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Strength of the AISI 316 Stainless Steel Above 800 °C

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Summary

Short time creep tests have been carried out in the temperature range 800 - 1300°C for AISI 316 H stainless steel in order to simulate the working conditions of the "catcher plate" component during an hypothetical core melt-down of the lower part of a LMFBR pressure vessel. Design creep curves which will be used as input to computerized stress calculations in order to predict "catcher plate" deformations, have been obtained.

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1. Introduction

The JRC Ispra program on LMFBR material behaviour studies in support of PAHR (Post Accident Heat Removal) activities includes a research area which is related to the development of data and methods for calculating the performance of loaded stainless steel structures at non-uniform temperatures above 800°C [1]. In fact the problem of the structural integrity of the "catcher plate" which works as a potential heat removal device and container of the fuel debris during a possible accident involving considerable core damage, requires a satisfactory knowledge of the mechanical behaviour of structural stainless steel AISI 316 series above 800°C and as close as possible to the melting point ($T_m \cong 1370°C$). In the literature there is a lack of data on this point and it is therefore difficult to perform inelastic stress analysis with the type of loading (primary and secondary loading) on the LMFBR component mentioned. One must then have available the short time creep data in the temperature range 800 - 1300°C for the stainless steels. Such tests have been performed for AISI 316 H (nuclear degree) stainless steel and the results are presented here.

2. Experimental

The AISI 316 H stainless steel used was the 50 mm thick reference plate supplied by Uddeholm (heat KL4290) which is already employed in Ispra for various research activities [2-5]. Its composition is given in Table I. The plate was machined into round specimens with a 4.0 mm diameter and a gauge length of 20 mm. All specimens were obtained with the tensile axis parallel to the rolling direction of the plate material and annealed at 1080°C for 30 minutes and water cooled to give an austenitic grain of the order of 4 - 6 according to ASTM-E-113.
The metallographic analysis shows quite equiaxial grains after the solution annealing treatment, the non-metallic inclusions being normal and of homogeneous distribution. The creep tests were carried out under a constant tensile load with an Adamel machine which was modified, by mounting a Brew-General Engineering vacuum (Mo-resistors) furnace especially designed for mechanical testing. A lever loading mechanism was employed to load the specimens but at the higher temperature (T = 1300°C) direct loading was used. The tests were performed in vacuum (5×10^{-6} torr). The reading precision of the comparator dial gauge for the measurement of the elongation was 0.001 mm. The creep temperatures were 800, 1000, 1200 and 1300°C and were kept constant ± 2.5°C. The creep lifetime range of 0.5 to 10 hours was investigated. The test data were statistically treated by a computer curve fitting program. The samples were observed after rupture by scanning electron microscopy (SEM) and optical microscopy.

3. Results

3.1 Creep curves

Selected curves for all the temperatures investigated (800, 1000, 1200 and 1300°C) are given in Figs. 1 - 4, which represent graphically the function between creep strain and time. It can be seen that the creep behaviour is affected strongly by temperature and stress. The data show that at higher temperatures and at higher stresses (corresponding to the more critical conditions for the catcher plate calculations) the tertiary stage of the creep occupies 50 - 70% of the total lifetime, whereas the secondary stage contracts to become only a turning point of the curves and the primary stage occupies the rest of the total lifetime. On the other hand, at the higher temperatures but at the lower stresses, the creep curves tend to become essentially linear, the secondary stage is then the major contribution to the total lifetime whereas the pirmary stage does not, in fact, exist and the tertiary is greatly reduced.

3.2 Stress dependence

The creep tests show that the secondary creep follows the Norton Law, i.e. a power relationship between the secondary creep strain rate $\dot{\epsilon}_s$ and the nominal stress σ (Fig. 5)

$$\dot{\epsilon}_s = A\,\sigma^n \qquad (1)$$

where n and A are independent of stress. The computed values of the index n are approximately 6.85 for 800°C and 5 for 1000, 1200 and 1300°C (Table II). These results agree with the literature because for annealed metals and alloys n has been found to range from 1 to 7 [6]. Moreover n is to some extent dependent upon temperature. The A values (Table II) also agree with the literature results [7].

3.3 Temperature dependence

Taking into account the fact that the creep is a thermally activated process, the constant A of the eq.(1) can be expressed as a function of the temperature by the relation:

$$A = A_0 \exp(-Q/RT) \qquad (2)$$

where Q is the creep activation energy, R is the gas constant, T is the absolute temperature and A_0 a constant. For the range 1000 - 1300°C a calculated value of Q = 89.5 Kcal/mol has been obtained. This value is slightly higher than the creep activation energy of pure iron (~ 80 Kcal/mol) [8]. At 800°C the experimental points do not allow any valuable energy activation data to be obtained.

3.4 Design curves

Design curves are shown in Figs. 6-9 for all temperatures investigated (800, 1000, 1200 and 1300°C). Creep strains of 2, 5, 10, 15, 20, 30 and 40% were chosen from the creep curves (Figs. 1-4). Other creep strains can be chosen from the creep curves and similar design curves can be constructed. The design curves allow a designer to select a stress which will produce a predetermined amount of creep strain at a particular temperature. In other words, the creep curves can be used as input to computerized stress calculations with the objective of predicting "catcher plate" deformation during a hypothetical accident involving considerable core damage.

4. Scanning electron microscopic examination

Scanning electron microscopic analyses exhibit two types of fracture models, intergranular fracture or intragranular fracture. For 800°C tests many dimples appear on the fracture surfaces (Fig. 10) although some cavities are also formed at the grain boundary. It is well known that the dimples are generally a kind of intragranular fracture as a result of internal necking deformation around the impurities in the grain interior. However, at 1000, 1200 and 1300°C tests the fracture surfaces mainly consist of cavities at the grain boundaries. As the creep time to rupture increases the brittle intergranular decohesion becomes preponderant (Fig. 11). Fig. 12 shows that under the action of high temperature and stress, the grain boundary has been seriously indented. It demonstrates that a large amount of sliding and migration has occurred in the grain boundary. This is a typical creep fracture mechanism.

References

[1] EUR Report

[2] Matteazzi, S., Piatti, G. and Boerman, D., Proc. Int. Conf. organized jointly CEC-JRC Ispra and The Metals Soc. on "Mechanical Behaviour and Nuclear Applications of Stainless Steel at Elevated Temperatures", Varese (Italy), 20-22 May, 1981, Book 280, The Metals Society, London, 1982, p.193.

[3] Matteazzi, S., Bernasconi, G., Piatti, G. and Boerman, D., Proc. 6th Int. Conf. SMIRT, Paris, North-Holland Publ. Co., Amsterdam, 1981, Paper L 4/7.

[4] Albertini, C. and Montagnani, M., ibidem, Paper L4/4.

[5] Farag, M.M., Matera, R., Sasaki, T. and Ruedl, E., Proc. 12th SOFT - Jülich, 13-17 Sept., 1982, Paper C6.

[6] Garofalo, F., "Fundamental of creep and creep-rupture in metals", The MacMillan Co., New York, 1966.

[7] Bernasconi, G. and Piatti, G. (Eds.), "Creep of engineering materials and structures", Applied Science Publ. Ltd., London, 1979.

[8] Sherby, O.D., Orr, R.L. and Dorn, J.E., Trans. AIME, 200, 1954, p.75.

TABLE I - Chemical composition (wt%) of AISI 316 H stainless steel

C	Si	Mn	P	S	Cr	Ni	Mo	Co	B	N	Fe
0.05	0.35	1.65	0.020	0.008	16.9	12.4	2.45	0.023	0.001	0.082	balance

TABLE II - Computed values of A and n

Test temperature	A	n	r^2
800°C	5.507×10^{-10}	6.85	0.9852
1000°C	1.758×10^{-12}	4.66	0.9907
1200°C	2.458×10^{-10}	4.80	0.9676
1300°C	1.440×10^{-9}	5.11	0.9784

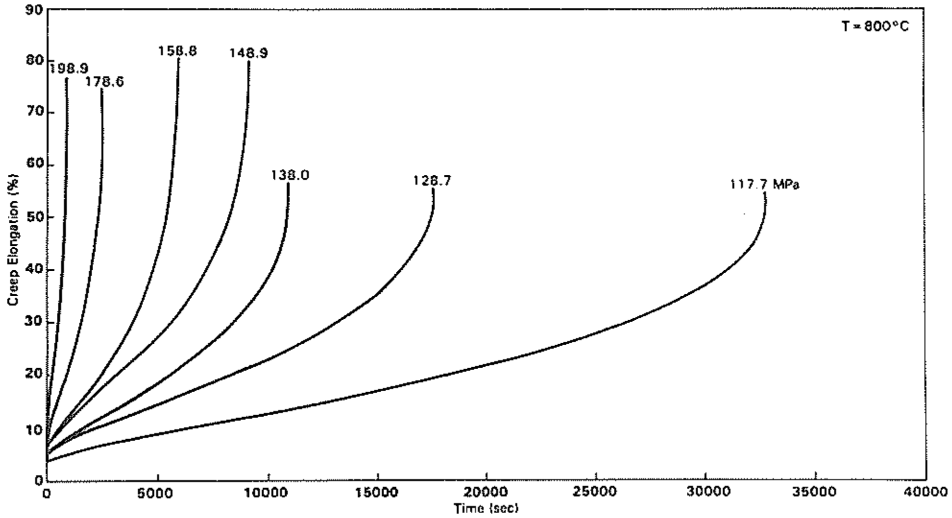

Fig. 1 - Creep curves of AISI 316 austenitic stainless steel tested at 800°C. (The numbers in the figure are initial stresses in MPa).

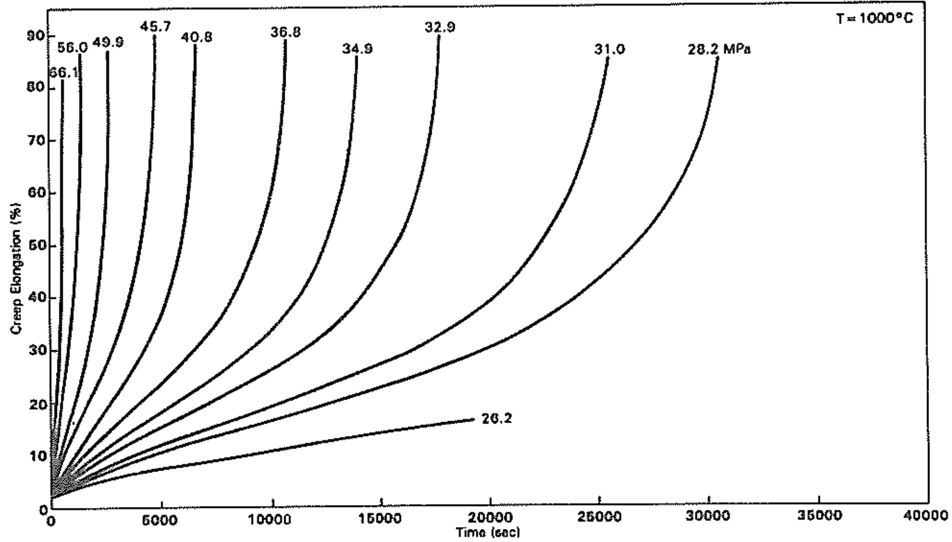

Fig. 2 - Creep curves of AISI 316 austenitic stainless steel tested at 1000°C. (The numbers in the figure are initial stresses in MPa).

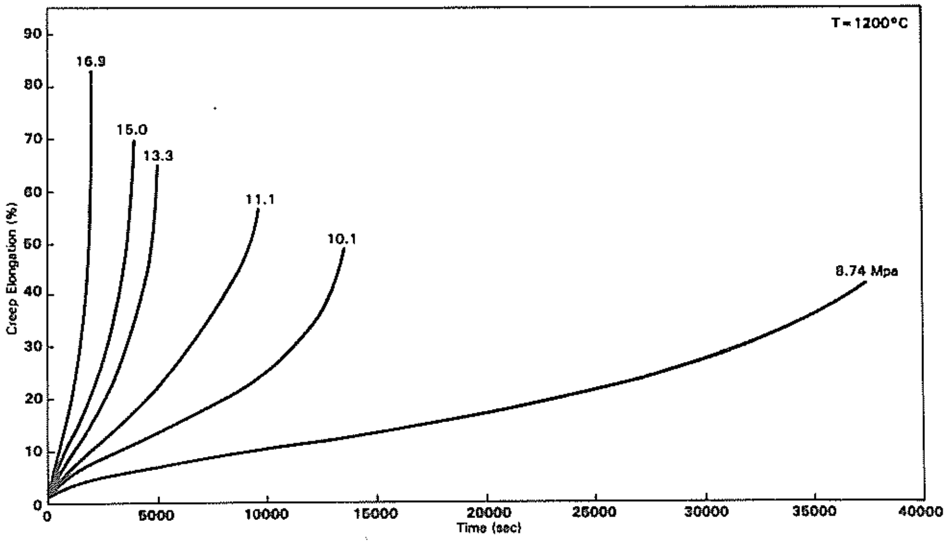

Fig. 3 - Creep curves of AISI 316 austenitic stainless steel tested at 1200°C.
(The numbers in the figure are initial stresses in MPa).

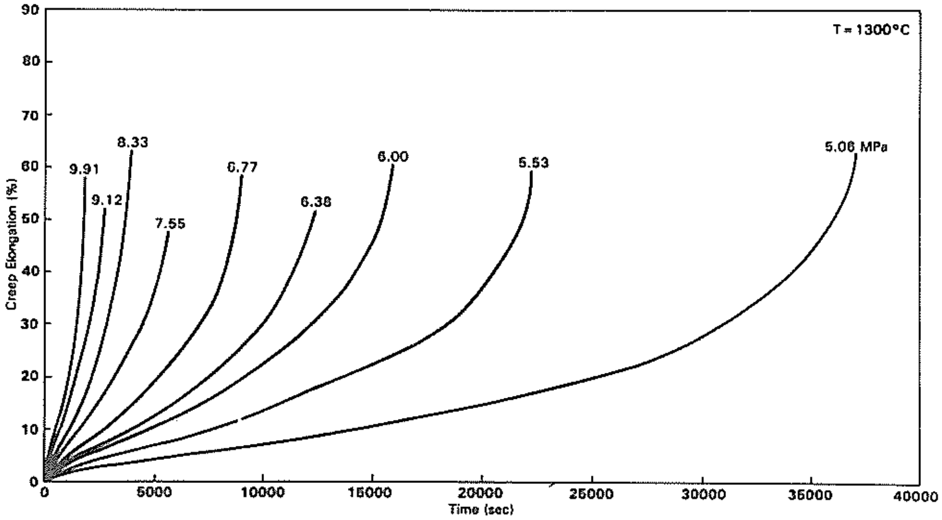

Fig. 4 - Creep curves of AISI 316 austenitic stainless steel tested at 1300°C.
(The numbers in the figure are initial stresses in MPa).

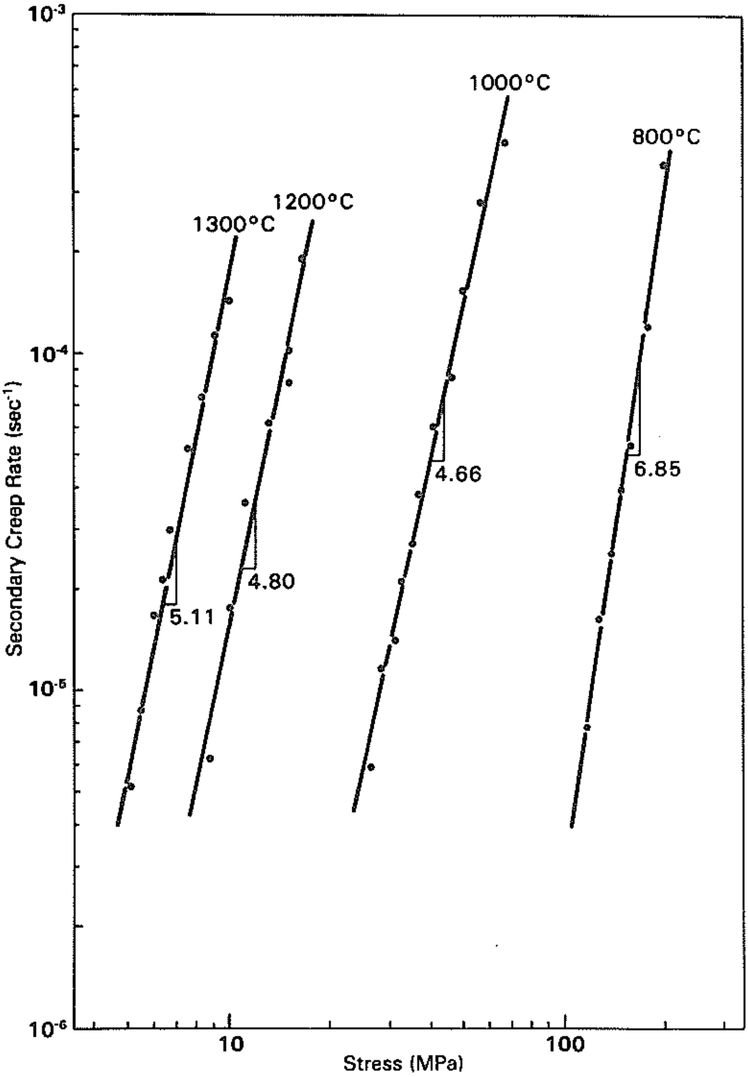

Fig. 5 - Secondary creep strain rate ($\dot{\epsilon}_S$) as a function of initial stress (σ).

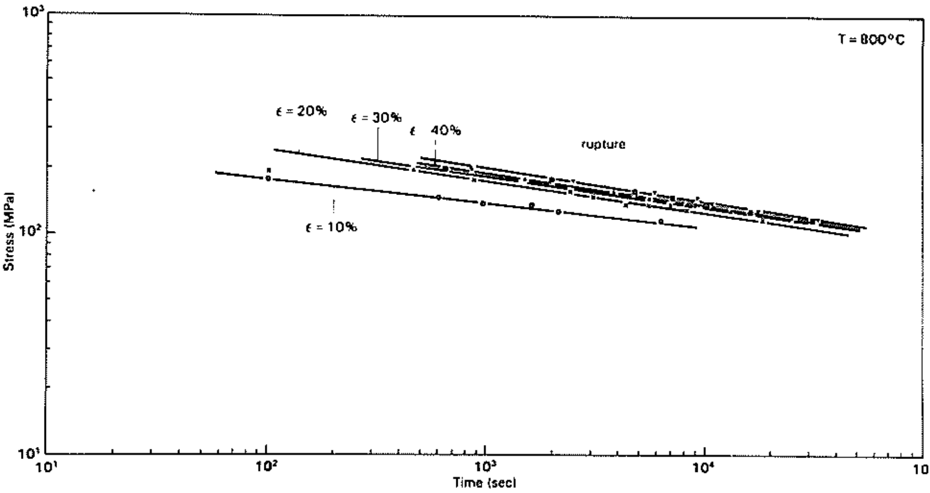

Fig. 6 - Design for the AISI 316 H stainless steel at 800°C.

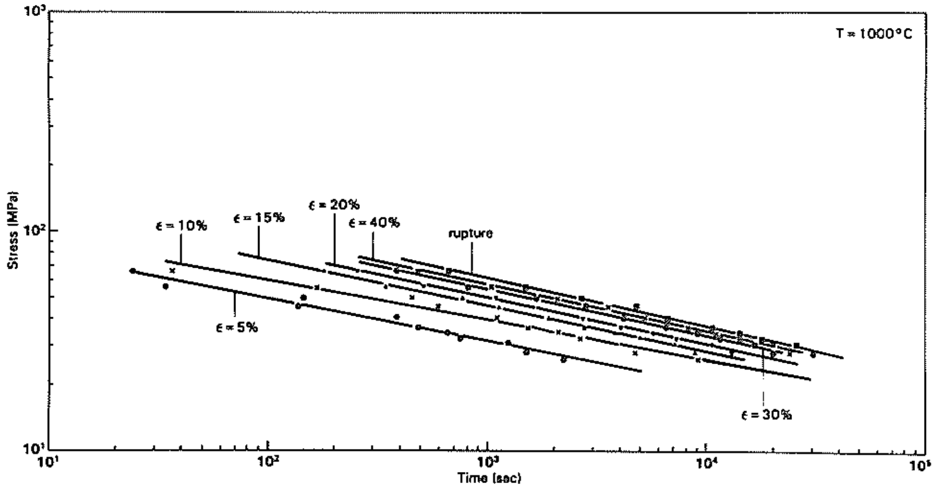

Fig. 7 - Design for the AISI 316 H stainless steel at 1000°C.

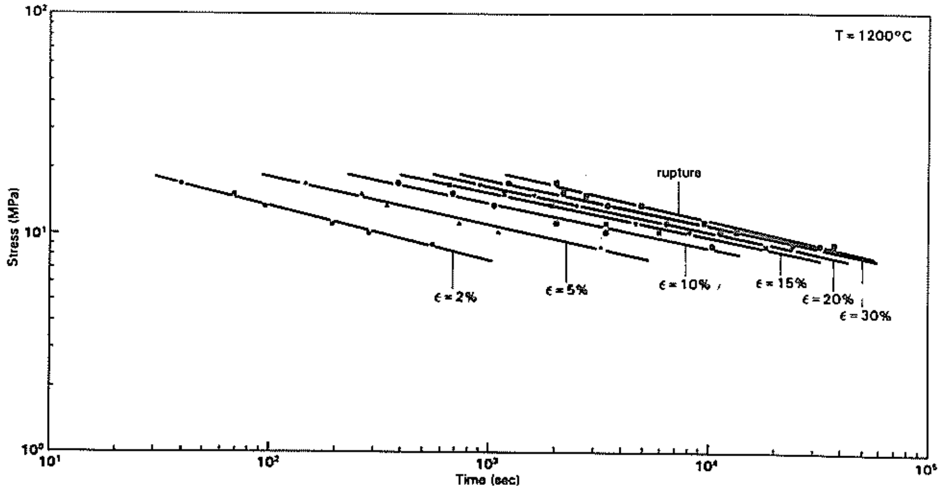

Fig. 8 - Design for the AISI 316 H stainless steel at 1200°C.

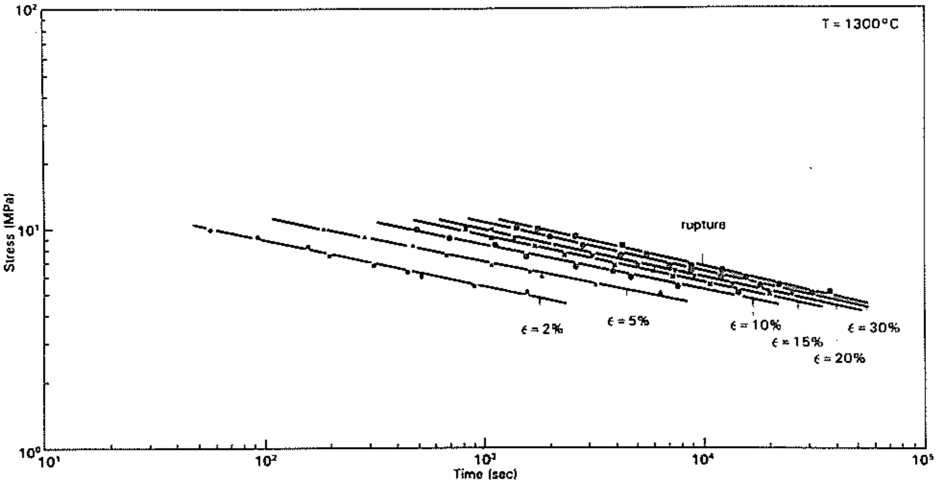

Fig. 9 - Design for the AISI 316 H stainless steel at 1300° C.

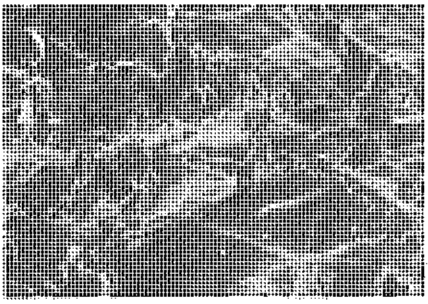

Fig. 10 -Fracture surface of AISI 316 H stainless steel specimen deformed at 800°C (time to rupture 5920 sec). Many dimples are visible (magnification x 800).

Fig. 11 - Intergranular decohesion on a specimen of AISI 316 H stainless steel deformed at 1300°C (magnification x 1000).

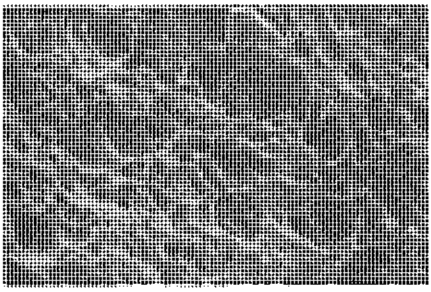

Fig. 12 - External surface of a specimen of AISI 316 H deformed at 1200°C (time to rupture 1500 sec) showing an indented grain boundary (magnification x 300).