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PROPAGAZIONE DI UNA CREPA PER FATICA NELLA LEGA AA 5356

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Sommario Particolari strutture saldate, realizzate con piastre di lega 7020(°) hanno evidenziato un comportamento a fatica che implica la propagazione di crepe nel cordone di saldatura. Questa peculiare caratteristica richiede pertanto la determinazione delle proprietà di propagazione della crepa nel materiale d'apporto, solitamente AA 5356(°°), in condizioni metallurgiche simili a quelle d'impiego.
A tal fine è stata studiata la curva da/dN in funzione di ΔK, in particolari provini CT ricavati da un saggio saldato opportunamente dimensionato.
La struttura dei provini ha richiesto una elaborazione dei dati sperimentali, che è stata effettuata per via numerica mediante un codice ad elementi finiti.

FRACTURE CRACK PROPAGATION IN A AA 5356 ALUMINIUM ALLOY

Abstract The Aluminium AA 5356 alloy is commonly used as a filler metal in Aluminium weldments. New design criteria pertaining welded structures of 7020 alloy plates, generally employing 5356 as filler metal, require engineering data about Fracture Crack Propagation (FCP) in the weld bead. Particular notched Compact Tension (CT) specimens have been used to detect the da/dN vs. ΔK curve for the investigated alloy. Experimental data have been corrected by using a Finite Element Model. Results are here reported.

(°) Al-Zn 4,5% - Mg 1,2% - Mn 0,25%
(°°) Al-Mg 5,0% - Mn 0,12% - Cr 0,12%

Introduction : The Al-Mg AA 5356 alloy is generally employed as filler metal in the Aluminium weldments.

Under ciclic loading, fatigue cracks generally propagate, in these welded structures, in the thermally modified zones near the weld beads known as Heat Affected Zones (HAZ), where the overheating caused by the welding process determines a deep metallurgical modification.

Nevertheless new design criteria adopted for joints made with thick plates of AA 7XXX alloys (1) (such as 7020 Al-Zn-Mg) cause an anomalous trend in the crack propagation path which lies completely inside the weld bead.

Design criteria for this kind of joints (in particular for fatigue life prediction) therefore requires engineering data about FCP in the weld bead.

With the aim of collecting data about the FCP in the 5356 filler metal after welding, we performed fatigue tests on Compact Tension (CT) specimens obtained by a welded joint made by using the typical industrial MIG technique; even if the width of CT samples does not completely fullfill the condition of plane strain propagation (but it is quite impossible to obtain samples having correct sizes), results so obtained are of great interest from a technological point of view to give an important aid in prediction of SN curves of particular Aluminium weldments.

Sample preparation : Two plates of 7020-T6 obtained from cast slabs by hot rolling (50 mm thick, 600 mm large) have been scalped in the short transverse direction, at an angle of 45°. They have been then joined by using the automatic MIG technique in about 50 passes (Fig.1) employing AA 5356 commercial wire as filler material (the chemical composition is reported in tab.I).

After natural ageing to ensure the maximum recovery of strength of the Heat Affected Zone, Compact Tension type 40 mm thick samples have been obtained as reported in fig.2, showing also a macrograph of a right section of the weldement.

During the preparation of specimens, non destructive tests have been carried out to check the quality of the weld beads; neither porosity nor microcracks have been detected; moreover residual stresses tending to open the arms of the samples have not been noted. As it can be seen from fig.2 the tip of the notch is located inside the first bead.

Crack propagation tests : FCP tests have been performed in load control, under standard conditions (air, 20°C, 65% relative humidity) by using an INSTRON mod. 1343 computerized material testing machine. A crack length monitoring task, based on the use of the compliance function, has been used to estimate the growth of the crack from COD clip gauge and load cell signals. Data pertaining the load, the opening of the arms and the number of cycles have been collected and stored on magnetic disk.

A sinusoidal loading having a frequency of 20 Hz and a R ratio between the minimum and maximum value equal to 0,15 has been used. A range of ΔK value from about 2 up to 14 $MPa\sqrt{m}$ has been investigated.

As the mechanical characteristics of the material of the samples are not constant, in particular the Young modulus E characterizing the features of the specimens in the elastic field, standard formulae describing the trend of crack propagation with respect to the opening of the arms can not be used.

The crack length and the ΔK values concerning the da/dN vs. ΔK curve have been therefore calculated, starting from stored data, by using a numerical code based on the Finite Element Method (2).

Fig.3 shows the mesh used in calculations, the loading scheme and the constraints; 275 8-noded quadrilateral isoparametric elements have been used.

The true stress/strain σ/ε curves concerning the parent metal (AA 7020-T6) and the filler metal (AA 5356) have been experimentally determined by using the same material testing machine previously mentioned.

A particular specimen made with MIG welded 5356 commercial wire has been used to perform the previous test.

To numerically simulate the stress/strain characteristics of the HAZ we used the experimental data of a 7020-T4 alloy. This one can be considered such as representative of an average metallurgical situation even if, actually, more complicated features can be detected near the weld bead. Fig.4 shows the σ/ε curves adopted to simulate the deformation trend of the sample.

A load vs. opening experimental test has been carried out with the aim of verifing the consistency of the model. As it can be seen from fig.5

the numerical results are in good agreement with the experimental curve; calculation have been performed considering essentially a plane stress situation; results pertaining plane strain are also reported showing that deformations normal to the specimen can not be considered as negligible. The numerical curve has been obtained both in the elastic and elastoplastic field; in this last case the incremental theory has been considered.

<u>Results and discussion</u> : The model has been used to determine a numerical correlation between the displacement of the opening arms (experimental determined by a strain gauge) and the actual crack length "a"; the values of ΔK corresponding to determined values of "a" have been also calculated. By using this method a da/dN vs. ΔK curve has been obtained; it is reported in fig.6. As it can be seen, the points so obtained are a little spread, but it can be explained by considering the kind of material involved in testing, typically having microvoids and defects in the bulk.
To make results more representative, only values corresponding to 3 mm of total "a" length completely inside the first weld bead have been monitored during testing, and this can be considered very close to the actual industrial practice where only two or three passes are enough to complete the welding. (It is not worthless to remember that every three passes the welding process has been interrupted in such a way to avoid a overheating of the filler material).
A typical fatigue fracture surface was examined by the Scanning Electron Microscope (SEM), corresponding to values of ΔK around 7 MPa$\sqrt{m}$ well inside zone II (continuum mechanism of crack growth is shown in fig.7). It is clearly visible the transgranular path of the crack; typical defect characteristics of the filler material can also be well evidentiated.
After FCP tests the samples have been used to determine a value of "K_{1C}" (even if the requirement of plane strain is not fullfilled) obtaining an average value of 18 MPA $\sqrt{m}$. Fig.8 reports a SEM micrograph showing the features of the ductile crack determined during testing; the dimple structure is well visible and the welding defects are clearly distinguishable.

Concluding remarks : New joining criteria recently developed for the AA-7XXX alloy plates, require engineering data about the FCP in the filler metal. Several tests performed on such joints have actually shown that fatigue cracks initiate and propagate completely inside the weld bead.

FCP tests performed on particular CT specimens have been therefore carried out with the aim of obtaining useful information about the trend of fatigue in the commercial AA 5356 Al-Mg filler metal.

Results have been obtained in condition of plane stress, and therefore experimental points have to be considered with some care when used in engineering design of welded structures; nevertheless plane strain tests performed on this kind of material are quite difficult, requiring high thickness base metal plates and a large amount of work to perform a good welding.

References

(1) E.DI RUSSO, S.ABIS,: Proceedings of the annual E-MRS International Conference - Strasbourg 1985

(2) CASTEM/INCA, CASTEM/MAYA Handbooks, Paris 1984

TAB.I – CHEMICAL COMPOSITION OF COMMERCIAL AA 5356 WELDING WIRE

Cu max.	Fe	Si	Mg	Mn	Cr	Zn max.	Ti	Be max.	Others		Al
									each max.	total max.	
0.05	Fe + Si ≤ 0.50		4.5÷5.5	0.05÷0.20	0.05÷0.20	0.10	0.05÷0.20	0.0008	0.05	0.15	remainder

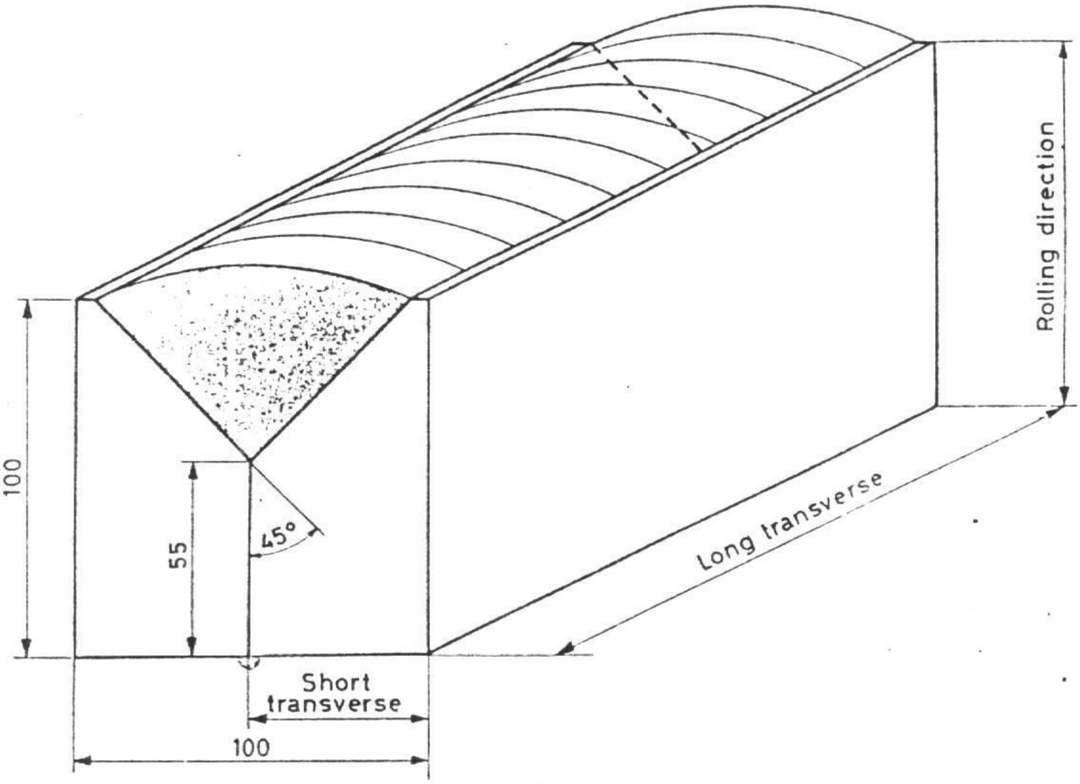

Fig.1 - Preparation of the weldment; two plates of 7020-T6 50 mm thick have been used.

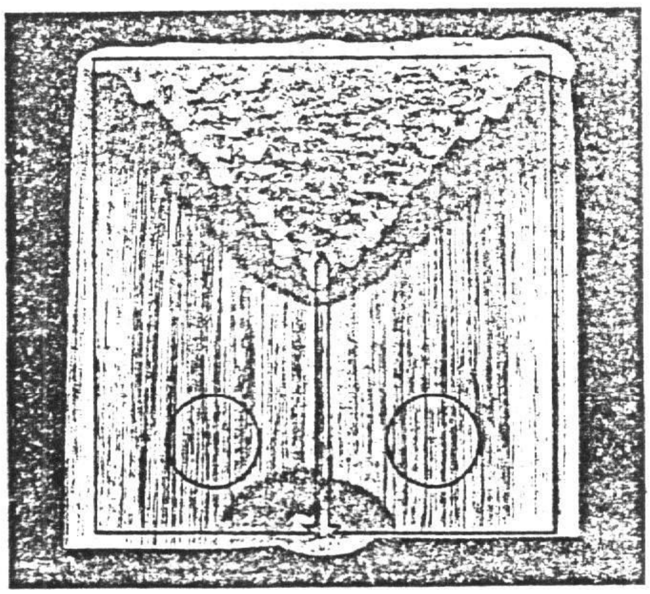

Fig.2 - Compact Tension specimens have been obtained from the weldment in such a way to obtain the propagation in the first weld bead.

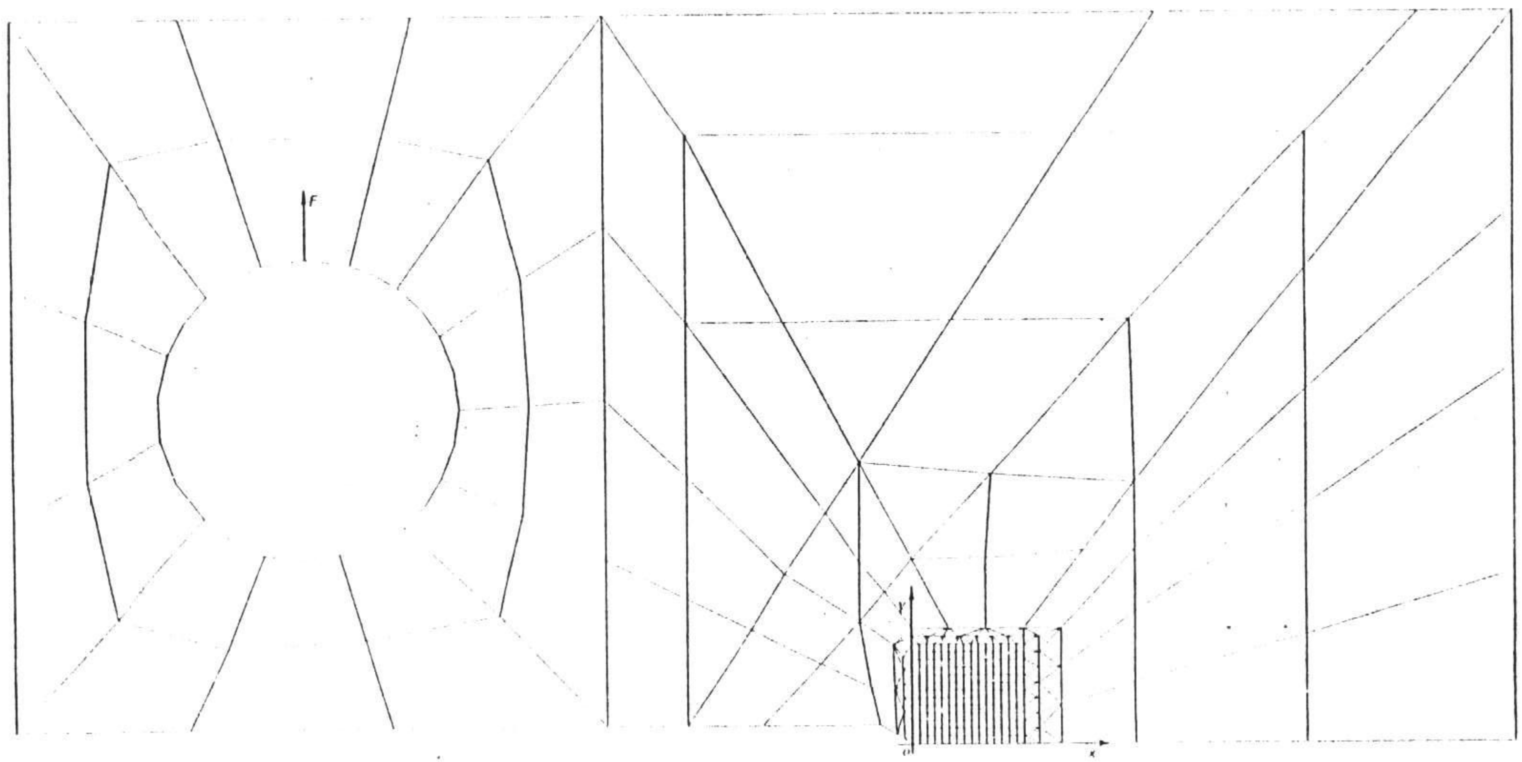

Fig.3 - Mesh used in calculations to obtain a numerical correlation between the crack length "a" and the displacement of the arms.

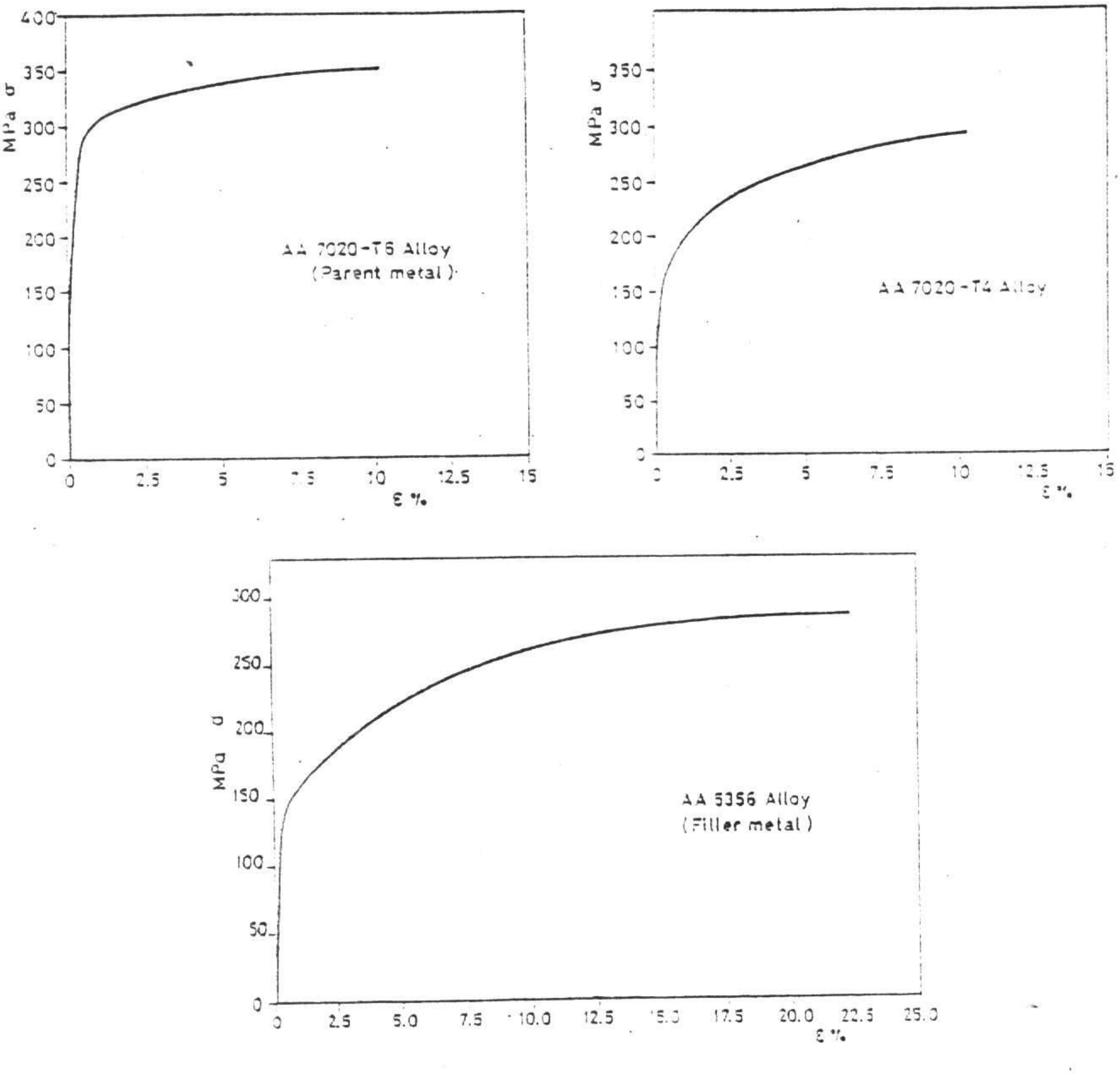

Fig.4 - Stress strain curves experimentally determined referring to the base metal 7020-T6, the HAZ (7020-T4) and the filler metal 5356.

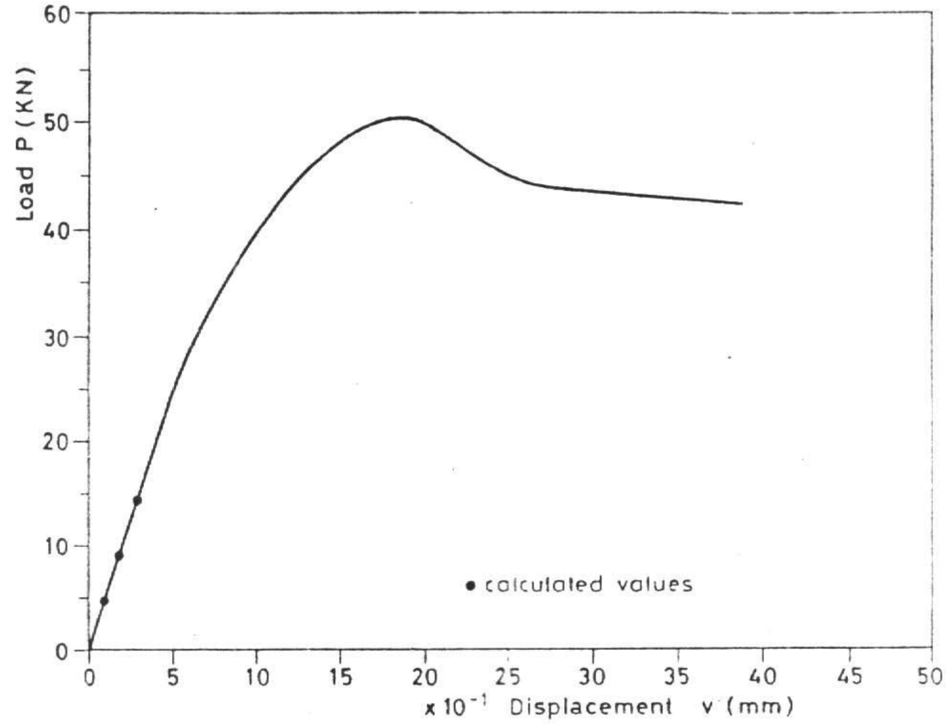

Fig.5 - Comparison between calculated and experimental values for a static test performed on a sample.

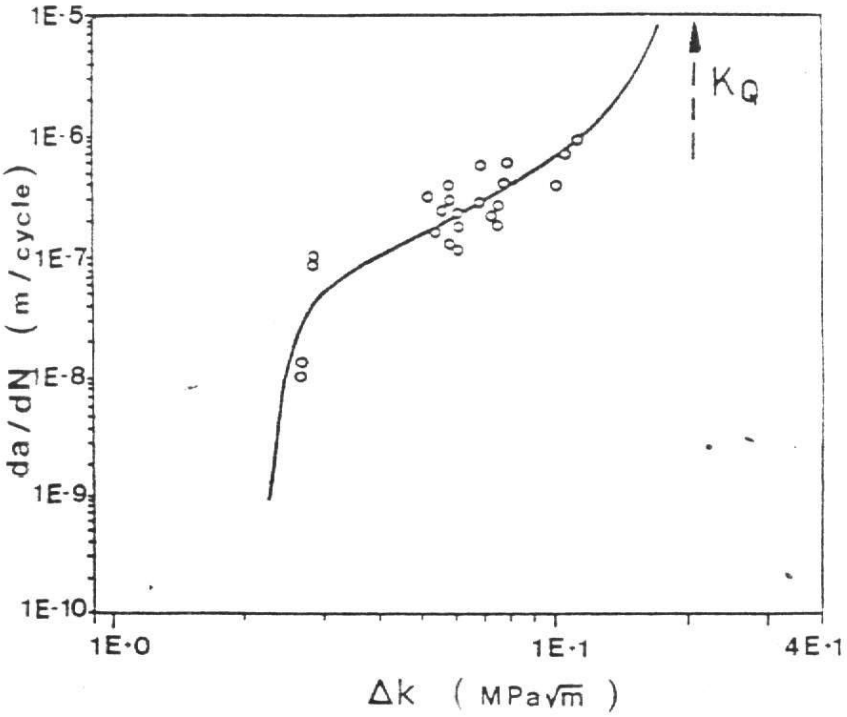

Fig.6 - Corrected da/dN vs. ΔK curve.

Fig.7 - SEM micrograph of a fracture surface corresponding to zone II
of the FCP curve.

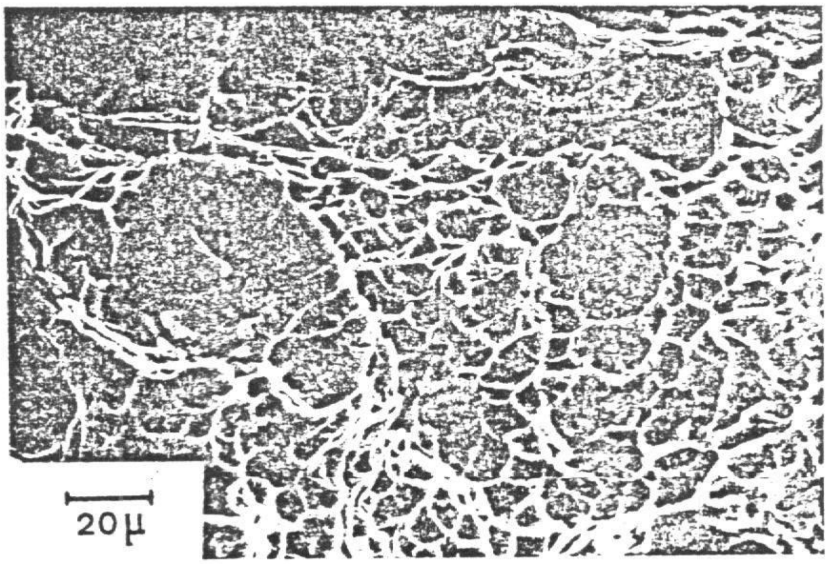

Fig.8 - SEM micrograph of a fracture surface corresponding to an overload
failure.