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(54) **Method of predicting die lives**

(57) Disclosed is a method of predicting lives of dies for plastic processing of metals, typically, forging dies, to enable improved die design by predicting an important factor, low cycle fatigue life FL (shot number possible until the die lives end). The method is characterized in that the low cycle damage value "Dc" defined by the formula: $Dc = \sigma_{eq} / (YS \times \text{softening rate})$, wherein, σ_{eq} is Von Mises's equivalent stress, YS is yield stress (including

both of those at tension and compression), and that the following formula is introduced: $FL = C_1 \times \exp(C_2 \times Dc^{C_3})$, wherein, FL is shot number until the die fracture, and C_1 , C_2 and C_3 are constants depending on the material used, so as to presume the possible shot number of the die.

Description

BACKGROUND OF THE INVENTION

5 Technical Field

[0001] The present invention concerns a method of predicting die lives. More specifically, the invention concerns predicting lives of dies for plastic processing of metals, typically, forging dies, by presuming low cycle fatigue lives, and utilizing the results for die design including choice of materials, hardness thereof and determining the die configuration so as to establish countermeasures for prolongation of the die lives.

Prior Art

[0002] In regard to manufacture and application of a forging die various methods of predicting damages in the die have been developed and utilized for enabling manufacture of dies having longer lives. As the method of prediction it is generally employed to calculate temperature and stress distribution in a die by finite element analysis and then substitute the calculated values for constitutive equations to presume low cycle fatigue lives and wearing. For example, Japanese Patent Disclosure No. 2002-321032 discloses technique of predicting die lives on the basis of die abrasion according to an abrasion model adopting conditions inherent in forging dies.

[0003] One of the main factors causing damage and shortening of life of a forging die during using is low cycle fatigue fracture life (hereinafter referred to as "low cycle life"). The low cycle fatigue has been described to date by the formula below on the basis of the relation between the stress posed on and the frequency thereof:

$$\text{LIFE} = f(\epsilon, RA)$$

wherein, ϵ is strain, and RA, reduction of area at tensile test.

[0004] More specifically, amplitude of repeated plastic deformation and number of repetition until fracture were formulated using the relation known as the "Manson-Coffin's formula". However, methods of predicting lives of dies proposed so far are not of so high accuracy.

[0005] The inventors intended to expedite the matter and noted the fact that the cause of the low cycle fatigue fracture is accumulation of strain. They succeeded in establishing a method of predicting die lives by presuming accumulated strain with a yield condition formula, in which direction of the stress posed on the die is considered, and by working out a regression formula from a low cycle fatigue curve.

SUMMARY OF THE INVENTION

[0006] The object of the present invention is to provide a method of predicting die lives enabling design of improved dies by predicting low cycle fatigue life of dies, which give important influence to die lives.

[0007] The method according to the invention achieving the above-mentioned object is a method of presuming the low cycle fatigue life properties influencing the lives of dies for plastic processing of metals to contribute to die design including choice of materials, hardness and configuration of the die.

[0008] The method of predicting die lives according to the invention is characterized in that, basically, the low cycle damage value "Dc" defined by the formula below is calculated:

$$Dc = \sigma_{eq} / (YS \times \text{softening rate})$$

wherein, σ_{eq} is Von Mises's equivalent stress, YS is yield stress (including both of those at tension and compression), and that the following formula expressing the low cycle fatigue life "FL" is introduced therefrom,

$$FL = C_1 \times \exp(C_2 \times Dc^{C_3})$$

wherein, FL is shot number until the die fracture, and C_1 , C_2 and C_3 are constants depending on the material used,

so as to presume the possible shot number of the die.

[0009] More specifically, the method according to the invention is the method of predicting lives of dies for plastic processing of metals so as to contribute to the die-design including choice of material, hardness thereof and determining configuration of the die, and is characterized in that low cycle life tests under "tension-tension" and "tension-compression" are carried out at respective die materials so as to comprehend the relation between the cycle and the stress amplitude, and using the results, the low cycle damage value "Dc" defined by the formula:

$$Dc_{fatigue} = \{ \text{maximum tensile stress } (\sigma_{damage}) + ?? \times \text{maximum compressive stress } |\sigma_{damage}| \} / (YS \times \text{softening rate})$$

wherein, " σ_{damage} " is damage stress defined as below, "?" is a constant depending on the material, and "YS" is as mentioned above:

$$\sigma_{damage} = \sigma_{eq} \quad (\text{in case where } \sigma_{1max} - \sigma_{1min} \geq 0)$$

$$\sigma_{damage} = -\sigma_{eq} \quad (\text{in case where } \sigma_{1max} - \sigma_{1min} < 0)$$

wherein, σ_{eq} is the above-mentioned Von Mises' equivalent stress, σ_{1max} is maximum main stress, and σ_{1min} is minimum main stress;

and that, on this basis, the following formula expressing the low cycle fatigue life "FL" is introduced:

$$FL = C_1 \times \exp(C_2 \times Dc_{fatigue} C^3)$$

wherein, FL is the shot number until the fracture, and C_1 , C_2 and C_3 are constants depending on the material used, so as to presume the possible shot number of a die.

BRIEF EXPLANATIO OF THE DRAWINGS

[0010]

Fig. 1 is a graph illustrating dynamic compressive yield strength of heat-treated state (HRC 60) and softened state (HRC 29.6) of MH85 steel, which is a matrix type high speed steel provided by Daido Steel Co., Ltd., depending on the temperature;

Fig. 2 is a graph prepared by plotting the relation between the cycle number and the stress amplitude at low cycle fatigue life test of the MH85 steel (HRC 58.7);

Fig. 3 is a figure showing the concept of "tension-tension" and "tension-compression" of the tests for preparing the graph of Fig. 2;

Fig. 4 is a graph prepared by plotting the relation between the plastic flow criteria value " D_c " and the low cycle fatigue life FL of the MH85 steel (HRC 58.7);

Fig. 5 is a graph obtained by plotting the relation between the Dc value ($Dc_{fatigue}$) and the low cycle fatigue life FL of the die material of Fig. 4;

Fig. 6 is a computer graphics (hereinafter referred to as "CG") showing the relation between the low cycle fatigue life FL and the intensity of cooling (A: mild cooling, B: strong cooling) of a forging punch obtained from the data of a working examples of the invention;

Fig 7 is a CG like Fig. 6 showing the relation between the low cycle fatigue life FL and the manner of cooling the forging punches (A: forging at 820°C-oil quenching, B: forging at 820°C-water quenching, and C: forging at 920°C-water quenching) also obtained from the data of a working examples of the invention;

Fig 8 is a CG like Fig. 6 showing the relation between the low cycle fatigue life FL and the forging temperature of the forging punches (A: forging at 820°C-oil quenching, B: forging at 820°C-water quenching, and C: forging at 920°C-water quenching) also obtained from the data of a working examples of the invention.

DETAILED EXPLANATION OF THE PREFERRED EMBODIMENTS

[0011] The present invention took note on the relation

$$Dc = \sigma_{eq} / (YS \times \text{softening rate})$$

instead of the strain, which was considered important in the known Manson-Coffin's formula. In our formula, σ_{eq} is the above-mentioned Von Mises's equivalent stress, YS is yield stress (including both tensile and compressive), and Dc is a criteria (critical value) of plastic flow. When the value of Dc goes up to 1.0, the plastic flow of the die will begin.

[0012] The above idea of " σ_{eq}/YS " could be extended to σ_{eq}/TS , $(\sigma_{1max}-\sigma_{1max})/TS$, $(\sigma_{1max}-\sigma_{1max})/YS$, and so on, and the results will be of no great difference. This can be expressed in the functional form as follows:

$$FL = f(\sigma_{eq}/TS), \quad FL = f(\sigma_{1max} - \sigma_{1max})/TS, \quad \text{and}$$

$$FL = f(\sigma_{1max} - \sigma_{1max})/YS.$$

wherein, TS is tensile strength.

[0013] The above-mentioned relation between the life cycle FL and Dc value in the low cycle fatigue life test, $Dc = \sigma_{eq}/(YS \times \text{softening rate})$, can be expressed with a regression formula by using a suitable function.

[0014] A typical example is the formula shown above in regard to the basic embodiment:

$$FL = C_1 \times \exp(C_2 \times Dc^{C_3}),$$

wherein, C_1 , C_2 and C_3 are constants,

and the above-mentioned formula is a materialization of this formula. Thus, by separate consideration of the Dc value into the tensile stress and the compressive stress, results fitted to the practical damage of dies can be obtained. The low cycle fatigue test is carried out with altered modes of the stress amplitude, "tensile-tensile" and "tensile-compressive", and the regression formula is thus computed. For computation of the FL it is necessary to consider stress components at various parts of the die practically used for forging. This is because both the tensile and the compressive stresses are posed during forging.

[0015] The above-mentioned damage stress, σ_{damage} , is the idea introduced on the basis of the understanding that the strain occurs not only at the moment of tensile stress but also at the moment of compressive stress in view of the low cycle fatigue test and the results of stress component calculation at one shot, in other words, the above idea of damage stress resulted from the discussion in which the stress posed on the die during forging is analyzed to the tensile stress and the compressive stress. On this basis the above formula of $Dc_{fatigue}$ was introduced. As the conclusion it can be generalized that the regression formula including the FL and the $Dc_{fatigue}$ is the following relation:

$$FL = C_4 \times f(Dc_{fatigue})$$

[0016] The above formula of FL is of this kind. The final goal is to predict damage of dies by computer simulation using indices such as the FL value and the Dc value and to find the optimum values concerning shapes and using conditions (such as forging temperature and the extent of cooling.)

[0017] Typical steel-marks suitable for die material are the following two. It is recommended to use them with heat treatment to the hardness shown in the parentheses. Formulae of the low cycle fatigue life FL at the suitable hardness are as follows. Possible shot numbers of the die manufactured with these steels may be predicted by the formulae: "MH85" (standard set by Daido Steel Co., Ltd., HRC 61)

$$FL=4.0679 \times 10^9 \exp(-16.135 \times Dc_{fatigue})$$

5 "SKD61" (one of the JIS Steels, HRC 48)

$$FL=3.1305 \times 10^{11} \exp(-17.239 \times Dc_{fatigue})$$

10 [0018] Presumption of the low cycle fatigue life of the die according to the invention enables predicting die lives with accuracy much higher than those given by the conventional damage predicting methods. Those skilled in the art may construct databases on any steel with reference to the working examples of the invention described below, calculate the low cycle fatigue life and carry out the optimum die design.

15 [0019] If the die enjoys a longer life, the contribution will be not only to decrease in die-manufacturing costs but also to decrease manufacturing costs of processed parts such as forged parts through reduction in time and labor for exchanging the dies

EXAMPLES

20 [0020] The above-noted matrix high speed tool steel, MH85, was used as the die material and the hardness was adjusted to be HRC 58.7. The material was subjected to measurement of compressive yield strength, YS, in the temperature range from room temperature to 800°C or 700°C to obtain the data shown in Fig. 1. The relations between the compressive yield strength and temperature T were as follows:

$$YS_{init} = -5 \times 10^{-6} T^3 + 0.0047 T^2 - 1.5574 T + 2510.7 \quad (T \leq 600^\circ C)$$

$$YS_{init} = 9411202 \times \exp(-0.0150 T) \quad (T \geq 600^\circ C)$$

$$YS_{low} = -0.0006 T^2 + 0.0542 T + 1049.2$$

35 [0021] The above MH85 steel (HRC58.7) was subjected to also low cycle fatigue life test to observe the relation between the cycle number and the stress amplitude. The relation is shown in the graph of Fig. 2. "Tensile-tensile" and "tensile-compressive" of the stress amplitude in this graph mean the manner of posing stress as shown in upper and lower parts of Fig. 3.

40 [0022] The relations between the low cycle life FL and the criteria values of plastic flow Dc are illustrated in the graph of Fig. 4 in both the cases of "tensile-tensile" and "tensile-compressive". The stress posed on the die varies continuously, depending on the location in the die, among the typical cases shown in Fig. 3, and unified treatment of the typical cases gave the "improved Dc value" in Fig. 5, which is the graph showing the relation between the $Dc_{fatigue}$ and the low cycle life FL. From regression analysis of this graph the above noted formula:

$$FL=4.0679 \times 10^9 \exp(-16.135 \times Dc_{fatigue})$$

50 was introduced.

[0023] Two kinds of forging punches of the shape as shown in Fig. 6 and Fig. 7 were manufactured with MH85 steel, and the punches were subjected to wear tests on a horizontal type parts former. The forging consists of two steps, the first for upsetting and the second for backward extrusion. The type and the extent of the damage of the die can be learned by observing the state of damaging after the second step. Stress-thermorelated elastoplasticity analysis (MSC/ Super Form 2004) was carried out under the following conditions:

Material of the Punch: MH85

Material of the Work: S53C
 Temperature of the Work: 820°C
 Heat-contacting Conductance: 120kW/m²K
 Forging Speed: 85spm
 Share Sliding Coefficient: 0.4

[0024] The punch as shown in Fig. 6 (in this case, without consideration of stress direction, tensile only) was used and the cooling conditions were controlled to strong and weak by adjusting flow rates of the forging oil. The results of simulation are as shown in Fig. 6A (weak cooling) and 6B (strong cooling), from which it is concluded that cooling should be strong. After the testing the punch was cut along the axis thereof to observe the texture. In case of weak cooling there was observed plastic flow at the part "R" of the tip of the punch. (This was so judged from the fact that the stripes made by corrosion curved at the surface.) On the other hand, no sign of the plastic flow was observed in case of strong cooling. Comparison of the Dc values in the cases of weak and strong cooling, the Dc value of the weak cooling was higher at the tip of the punch.

[0025] Then, the punch as shown in Fig. 7 was used to carry out forging of backward extrusion. (In this case the direction of the stress is considered.) Conditions for forging and cooling were chosen as follows, and the possibility of occurring damage in the punch due to the plastic flow was simulated by a computer. The results are shown in Figs. 7A-C and Figs. 8A-C.

Forging at 720°C-oil cooling (Fig. 7A)
 Forging at 820°C-oil cooling (Fig. 7B)
 Forging at 820°C-water cooling (Fig. 7C)
 Forging at 720°C-oil cooling (Fig. 8A)
 Forging at 820°C-water cooling (Fig. 8B)
 Forging at 820°C-water cooling (Fig. 8C)

[0026] The results of analysis indicates that, even if the forging temperature is the same, it is preferable to enhance cooling (oil cooling → water cooling) for the die lives, and that, even if the forging temperature is high, the die lives may be prolonged by enhancing the cooling. The results of computer simulation according to the invention and the results of observation of the used punches are in good concordance, and thus, it is concluded that the present invention provides a method of prediction with high liability.

Claims

1. A method of predicting die lives enabling design of improved dies by predicting low cycle fatigue life of dies, which give important influence to die lives, **characterized in that** the low cycle damage value "Dc" defined by the formula below is calculated:

$$Dc = \sigma_{eq} / (YS \times \text{softening rate})$$

wherein, σ_{eq} is Von Mises's equivalent stress, YS is yield stress (including both of those at tension and compression), and that the following formula expressing the low cycle fatigue life "FL" is introduced:

$$FL = C_1 \times \exp(C_2 \times Dc^{C_3})$$

wherein, FL is shot number until the die fracture, and C_1 , C_2 and C_3 are constants depending on the material used, so as to presume the possible shot number of the die.

2. A method of predicting die lives enabling design of improved dies by predicting low cycle fatigue life of dies, which give important influence to die lives, **characterized in that** low cycle life tests under "tension-tension" and "tension-compression" are carried out at respective die materials so as to comprehend the relation between the cycle and the stress amplitude, and using the results, the low cycle damage value "Dc" defined by the formula:

$$Dc_{fatigue} = \{ \text{maximum tensile stress } (\sigma_{damage}) + ?? \times \\ \text{maximum compressive stress } | \sigma_{damage} | \} / (YS \\ \times \text{softening rate})$$

wherein, " σ_{damage} " is damage stress defined as below, "?" is a constant depending on the material, and "YS" is as mentioned above:

$$\sigma_{damage} = \sigma_{eq} (\sigma_{1max} - \sigma_{1min} \geq 0)$$

$$\sigma_{damage} = - \sigma_{eq} (\sigma_{1max} - \sigma_{1min} < 0)$$

wherein, σ_{eq} is the above-mentioned Von Mises's equivalent stress, σ_{1max} is maximum main stress, and σ_{1min} is minimum main stress;
and that, on this basis, the following formula expressing the low cycle fatigue life "FL" is introduced:

$$FL = C_1 \times \exp(C_2 \times Dc^{C_3})$$

wherein, FL is the shot number until the fracture, and C_1 , C_2 and C_3 are constants depending on the material used, so as to presume the possible shot number of the die.

FIG.1

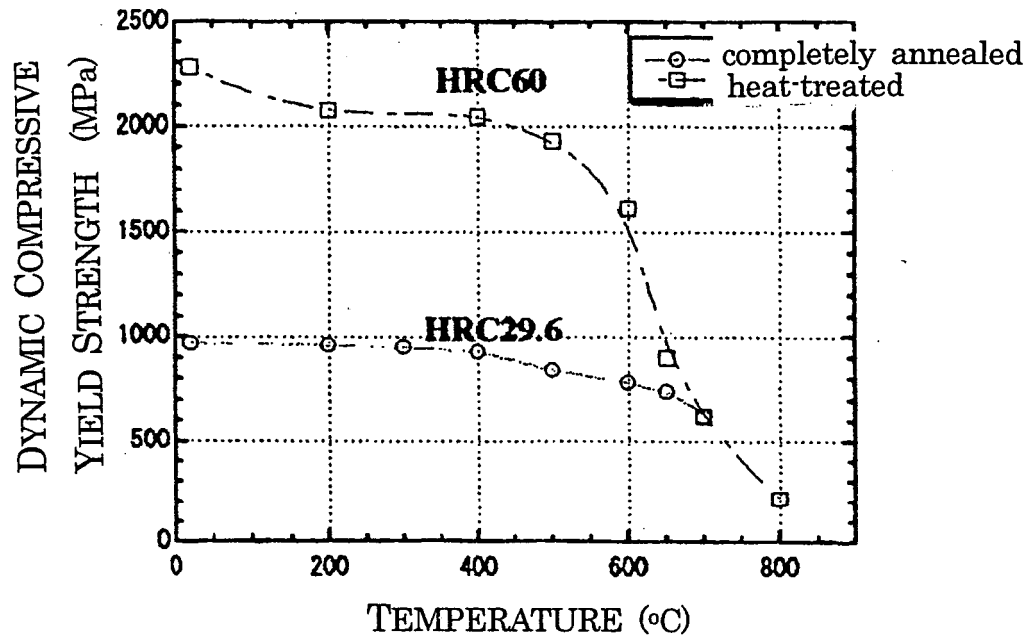


FIG.2

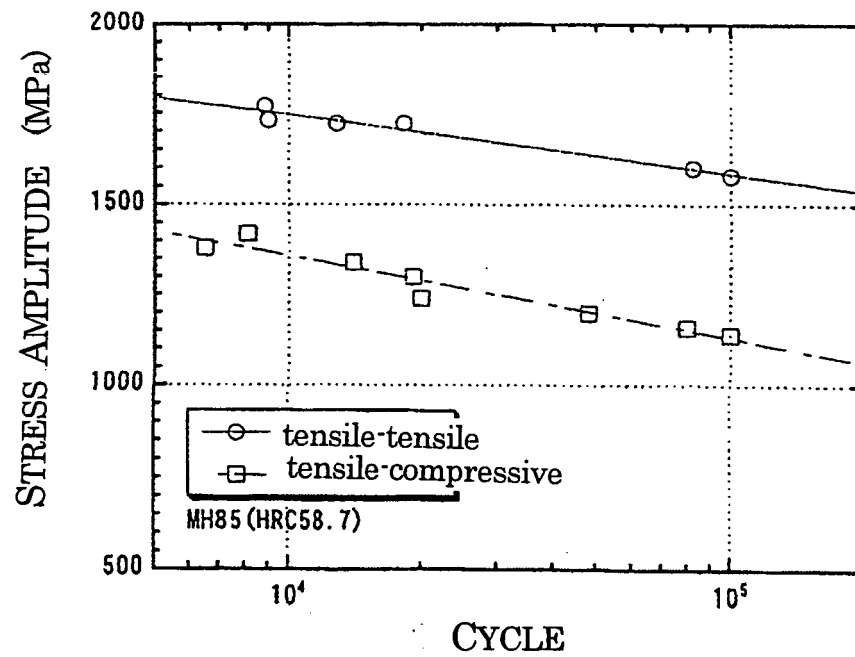


FIG.3

LOW CYCLE FATIGUE LIFE TEST

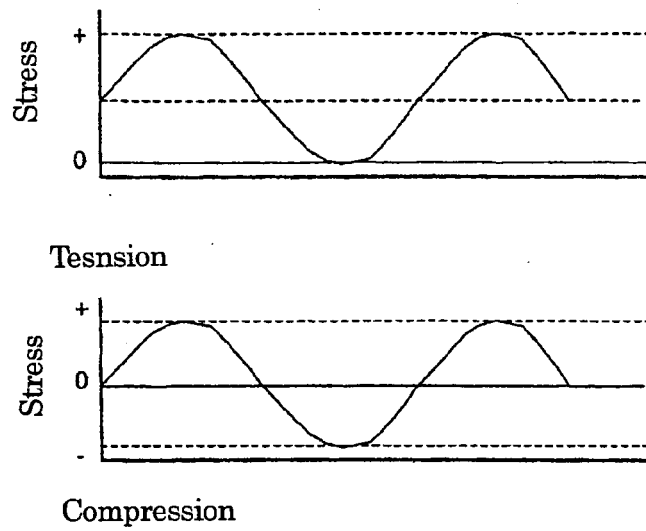


FIG.4

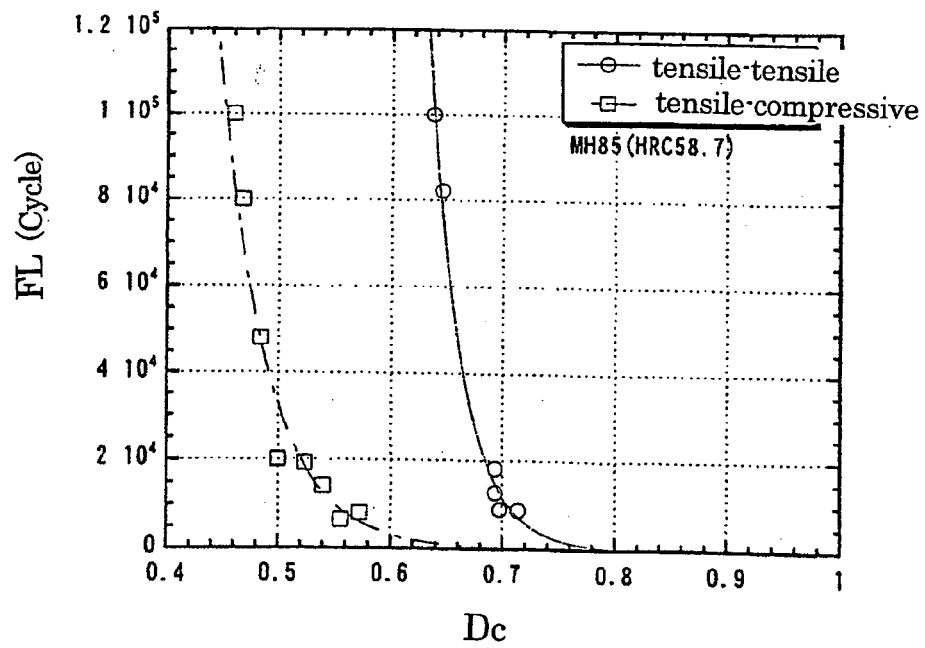


FIG.5

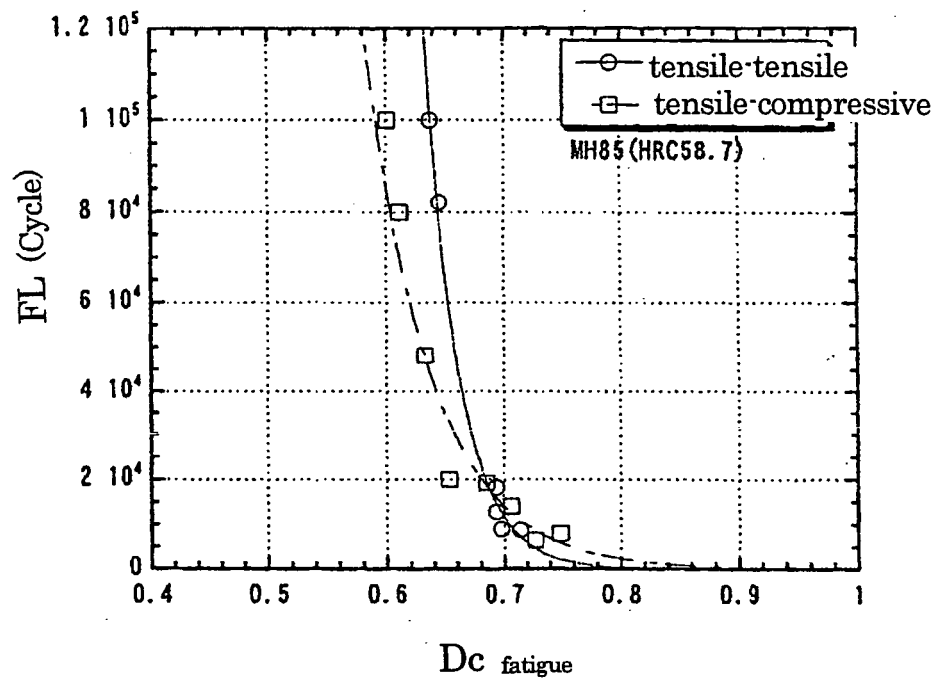


FIG.6 A

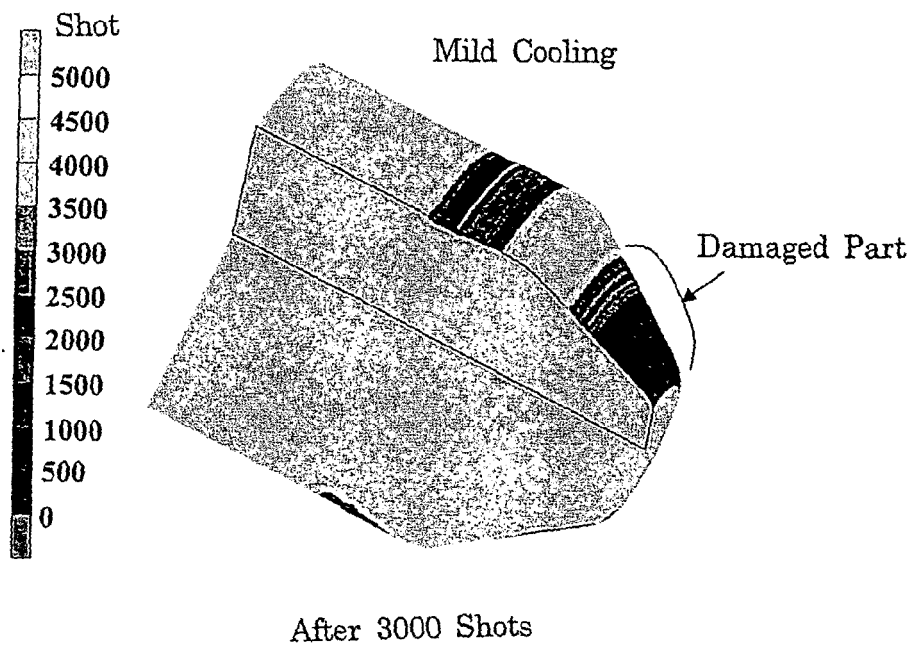


FIG.6 B

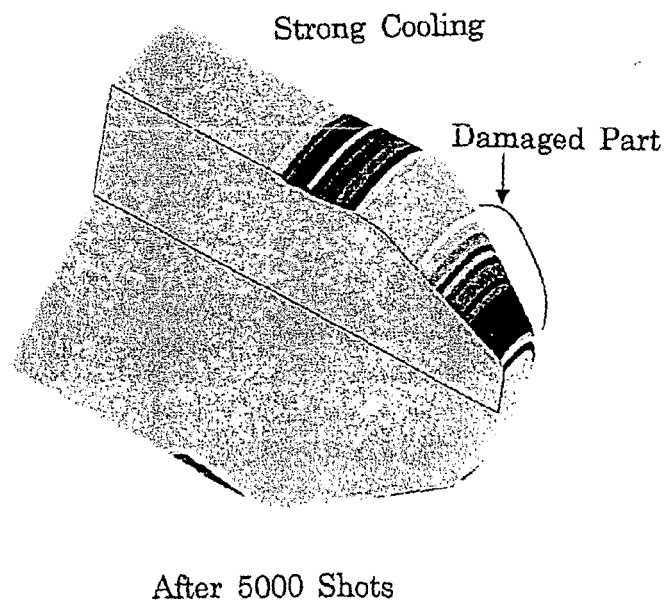


FIG.7A

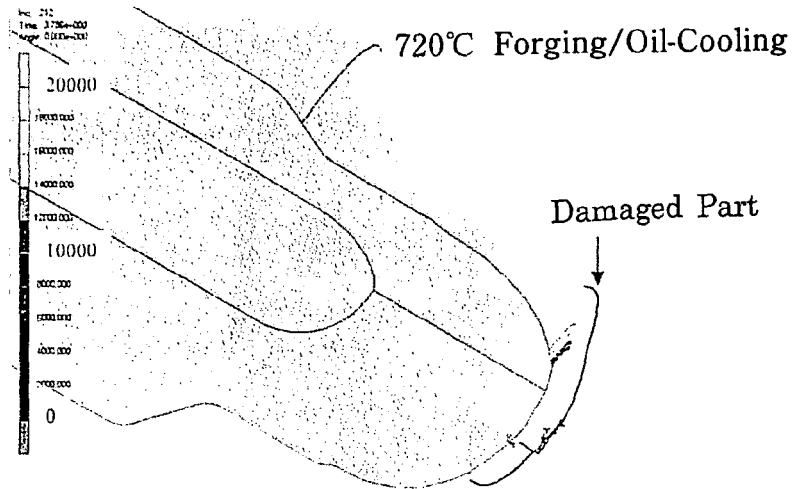


FIG.7B

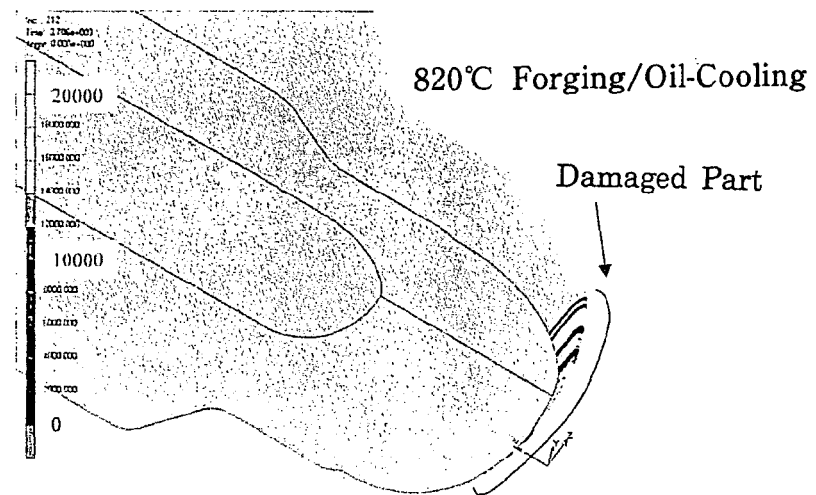


FIG.7C

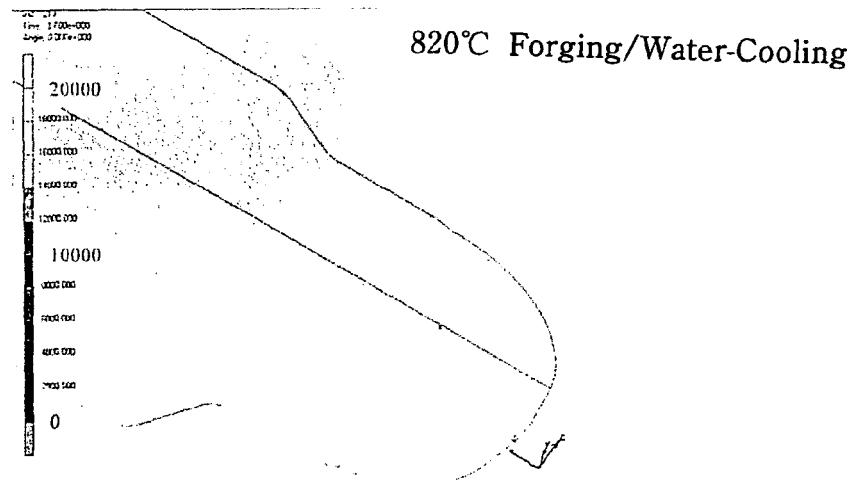


FIG.8A

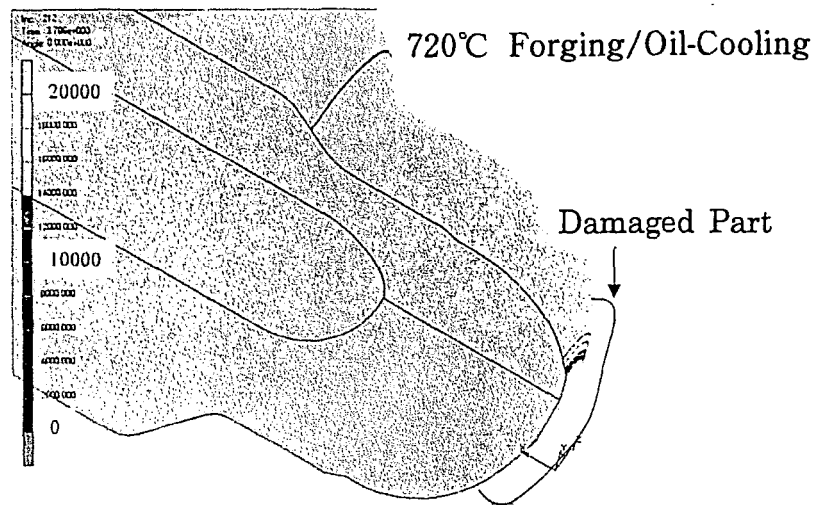


FIG.8B

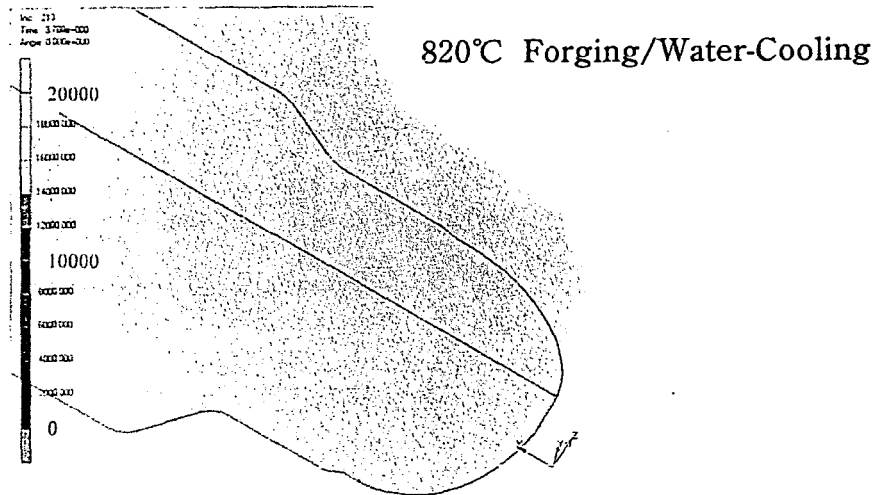
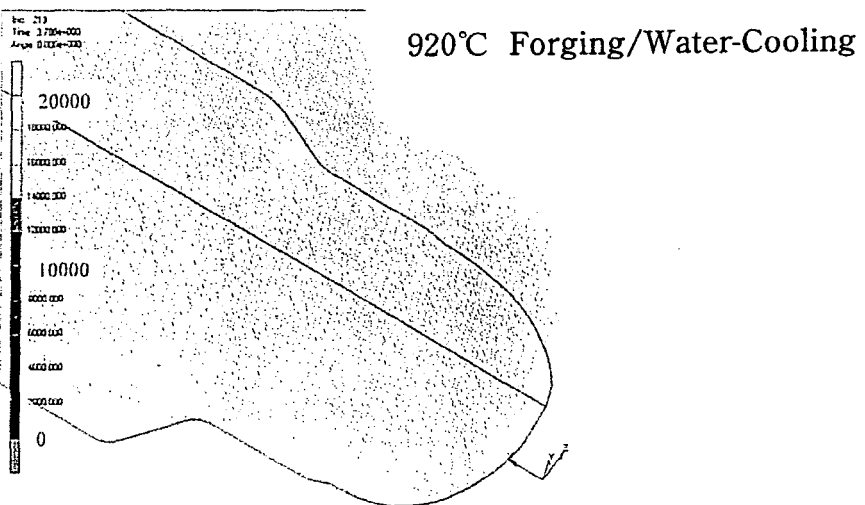


FIG.8C





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 06 01 0678

DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 31 August 2006	Examiner Barrow, J
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EP 06 01 0678

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