongation and unfavourable brittleness at ambient temperature. Considering such tendencies, the content of Si in the cast irons of the present invention is limited within the range from 3.5% to 5.5%.

(3) Chromium

In a spheroidal graphite cast iron of the invention, Cr is an alloying element which contributes to reinforcement of the oxidation resistance of the case iron at high temperatures. The minimum Cr content is set at 0.1% because the expected effects are insufficient if the Cr content is less than 0.1%. Since the effect of reinforcing the ferrite matrix augments as the Cr content is increased, it is preferred that the Cr content of the cast irons of the present invention is at least 0.25%. However, the content of Cr is limited to a maximum of 0.7% because the addition of more than 0.7% of Cr is liable to deteriorate the workability and other mechanical properties of the cast iron by reason of formation of free carbides.

(4) Molybdenum

Mo has the effect of reinforcing the ferrite matrix of the cast iron and thereby enhancing the high temperature strength of the cast iron. The expected effect is insufficient if the Mo content is below 0.3%. However the Mo content is limited to a maximum of 0.9% because the addition of more than 0.9% of Mo is liable to cause formation of free carbides and to result in a deterioration of the mechanical properties of the cast iron.

(5) Manganese

Mn is an alloying element having a desulphurizing ability. The content of Mn is limited to a maximum of 0.6% because the presence of an unnecessarily large amount of Mn in the cast iron produces an unwanted effect of stabilizing pearlite in the cast iron.

(6) Spheroidizing Agent

In the cast irons of the present invention the spheroidizing agent may be freely selected from known spheroidizing agents such as Mg, Ca and Ce for example. It is undesirable to use an unnecessarily large amount of spheroidizing agent because of its unfavourable side-effects. For example, the use of an unduly large amount of Mg, which is a typical spheroidizing agent, has the unwanted effect of stabilizing cementite in the cast iron. Therefore, the amount of the spheroidizing agent is limited to a maximum of 0.1%.

In practice, it is permissable that a spheroidal graphite cast iron of the invention contains very small amounts of impurities besides the above described essential alloying elements and Fe. Typical examples of such impurity elements are phosphorus and sulphur. It is preferred that the P content is below 0.1% because a higher P content is detrimental to the workability, typified by ductility, of the cast iron. Also it is preferred that the S content is below 0.1% because a higher S content is obstructive to spheroidization of graphite.

A spheroidal graphite cast iron of the invention can be prepared by a known method for the preparation of a ferritic spheroidal graphite cast iron. In brief, a molten metal of a suitable composition including a spheroidizing agent is allowed to solidify in a mould, and the solidified casting is then subjected to a spheroidizing-ferritizing heat treatment.

In order that the invention may be well understood the following Examples are given by way of illustration only.

EXAMPLE 1

A spheroidal graphite cast iron has the composition shown in Table 1 below was prepared by a usual method, in which the solidified casting was subjected to a spheroidizing-ferritizing annealing treatment under the conditions shown in Fig. 3 of the drawings. Besides the elements listed in the Table, a small quantity of Mg was used as spheroidizing agent so that the product contained 0.039% of Mg. As shown in Fig. 3, the annealing treatment consisted of heating at 930°C for 2.5 hr, initial low-rate cooling from 930°C to 300°C performed as furnace cooling and subsequent air cooling. Fig. 5 is a photomicrograph (100 x magnification) showing the structure of the cast iron obtained in this way. The structure of this cast iron may be expressed as being a ferrite matrix containing spheroidal cementite and a very small portion of pearlite containig certain carbides therein. That is, the cast iron was a ferritic spheroidal graphite cast iron.

EXAMPLE 2

Another spheroidal graphite cast iron having the composition shown in Table 1 below was prepared by the same method as described in Example 1. Besides the elements noted in the Table, 0.045% of Mg was present in the product by reason of the use of Mg as spheroidizing agent. The structure of this cast iron was fundamentally similar to that of the cast iron of Example 1. As can be seen in the Table, substantially the sole difference of the cast iron of Example 2 from that of Example 1 was about a 45% decrease in the Cr content accompanied by a slight decrease in the Mo content.

Test pieces cut out of the cast irons of Examples 1 and 2 were subjected to tensile strength tests at ambient temperature and also to oxidation resistance tests at high temperatures. For comparison, a conventional high nickel spheroidal graphite cast iron (Refernce 1) and a conventional ferric spheroidal graphite cast iron (Reference 2) were subjected to the same tests. The compositions of the cast irons of References 1 and 2 are shown in Table 1 below. In addition to the elements noted in the Table, the cast irons of references 1 and 2 contained 0.080% of Mg and 0.070% of Mg, respectively.

Each test piece for the tensile strength test was 50 mm in gauge length, 70 mm in the length of the straight portion and 7 mm in the diameter of the straight portion, and the straining speed at the test was 20% min. The result of the test is presented in Table 1.

The oxidation resistance test was carried out at 750°C, 850°C and 950°C. At each temperature the test pieces were kept heated in air for 200 hr, and the oxidation resistance of each sample was estimated from the maximum thickness of an oxidised scale layer on each test piece. Fig. 4 shows the results of these tests.

TABLE 1

	Chemical Composition (Wt%)							
	C	Si	Mn	Ni	Cr	P	Mo	Fe
Ex. 1	3.09	4.10	0.22	0.03	0.49	0.034	0.59	balance
Ex. 2	3.05	4.12	0.21	0.03	0.27	0.036	0.47	balance
Ref. 1	1.94	5.10	0.53	34.6	1.96	0.013	0.03	balance
Ref. 2	2.87	4.00	0.54	0.07	0.06	0.034	0.60	balance

Tensile Strength (kgf/mm^2)	0.2% Proof Stress (kgf/mm^2)	Elongation (%)
66.5	53.0	10.0
62.0	49.0	12.0
45.1	21.7	19.3
51.0	38.2	14.0

As can be seen from Table 1, the spheroidal graphite cast irons of Examples 1 and 2 were both superior in the tensile strength and proof stress to the conventional spheroidal cast irons of References 1 and 2. Also it can be seen that the cast irons of Examples 1 and 2 were inferior in the elongation to the cast irons of References 1 and 2. However, the 10% and 12% elongation values indicate that either of the cast irons of Examples 1 and 2 is fully satisfactory as a material for turbine housings of automotive exhaust gas turbochargers, for example.

As shown in Fig. 4, the spheroidal graphite cast irons of Examples 1 and 2 were higher in resistance to oxidation than the conventional spheroidal graphite cast iron of Refernce 2 over the entire range of high temperatures in this test. At 750°C the cast irons of Examples 1 and 2 were even comparable in oxidation resistance to the high nickel spheroidal graphite cast iron of Reference 1. At higher temperatures the oxidation resistance of the cast irons of Examples 1 and 2 became lower than that of the cast irons of Refernce 1, but this fact does not seriously affect the merit of the invention firstly because the high nickel cast iron of Reference 1 is far more costly that the cast irons according to the invention and secondly the oxidation resistance values of the cast irons of Examples 1 and 2 at 850°C and 950°C can be taken as very good values.

CLAIMS

1. A heat-resistant ferritic spheroidal graphite cast iron, characterised in that it consists essentially of not more than 3.4 wt% of C, 3.5 wt% to 5.5 wt% of Si, not more than 0.6 wt% of Mn, 0.1 to 0.7 wt% of Cr, 0.3 to 0.9 wt% of Mo, not more than 0.1 wt% of spheroidizing agent and the balance of Fe.

2. A spheroidal graphite cast iron according to Claim 1, characterized in that it contains at least 1.7 wt% of C.

3. A spheroidal graphite cast iron according to claim 1 or claim 2, characterized in that it contains from 0.25 to 0.7 wt% of CR.

4. A spheroidal graphite cast iron according to anyone of the preceding claims characterized in that the principal component of the spheroidizing agent is Mg, Ca or Ce.

FIG.1

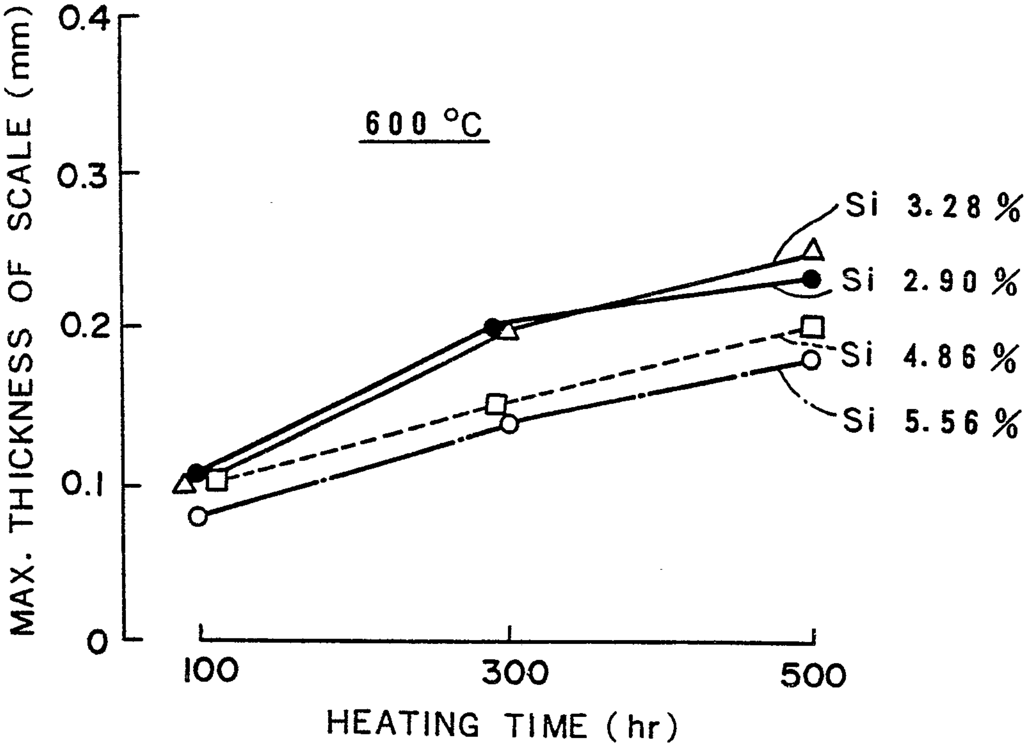
600 °C
Si 3.28 %
Si 2.90 %
Si 4.86 %
Si 5.56 %
MAX. THICKNESS OF SCALE (mm)
0.4
0.3
0.2
0.1
0
100
300
500
HEATING TIME (hr)

FIG.2

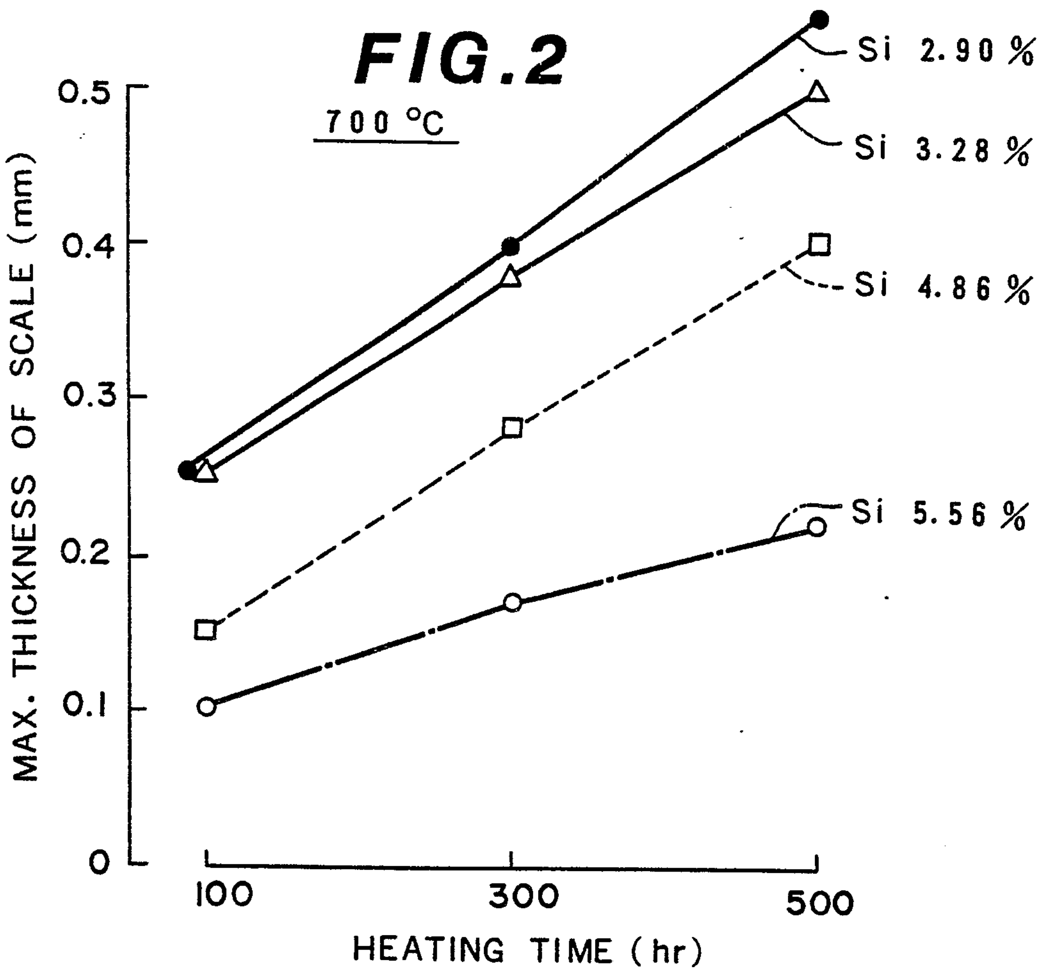
700 °C
Si 2.90 %
Si 3.28 %
Si 4.86 %
Si 5.56 %
MAX. THICKNESS OF SCALE (mm)
0.5
0.4
0.3
0.2
0.1
0
100
300
500
HEATING TIME (hr)

FIG.3

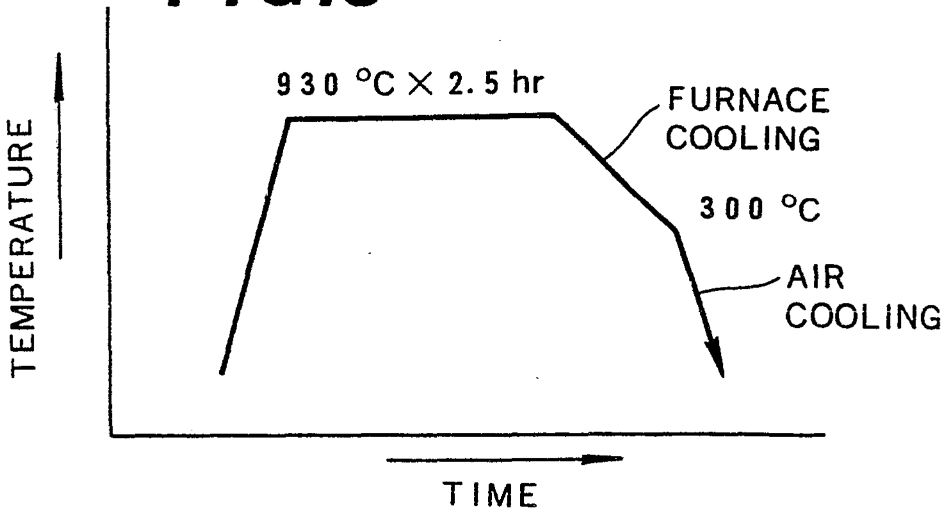
930 °C × 2.5 hr
FURNACE COOLING
300 °C
AIR COOLING
TEMPERATURE
TIME

FIG.4

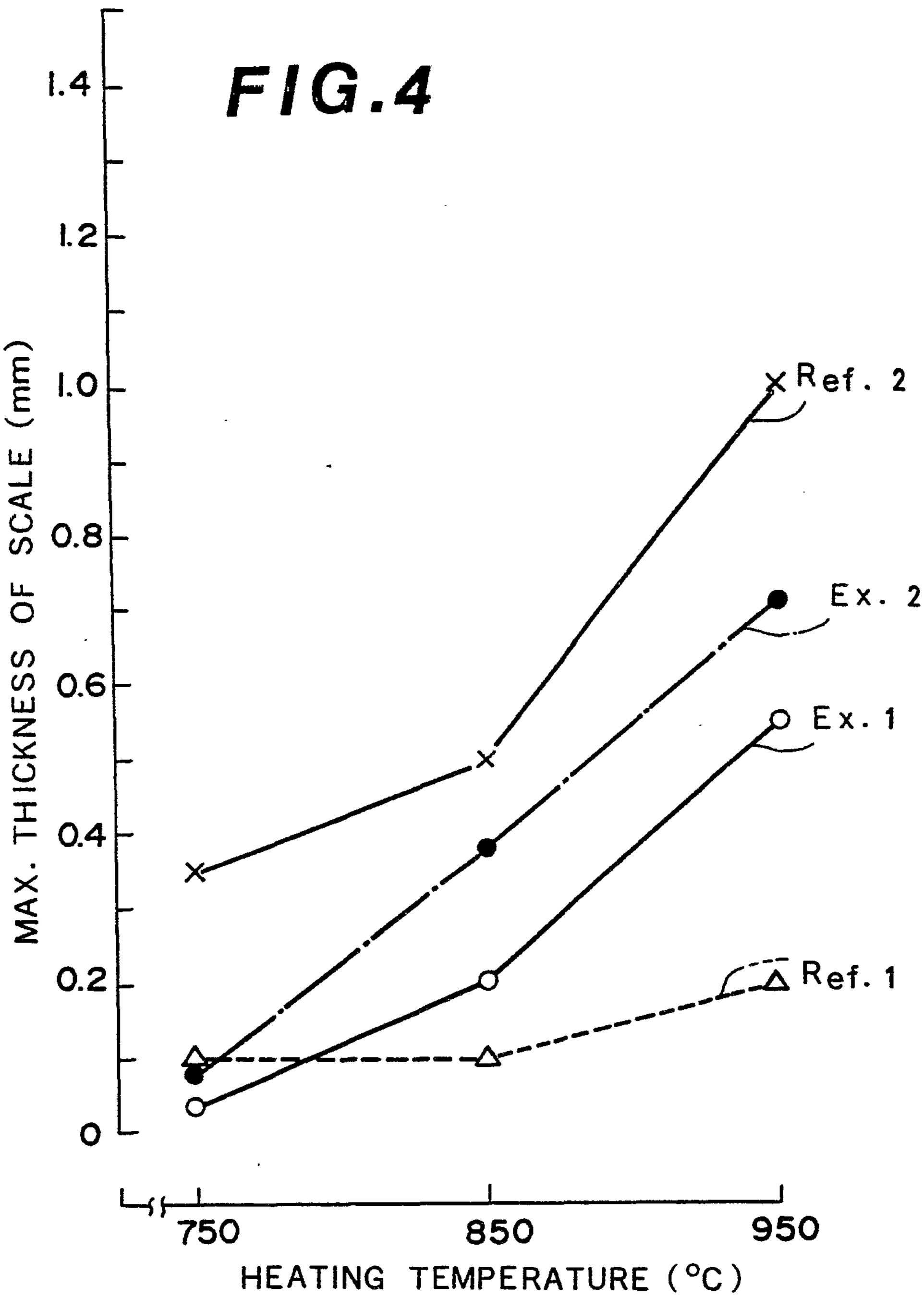
MAX. THICKNESS OF SCALE (mm)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Ref. 2
Ex. 2
Ex. 1
Ref. 1
750
850
950
HEATING TEMPERATURE (°C)

FIG. 5