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(54) **Method of predicting damage of dies**

(57) Disclosed is a method of predicting damage of dies for plastic processing of metallic materials, typically, forging dies, by predicting brittle fracture ("great crack" or "initial crack") dominating die lives contribute to die design including choice of materials, hardness and configuration of the die. The method is characterized in that the die design is carried out by choosing the condition that none of the anticipated values of brittle fracture, F_{c1} to F_{c3}, calculated by the formulae 1 to 3 below exceed the critical values depending on the material used.

$$\text{[formula 1]} \quad F_{c1} = (\sigma_m / \sigma_{eq})$$

$$\text{[formula 2]} \quad F_{c2} = (\sigma_m / \sigma_{1max})$$

$$\text{[formula 3]} \quad F_{c3} = (\sigma_{1max} / \sigma_{eq})$$

σ_m: mean normal stress loaded to the tensile side of the die
σ_{eq} : Von Misese's equivalent stress
σ_{1max} : maximum principal stress

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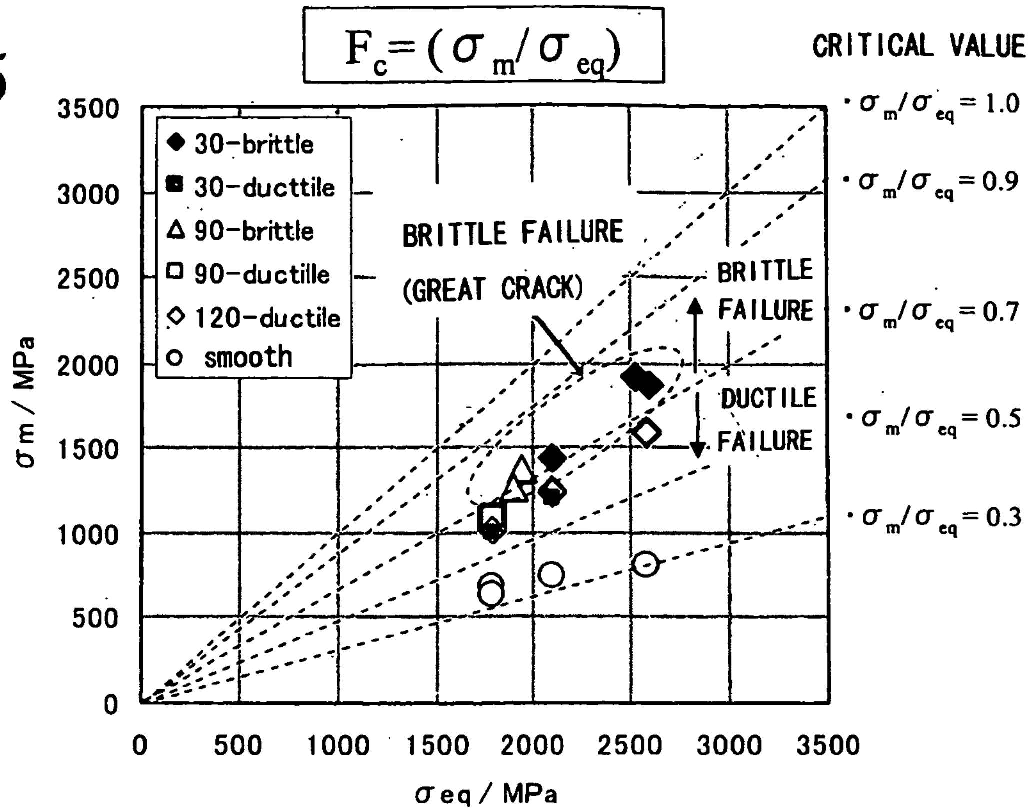
Fig.5


$F_c = (\sigma_m / \sigma_{eq})$
CRITICAL VALUE
$\cdot\ \sigma_m/\sigma_{eq} = 1.0$
$\cdot\ \sigma_m/\sigma_{eq} = 0.9$
$\cdot\ \sigma_m/\sigma_{eq} = 0.7$
$\cdot\ \sigma_m/\sigma_{eq} = 0.5$
$\cdot\ \sigma_m/\sigma_{eq} = 0.3$
30-brittle
30-ducttile
90-brittle
90-ductille
120-ductile
smooth
BRITTLE FAILURE
(GREAT CRACK)
BRITTLE FAILURE
DUCTILE FAILURE
σm / MPa
σeq / MPa
0
500
1000
1500
2000
2500
3000
3500

Description

BACKGROUND OF THE INVENTION

Technical Field

[0001] The present invention concerns a method of predicting damages of dies. More specifically, the invention concerns predicting damages in dies for plastic processing of metals, typically, forging dies by predicting "great crack" damage caused by brittle fracture which dominates die 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 die lives.

Prior Art

[0002] At manufacturing and application of forging dies various methods of predicting damages in dies have been developed and utilized for enabling manufacture of dies of 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 predict low cycle fatigue lives and abrasion. 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] Fracture factors causing damage of forging dies during using are four, namely, "great crack" or static brittle fracture, plastic flow, abrasion and low cycle fatigue destruction. The brittle fracture is a sudden phenomenon occurring at an initial stage before substantial use of the die, and also called "initial crack", which is a fatal damage. However, methods of predicting damage of dies proposed so far are not effective for this kind of brittle fracture. As to ductile fracture there has been proposed Cockroft's formula, Oyane's formula and Ayada's formula, which have been acknowledged. These formulae are, however, not applicable to the brittle fracture. Thus, there has been demand for formula or formulae which enable effective prediction of damage of dies caused by brittle fracture.

SUMMARY OF THE INVENTION

[0004] The object of the present invention is to provide a method of predicting damage of dies enabling design of improved dies by predicting brittle fracture which give, among various factors causing damage to forging die, fatal influence to die lives.

[0005] The method according to the invention achieving the above-mentioned object is a method of predicting "great crack" by brittle fracture which dominates the lives of dies for plastic processing of metals to contribute to die design including choice of materials, hardness and configuration of the die. The method of predicting damages of dies according to the invention is characterized in that the die design is carried out by choosing the condition that none of the predicted values of brittle fracture, F_{c1} to F_{c3}, calculated by the formulae 1 to 3 below exceed the critical values determined on the basis of the material used.

$$[\text{formula 1}] \quad F_{c1} = (\sigma_m / \sigma_{eq})$$

$$[\text{formula 2}] \quad F_{c2} = (\sigma_m / \sigma_{1max})$$

$$[\text{formula 3}] \quad F_{c3} = (\sigma_{1max} / \sigma_{eq})$$

σ_m: mean normal stress loaded to the tensile side of the die

σ_{eq}: Von Misese's equivalent stress

σ_{1max}: maximum principal stress

BRIEF EXPLANATIO OF THE DRAWINGS

[0006]

Fig. 1 is a plan view illustrating the shape and dimension of a smooth test piece of the tensile test pieces prepared for constructing database of the material properties prior to conducting the present invention;
Fig. 2 is a plan view like Fig. 1 illustrating the shape and dimension of the test piece having a surrounding V-notch with notch angle of 30°;
Fig. 3 is a plan view like a part of Fig. 2 illustrating the detail of the notched part of the test piece with notch angle of 90°;
Fig. 4 is a plan view like a part of Fig. 3 illustrating the detail of the notched part of the test piece with notch angle of 120°;
Fig. 5 is a graph obtained by plotting mean normal stress (σ_m) corresponding to equivalent stress (σ_{eq}) based on the data given by tensile tests in working example of the present invention;
Fig. 6 is a graph obtained by plotting mean normal stress (σ_m) corresponding to maximum principal stress (σ_{1max}) based on the data given by tensile tests in working example of the present invention;
Fig. 7 is a graph obtained by plotting maximum principal stress (σ_{1max}) corresponding to equivalent stress (σ_{eq}) based on the data given by tensile tests in working example of the present invention;
Fig. 8 is a section view illustrating the shape of a ring-die and a work used at hot forging a final gear (an automobile part);
Fig. 8 is data of a working example and a computer graphics (hereinafter referred to as "CG") obtained by FEM analysis showing distribution of the critical values F_{c1} of brittle fracture in a ring-die before improvement by the invention;
Fig 10 is a CG like Fig. 9 showing distribution of the critical values F_{c2} of brittle fracture in a ring-die before improvement by the invention;
Fig 11 is a CG like Fig. 9 showing distribution of the critical values F_{c3} of brittle fracture in a ring-die before improvement by the invention;
Fig 12 is a CG like Fig. 9 showing distribution of the critical values F_{c1} of brittle fracture in a ring-die after improvement by the invention;
Fig 13 is a CG like Fig. 9 showing distribution of the critical values F_{c2} of brittle fracture in a ring-die before improvement by the invention;
Fig 14 is a CG like Fig. 9 showing distribution of the critical values F_{c3} of brittle fracture in a ring-die before improvement by the invention;

DETAILED EXPLANATION OF THE PREFERRED EMBODIMENTS

[0007] The factors dominating the brittle fracture of dies are three, as noted above, i.e., mean normal stress (σ_m), equivalent stress (σ_{eq}) and maximum principal stress (σ_{1max}). It can be hence said that there is generally the following relation:

$$Fc=f(\sigma_m,\ \sigma_{eq},\ \sigma_{1max})$$

[0008] All the dominating factors are considered in the above formulae 1 to 3. In practical use of these formulae an improved formula or formulae (such as those with adjusted coefficients) may be found by experience. They will give the same effect as those discussed above, and thus the invention includes the embodiments using such formulae.

[0009] By predicting the damages of dies it will be possible to establish effective countermeasures to the brittle fracture (so-called "great crack" or "initial crack"), to which, though it is an important factor, no conventional method of predicting damages has not been confronted. Those skilled in the art will be able to manufacture the optimum die by constructing databases in regard to the respective steels with reference to the working examples described below, by choosing the condition where all the predicted brittle fracture values F_{c1} to F_{c3} do not reach the critical limits, and by designing the dies. If the dies enjoy prolonged lives it will contribute to decrease in processing costs of various forged products through not only reducing the die cost itself but also saving time and labor for exchanging the worn dies.

[0010] The method of predicting damages of dies according to the invention may exhibit the performance to the dies for forming. It will be, however, applicable to other dies such as those for die-casting, which are used under similar environment of high temperature and high stress. Through the prediction of damages of dies desired properties of die materials may be known as a matter of course and the indices for developing the die materials can be obtained. Thus, the invention may contribute to development of alloy technologies.

EXAMPLES

Example 1

[0011] SKD61, one of the steels for hot processing tools, was used as the die material and the hardness was adjusted to be HRC 46, 49 or 52. JIS No.4 tensile test pieces were prepared and some of them were subjected to machining to provide surrounding V-shaped notches of depth 50%. The shapes and dimensions of the test pieces are shown in Fig. 1 (smooth surface), Fig. 2 (notch angle 30°), Fig. 3 (90°) and Fig. 4 (120°). Curvature of the bottom of the notches is 0.2mm.
[0012] The test pieces were subjected to tensile tests to determine mean normal stress (σ_m) at which fracture occurs and at the same time whether the fracture is ductile fracture or brittle fracture was recorded. The equivalent stress (σ_{eq}) and the maximum principal stress (σ_{1max}) were calculated. By plotting the mean normal stress (σ_m) in correspondence of the equivalent stress (σ_{eq}) there was obtained Fig. 5, by plotting the mean normal stress (σ_m) in correspondence of the maximum principal stress (σ_{1max}), Fig. 6, and plotting the maximum principal stress (σ_{1max}) in correspondence of the equivalent stress (σ_{eq}), Fig. 7, respectively.
[0013] Based on the graphs of Figs. 5 to 7 the critical values C_1 to C_3 for the brittle fracture of SKD61 steel were determined as follows:

[formula 1] $$F_{c1} = (\sigma_m / \sigma_{eq}) = 0.7$$

[formula 2] $$F_{c2} = (\sigma_m / \sigma_{1max}) = 0.5$$

[formula 3] $$F_{c3} = (s_{1max} / s_{eq}) = 1.25 \quad .$$

Example 2

[0014] The prediction of die life according to the present invention was carried out in regard to a ring-die, a die for limiting the outer surface of the work forged by a punch and a counter punch from top and bottom used for hot forging a final gear, an automobile part, having the cross section shown in Fig. 8. A used die made of SKD61 steel was inspected and it was found that crack of the ring-die occurred from the outer surface.
[0015] The following three CG's were obtained by analyzing distribution of the critical fracture values F_{c1} to F_{c3} on the basis of the above database by computer simulation (FEM analysis).

Fig. 9 (former shape) $F_{c1} = (\sigma_m / \sigma_{eq})$

Fig.10 (former shape) $F_{c2} = (\sigma_m / \sigma_{1max})$

Fig.11 (former shape) $F_{c3} = (\sigma_{1max} / \sigma_{eq})$

[0016] All the CG's showed that in some parts of outer surface of the ring-die F_{c1} to F_{c3} exceed the critical values. The fact agrees with the results of the above inspection.
[0017] Then, supposing the cases where the outer diameter of the ring-die is increased to prevent the brittle fracture, the computer simulation was carried out again. Three CG's as mentioned below were obtained. The CG's showed that there existed no longer the parts where the F_{c1} to F_{c1} exceeded the critical values.

Fig.12 (improved shape) $F_{c1}=(\sigma_m/\sigma_{eq})$

Fig.13 (improved shape) $F_{c2}=(\sigma_m/\sigma_{1max})$

Fig.14 (improved shape) $F_{c3}=(\sigma_{1max}/\sigma_{eq})$

Claims

1. A method of predicting damage of dies used for plastic processing of metallic materials by predicting "great crack" caused by brittle fracture dominating the die lives so as to contribute to die design including choice of die materials, hardness of the material and determination of die shape, which comprises carrying out the die design by selecting the conditions that none of the anticipated brittle fracture values F_{c1} to F_{c3} calculated by the formulae below exceed the critical values depending on the materials:

[formula 1] $$F_{c1}=(\sigma_m/\sigma_{eq})$$

[formula 2] $$F_{c2}=(\sigma_m/\sigma_{1max})$$

[formula 3] $$F_{c3}=(s_{1max}/s_{eq})$$

where,

σ_m: mean normal stress loaded to the tensile side of the die
σ_{eq} : Von Misese's equivalent stress
σ_{1max} : maximum principal stress.

2. The method of predicting damage of die according to claim 1, wherein the material of the die is SKD61 steel and F_{c1}=0.7, F_{c2}=0.5 and F_{c3}=1.25.

Fig.1 SMOOTH TEST PIECE

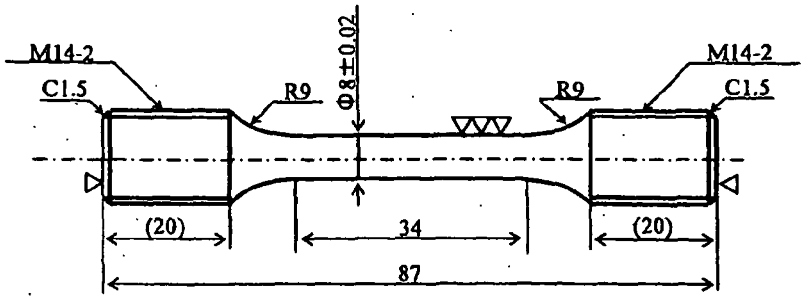


Fig.2 30° NOTCHED TEST PIECE

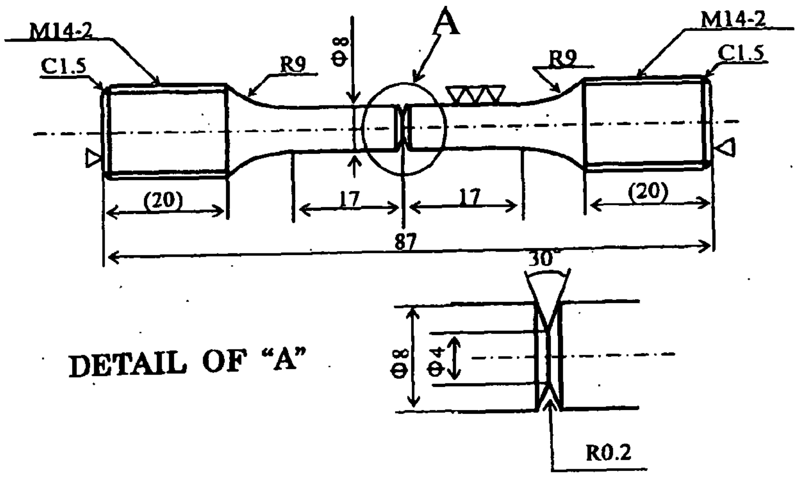


Fig.3 90° NOTCHED TEST PIECE

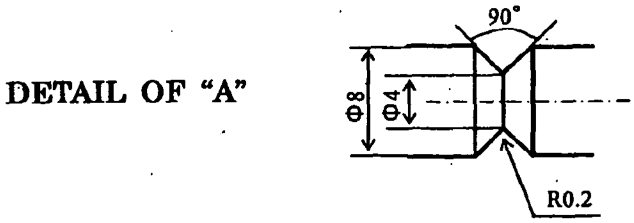


Fig.4 120° NOTCHED TEST PIECE

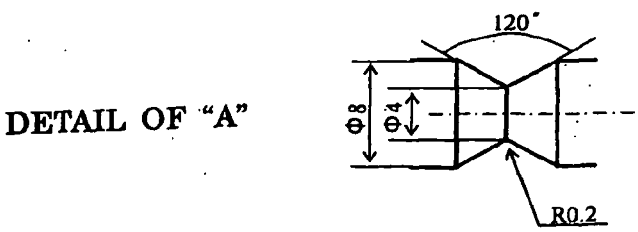


Fig.5

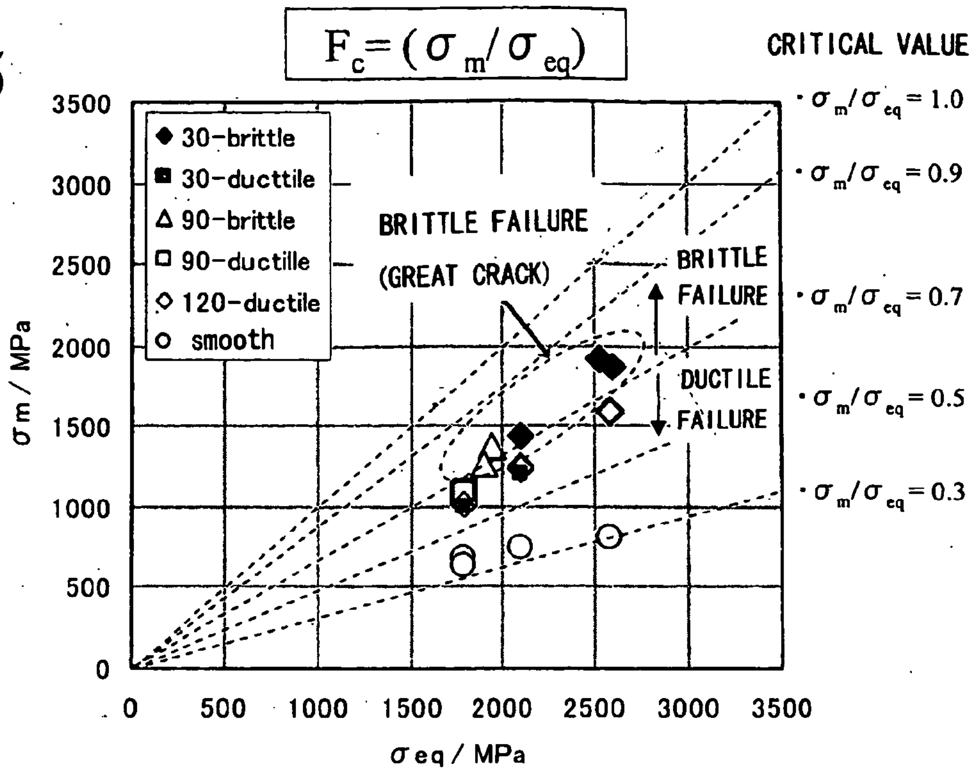

$F_c = (\sigma_m / \sigma_{eq})$
CRITICAL VALUE
$\sigma_m/\sigma_{eq} = 1.0$
$\sigma_m/\sigma_{eq} = 0.9$
$\sigma_m/\sigma_{eq} = 0.7$
$\sigma_m/\sigma_{eq} = 0.5$
$\sigma_m/\sigma_{eq} = 0.3$
30-brittle
30-ducttile
90-brittle
90-ductille
120-ductile
smooth
BRITTLE FAILURE
(GREAT CRACK)
BRITTLE FAILURE
DUCTILE FAILURE
σ m / MPa
σ eq / MPa
0
500
1000
1500
2000
2500
3000
3500

Fig.6

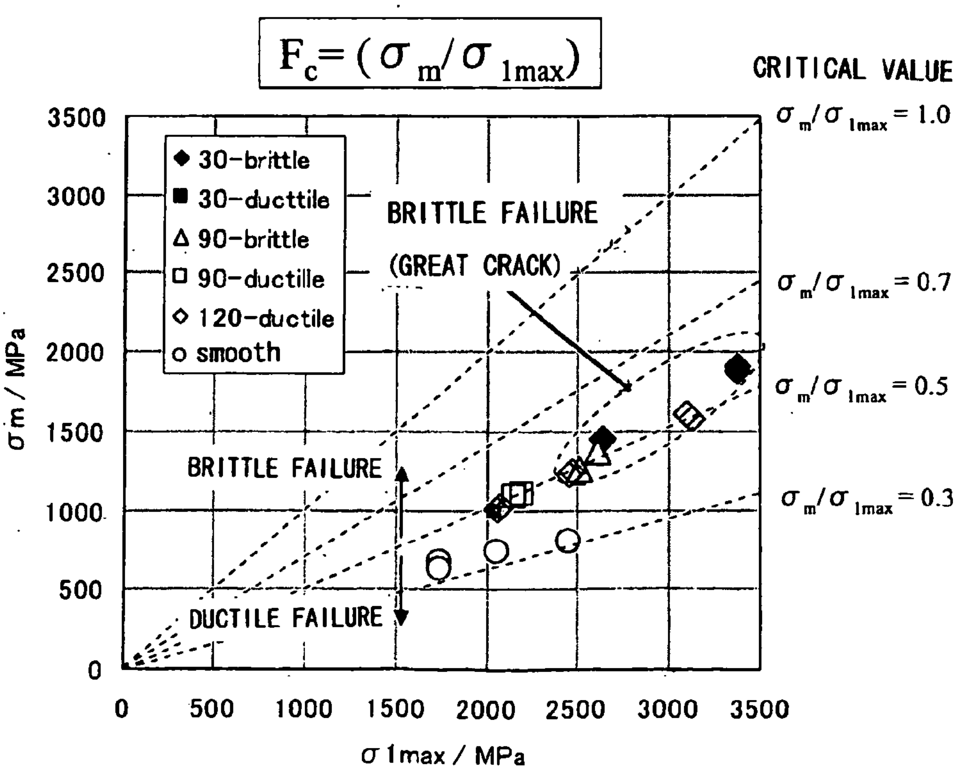
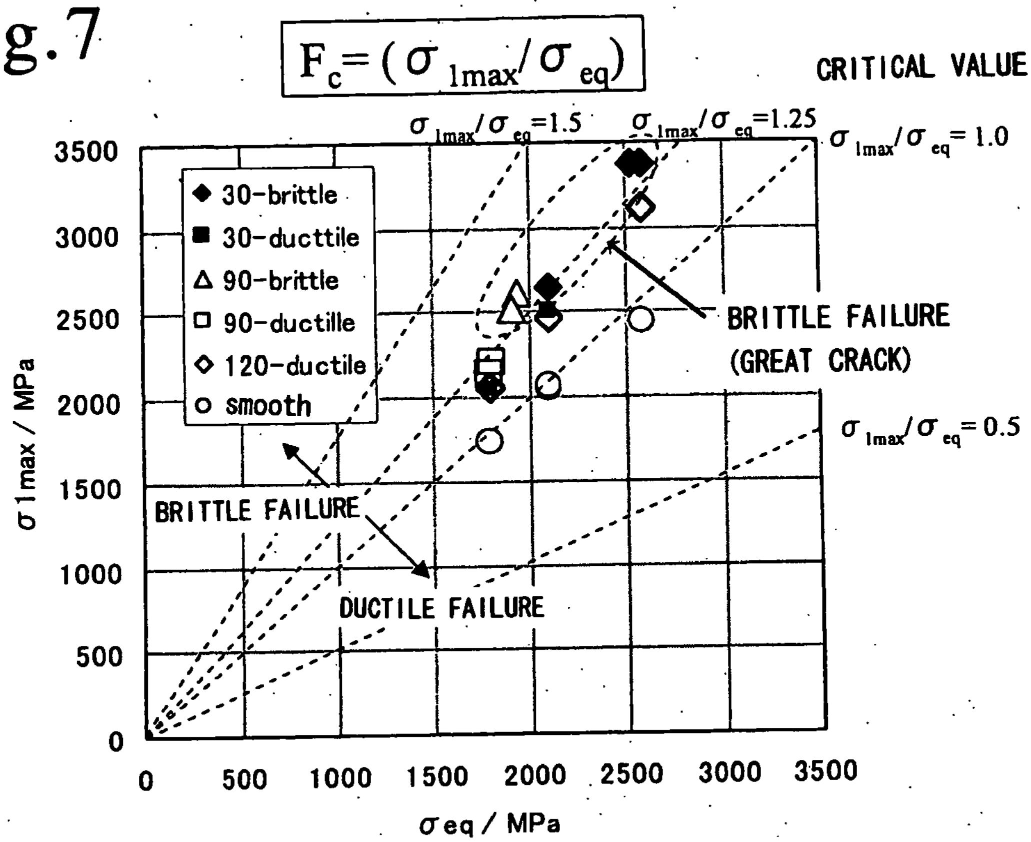
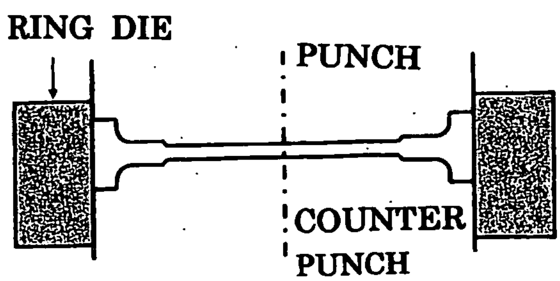

$F_c = (\sigma_m / \sigma_{1max})$
CRITICAL VALUE
$\sigma_m/\sigma_{1max} = 1.0$
$\sigma_m/\sigma_{1max} = 0.7$
$\sigma_m/\sigma_{1max} = 0.5$
$\sigma_m/\sigma_{1max} = 0.3$
30-brittle
30-ducttile
90-brittle
90-ductille
120-ductile
smooth
BRITTLE FAILURE
(GREAT CRACK)
BRITTLE FAILURE
DUCTILE FAILURE
σ m / MPa
σ 1max / MPa
0
500
1000
1500
2000
2500
3000
3500

Fig.7



$F_c = (\sigma_{1max}/\sigma_{eq})$
CRITICAL VALUE
$\sigma_{1max}/\sigma_{eq}=1.5$
$\sigma_{1max}/\sigma_{eq}=1.25$
$\sigma_{1max}/\sigma_{eq}=1.0$
$\sigma_{1max}/\sigma_{eq}=0.5$
30-brittle
30-ducttile
90-brittle
90-ductille
120-ductile
smooth
BRITTLE FAILURE (GREAT CRACK)
BRITTLE FAILURE
DUCTILE FAILURE
σ 1max / MPa
σ eq / MPa
0
500
1000
1500
2000
2500
3000
3500

Fig.8



RING DIE
PUNCH
COUNTER PUNCH

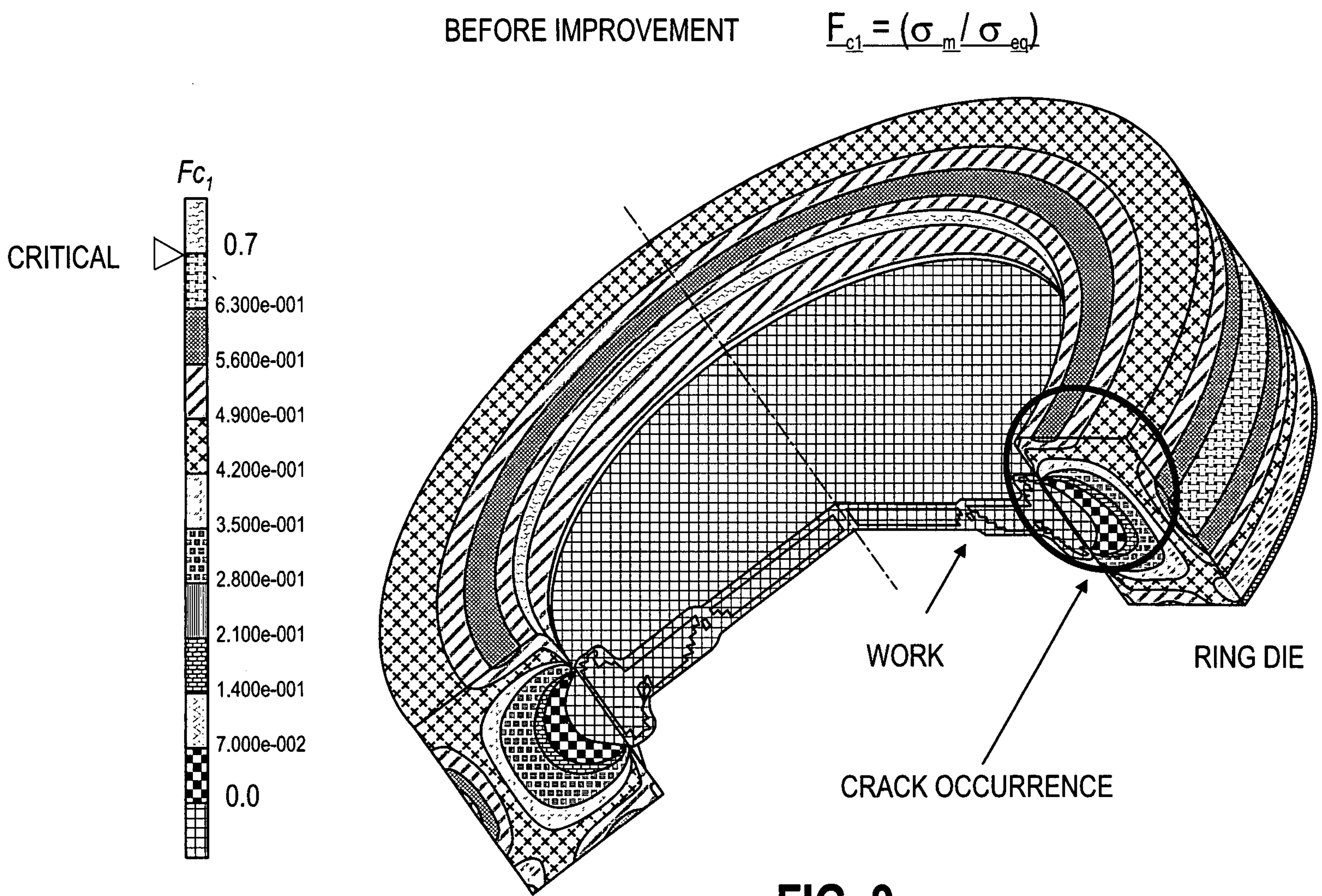

BEFORE IMPROVEMENT
$F_{c1} = (\sigma_m / \sigma_{eq})$
Fc_1
CRITICAL
0.7
6.300e-001
5.600e-001
4.900e-001
4.200e-001
3.500e-001
2.800e-001
2.100e-001
1.400e-001
7.000e-002
0.0
WORK
RING DIE
CRACK OCCURRENCE

FIG. 9

BEFORE IMPROVEMENT $F_{c2} = (\sigma_m / \sigma_{1max})$

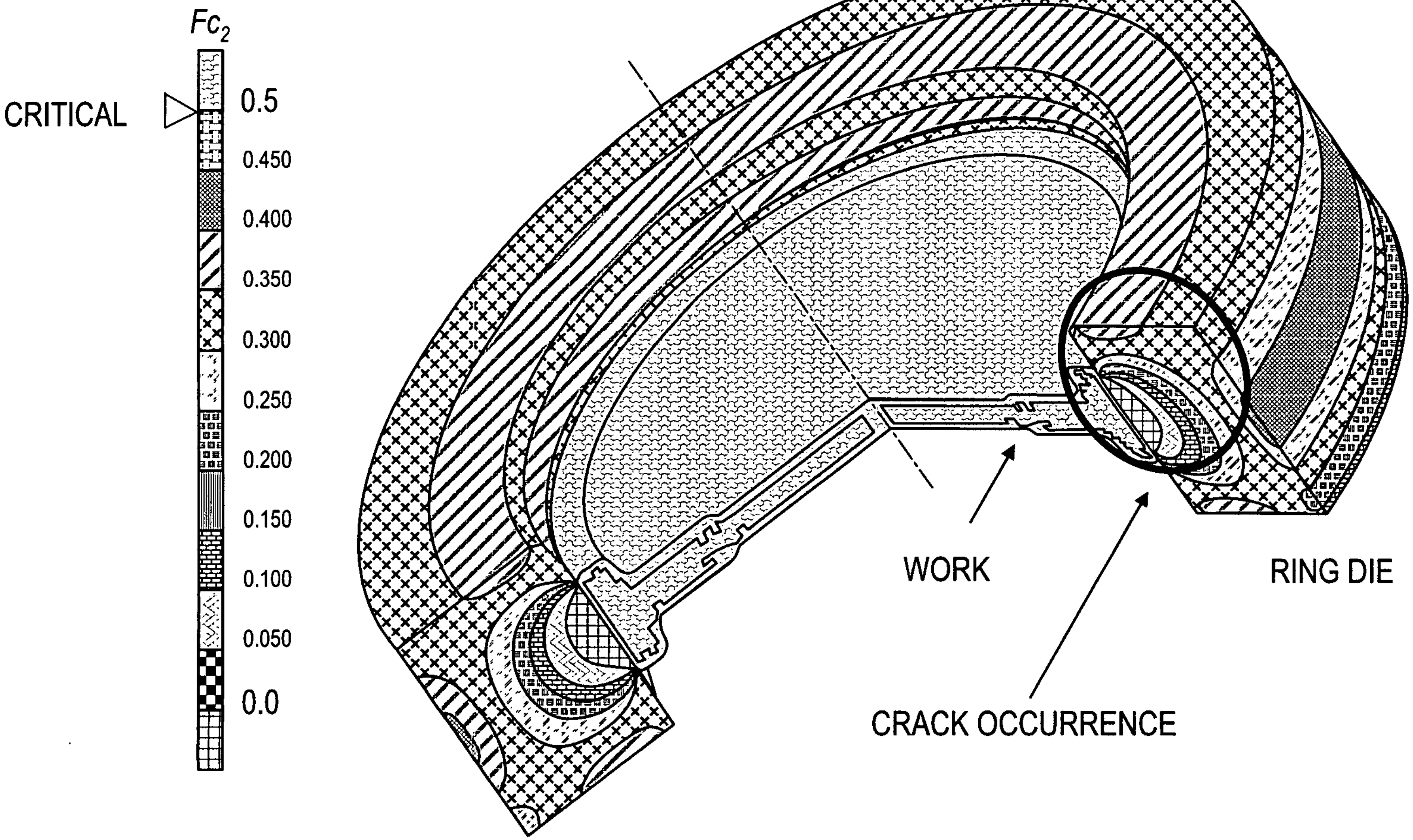


FIG.10

BEFORE IMPROVEMENT $\underline{F_{c3} = (\sigma_{1max} / \sigma_{eq})}$

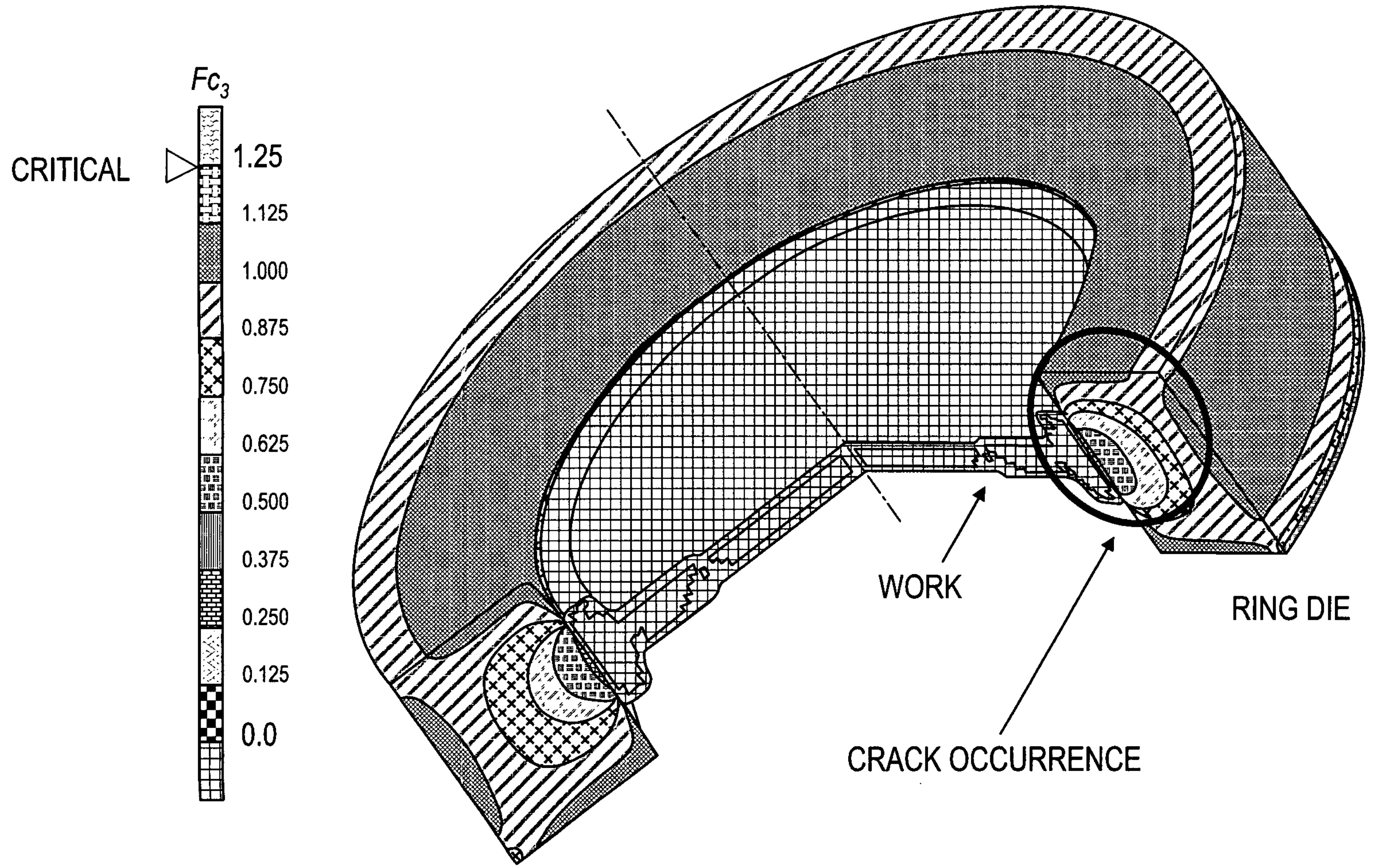


FIG.11

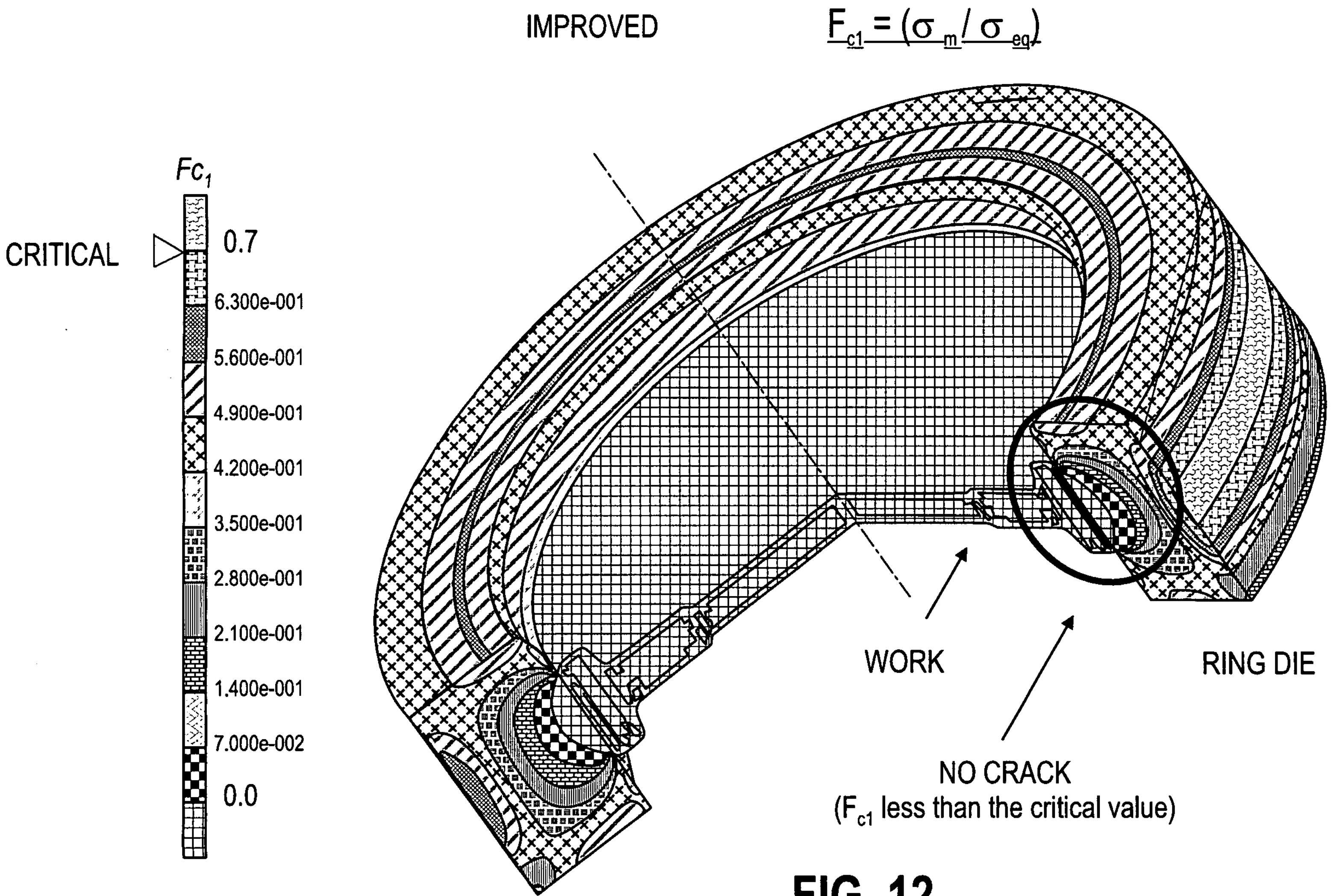

IMPROVED
$F_{c1} = (\sigma_m / \sigma_{eq})$
Fc_1
CRITICAL
0.7
6.300e-001
5.600e-001
4.900e-001
4.200e-001
3.500e-001
2.800e-001
2.100e-001
1.400e-001
7.000e-002
0.0
WORK
RING DIE
NO CRACK
(F_{c1} less than the critical value)

FIG. 12

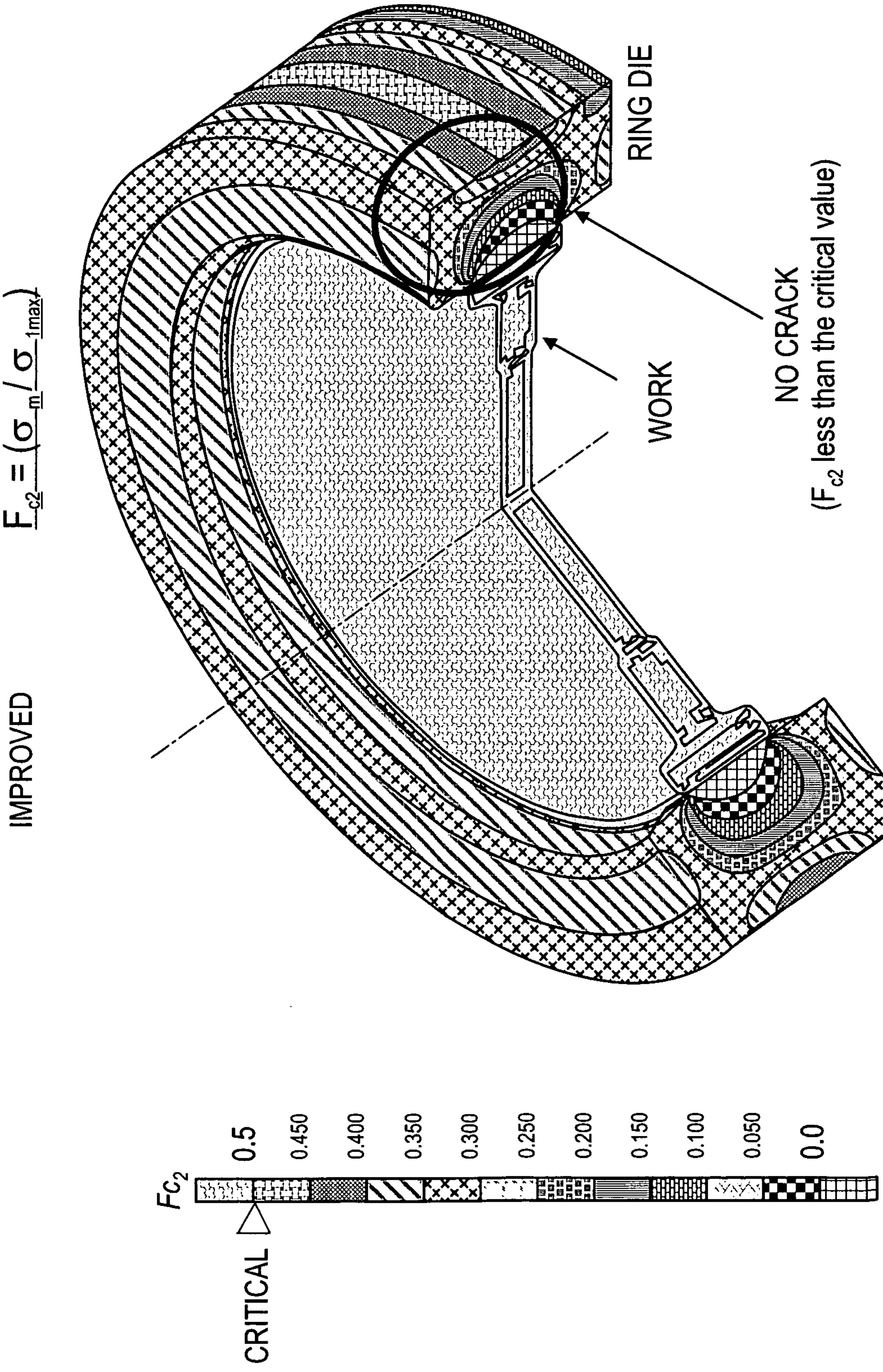

IMPROVED
$F_{c2} = (\sigma_m / \sigma_{1max})$
RING DIE
WORK
NO CRACK
(F_{c2} less than the critical value)
Fc_2
0.5
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.0
CRITICAL

FIG. 13

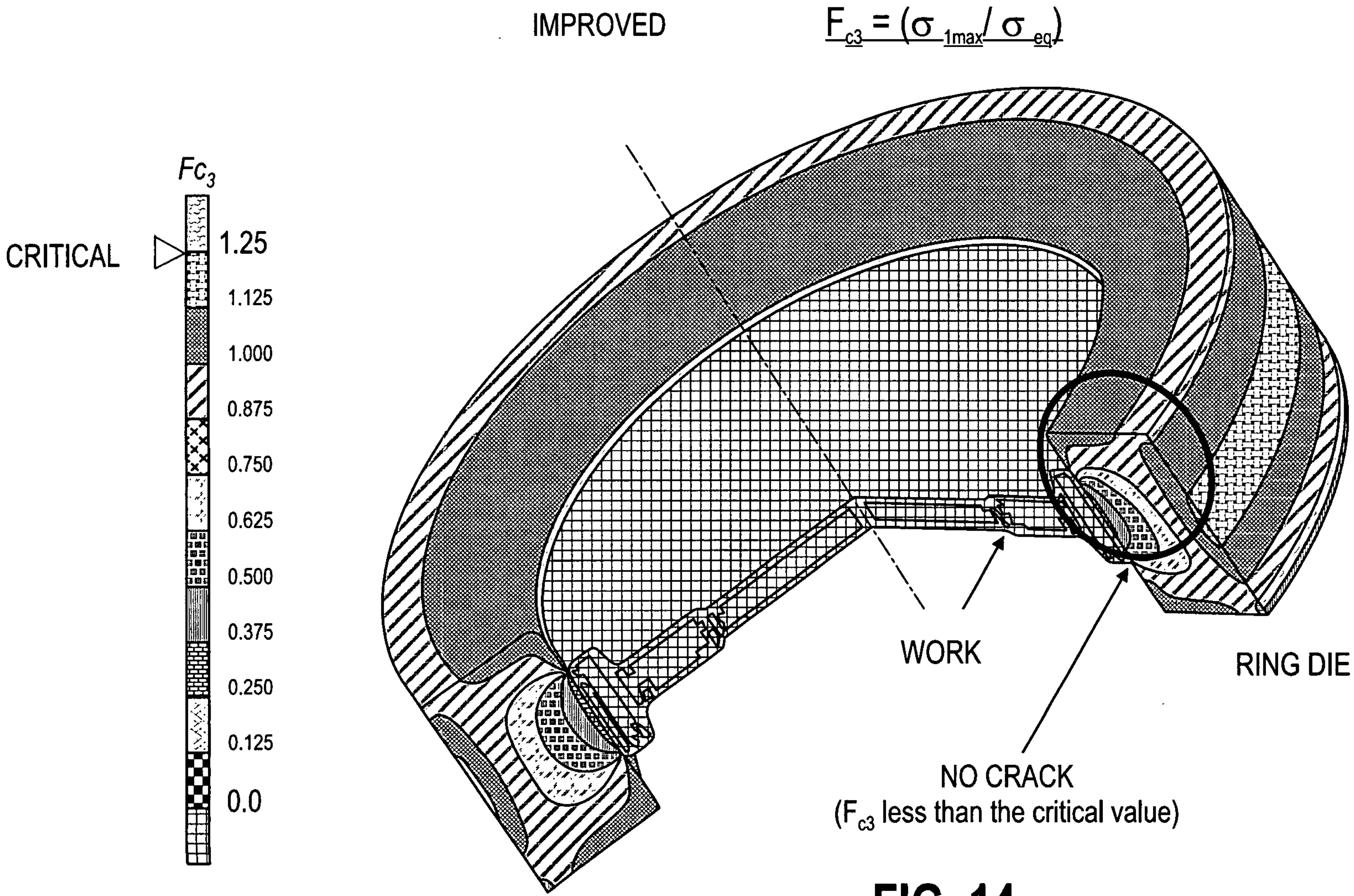

IMPROVED
$F_{c3} = (\sigma_{1max} / \sigma_{eq})$
Fc_3
CRITICAL
1.25
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.0
WORK
RING DIE
NO CRACK
(F_{c3} less than the critical value)

FIG. 14

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 00 8110

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 03, 5 May 2003 (2003-05-05) -& JP 2002 321032 A (TOYOTA MOTOR CORP; TOYOTA CENTRAL RES & DEV LAB INC), 5 November 2002 (2002-11-05) * abstract * -----	1	INV. B21J13/02 B22C9/06
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 12, 3 January 2001 (2001-01-03) -& JP 2000 246394 A (HITACHI METALS LTD), 12 September 2000 (2000-09-12) * abstract * -----	1	
A	PATENT ABSTRACTS OF JAPAN vol. 2002, no. 05, 3 May 2002 (2002-05-03) -& JP 2002 001475 A (TOYOTA MOTOR CORP), 8 January 2002 (2002-01-08) * abstract * -----	1	
P,A	KIM ET AL: "Estimation of die service life against plastic deformation and wear during hot forging processes" JOURNAL OF MATERIALS PROCESSING TECHNOLOGY, ELSEVIER, AMSTERDAM, NL, vol. 166, no. 3, 20 August 2005 (2005-08-20), pages 372-380, XP005023923 ISSN: 0924-0136 * the whole document * -----	1	TECHNICAL FIELDS SEARCHED (IPC) B21J B22C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	14 July 2006	Ritter, F

CATEGORY OF CITED DOCUMENTS

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14-07-2006

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2002321032 A	05-11-2002	NONE	
JP 2000246394 A	12-09-2000	NONE	
JP 2002001475 A	08-01-2002	NONE	

EPO FORM P0459

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Patent documents cited in the description

- JP 2002321032 A **[0002]**