COMMISSARIAT A L'ENERGIE ATOMIQUE

CENTRE D'ETUDES NUCLEAIRES DE SACLAY
Service de Documentation
F91191 GIF SUR YVETTE CEDEX

CEA-CONF -- 9137

M2

HIGH CYCLE FATIGUE OF AUSTENITIC STAINLESS STEELS UNDER RANDOM LOADING

Gauthier, J.P.; Petrequin, P. CEA CEN Saclay, 91-Gif-sur-Yvette (France)
IRDI, DTech

Communication présentée à : Conference post-SMIRT. 6. International seminar on inelastic analysis and life prediction in high temperature environment
Paris (France)
24-25 Aug 1987

COMMISSARIAT A L'ENERGIE ATOMIQUE
CEA TECHNOLOGIE
DIVISION DE METALLURGIE ET D'ETUDES DES COMBUSTIBLES NUCLEAIRES

CONFERENCE POST SMIRT SIXTH INTERNATIONAL SEMINAR ON INELASTIC ANALYSIS AND LIFE PREDICTION IN HIGH TEMPERATURE ENVIRONMENT
PARIS - August 24-25 1987

FATIGUE A GRAND NOMBRE DE CYCLES D'ACIERS AUSTENITIQUES SOUS CHARGEMENT ALEATOIRE

Jean Pierre GAUTHIER, Pierre PETREQUIN

RESUME

Les matériaux utilisés pour les composants nucléaires peuvent être soumis à des chargements aléatoires dans plusieurs cas, par exemple :

. Fluctuations thermiques à l'interface eau-vapeur dans les G.V.

. Fluctuations thermiques superficielles résultant de flux de sodium liquide à différentes températures

Pour étudier l'influence de ce type de sollicitations sur les composants de réacteur, des essais de fatigue aléatoire en contrôle de charge ont été effectués à 300 et 550 °C sur des échantillons prélevés en sens travers dans des plaques d'aciers austénitiques inoxydables.

Les sollicitations aléatoires sont produites sur la boucle fermée d'une machine hydraulique asservie par un micro-ordinateur qui produit des séquences de charge aléatoire à l'aide d'une matrice réduite de Markov. Cette méthode présente l'avantage de tenir compte de la charge moyenne pour chaque cycle.

Les sollicitations produites sont celles d'un processus stationnaire gaussien. Les essais de fatigue ont été principalement effectués dans la zone d'endurance de la courbe de fatigue en mesurant la dispersion par la méthode de l'escalier.

Les résultats expérimentaux ont été analysés dans le but de déterminer des lois pour le dimensionnement des composants qui dépendent du facteur d'irrégularité et de la température. Une analyse en termes du calcul de la valeur quadratique moyenne de la limite de fatigue montre qu'un chargement aléatoire conduit à un endommagement plus important qu'un chargement d'amplitude constante.

Les calculs du dommage à l'aide de la règle de Miner ont été effectués en utilisant la fonction de densité de probabilité dans le cas où le facteur d'irrégularité est proche de 100 %.

La comparaison avec les données expérimentales montre que la règle de Miner est trop conservative pour nos résultats.

Une méthode utilisant des courbes de dimensionnement incluant les effets d'un chargement aléatoire avec comme paramètre d'interaction un facteur d'irrégularité est proposée.

CONFERENCE POST SMIRT SIXTH INTERNATIONAL SEMINAR ON INELASTIC ANALYSIS AND LIFE PREDICTION IN HIGH TEMPERATURE ENVIRONMENT

PARIS - August 24-25, 1987

HIGH CYCLE FATIGUE OF AUSTENITIC STAINLESS STEELS UNDER RANDOM LOADING

J.P. GAUTHIER, P. PETREQUIN

Centre d'Etudes Nucléaires de Saclay

91191 GIF-sur-YVETTE CEDEX - FRANCE -

SUMMARY

Materials used in nuclear components, may be subjected to random loading in several cases, for example :

- Thermal fluctuations of the steam-water interface in steam generators
- Surface thermal fluctuations resulting from liquid sodium streams having different temperatures.

To investigate the effect of such solicitations on reactor components, load control random fatigue tests were performed at 300 °C and 550 °C, on specimens from austenitic stainless steels plates in the transverse orientation. Random solicitations are produced on closed loop servo-hydraulic machines by a mini computer which generates random load sequence by the use of reduced Markovian matrix. The method has the advantage of taking into account the mean load for each cycle.

The solicitationsgenerated are those of a stationary gaussian process. Fatigue tests have been mainly performed in the endurance region of fatigue curve, with scattering determination using stair case method.

Experimental results have been analysed aiming at determining design curves for components calculations, depending on irregularity factor and temperature.

Analysis in term of mean square root fatigue limit calculation, shows that random loading gives more damage than constant amplitude loading.

Damage calculationsfollowing Miner rule have been made using the probability density function for the case where the irregularity factor is nearest to 100 %.

The comparaison with experimental data shows than Miner rule is too conservative for our results.

A method using design curves including random loading effects with irregularity factor as an indexing parameter is proposed.

HIGH CYCLE FATIGUE OF AUSTENITIC STAINLESS STEELS UNDER RANDOM LOADING

J.P. GAUTHIER, P. PETREQUIN
Centre d'Etudes Nucléaires de Saclay
91191 GIF-sur-YVETTE CEDEX - FRANCE -

I - INTRODUCTION

Materials used in nuclear components, are subjected to random loading in several cases, for example :

- thermal fluctuations of the steam-water interface in steam generators,
- surface thermal fluctuations resulting from liquid sodium streams having different temperatures (thermal striping).

To investigate the effect of such solicitations on reactor components, it appears useful to perform fatigue tests under random loading.

As a matter of fact, the rules employed in the codes are too conservative, since in order to avoid complicated damage calculations, they consider in their principle, only the maximum amplitudes of these solicitations.

To take into account the complexity of random solicitations, damage summation analysis, using simple rules (like Miner rule), are performed.

These rules are generally not reliable, in particular to estimate the effect of small amplitude cycles.

Consequently, random fatigue tests are necessary for validating the hypothesis that can be made for damage calculations, from the S-N curves (constant amplitude loading).

In order to minimize the effect of scattering in result analysis, as the choice of the reference S-N curve, has a great importance for damage calculations, it is useful to determine the S-N curves and random fatigue response on the same products.

In the general case, fatigue damage includes an initiation stage which is then followed by fatigue crack growth.

One can consider one or the other aspect depending on the material and on the component that one looks for.

The present study deals with the crack initiation problem.

We are presenting here two methods of analysis using random fatigue test results on an austenitic stainless steel.

- The first is based on the concept of design fatigue curves under random loading.
- The second is based on damage calculations using Miner's rule.

It is well known that many parameters can influence the fatigue endurance of materials :

- temperature
- mean stress
- surface roughness
- metallurgical properties
- etc...

This study presents a temperature effect (300 °C, 550 °C) and a product effect as the two different steels used here have different origins.

II - METHODOLOGY OF RANDOM FATIGUE TESTS

Most of the high cycle fatigue tests are run with constant amplitude under load control.

Fatigue tests under variable amplitude loading were known many years ago (specially in aeronautics), but the technical means employed have made them very specialized and have resulted in solicitations different to those actually observed in nuclear energy [1], [2], [3], [4].

Signifiant progress have been made through the introduction of closed loop servo-hydraulic machines, mini cimputers and also through new concept tools.

Old techniques did not allow one to obtain random mean stresses. The method employed here is derived from that used by Haibach and al [5] based on matrix representation of the load distribution versus time.

This method avoids most of the drawbacks of the old ones.

It is well employed today [6], [7], because of its general and standard character.

The execution of random fatigue tests includes several stages [8], [9], [10], briefly described here :

- pick-up and transmission of accurate informations on real solicitations [8].
- analysis of solicitation informations [9], [11], [12].
- simulation tests in laboratory [10].

As we showed before, we use in our case the simulation method based on transition matrix (Markov matrix).

This method deals with stationary gaussian process. Thus, it is necessary to verify that the actual solicitations are near to a gaussian process or can be approximated to a gaussian process.

There are only few informations available on the spectrum analysis on random loadings in nuclear plants because they are often difficult to perform. However some data available today (thermal fluctuation measurements) allow us to assume that the gaussian process hypothesis is reasonable and can be generalized to many cases of random solicitations in nuclear plants.

III - METHOD FOR PROVIDING RANDOM SOLICITATIONS : MARKOV MATRIX METHOD

The method is based on the distribution of frequency of successive minimum and maximum stress generation. The (random) fluctuation of mean stress can be defined by the value of the irregularity factor I.

$I = N_o/N_m$ with :
N_o = the number of mean level crossings with a positive slope
N_m = the number of peaks (or troughs).

The principal characteristics of the signal then provided are :

- gaussian type sequence : stationary gaussian process.
- sequence defined by $N_o = 10^6$ cycles = number of mean level crossings with a positive slope.
- number of peaks N_m (equal to the number of troughs) , depending on the irregularity factor $I = N_o/N_m$.
- maximum peak value : σ.
- total range of peaks divided into 32 intervals.
- stress interval value $k = 2/31\ \sigma$.

- ratio C of maximum peak value over RMS value . For a gaussian spectrum :

$$C = \sqrt{2 \, L_N \, No} \quad = \quad 5{,}25652 = \frac{\sigma}{\sigma_{RMS}}$$

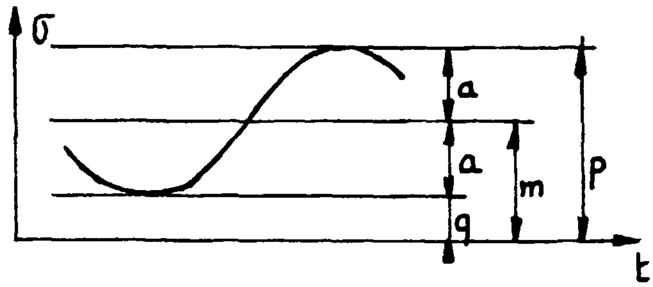
- probability density function :

$$h(m,a) = \frac{N_m}{\sqrt{2\pi \, \sigma_{RMS}^2 \, (1-I^2)}} \cdot Exp\left[\frac{-m^2}{2\,\sigma_{RMS}^2\,(1-I^2)}\right] \cdot \frac{a}{\sigma_{RMS}^2 \, I^2} \cdot Exp\left[\frac{-a^2}{2\,\sigma_{RMS}^2\, I^2}\right]$$

with :

m = mean stress

a = stress amplitude



Thus the signal with a gaussian spectrum, is fully defined by its frequency, its maximum stress value σ, its irregularity factor I.

IV - RANDOM FATIGUE TESTS WITH LOAD CONTROL AT 550 °C AND 300 °C ON AN AUSTENITIC STAINLESS STEEL TYPE 316 L (N)

IV.1 - Experimental details

IV.1.1 - Materials

Two materials have been employed. For the tests performed at 550 °C, an austenitic stainless steel type 316 L (N) with low carbon and controlled nitrogen content has been used. The product referred to material A is a plate 45 mm thick, slightly cold worked in bending.

For the tests performed at 300 °C, the steel is corresponding to the same specification type 316 L (N); the product referred to material B is a plate 26,5 mm thick. The chemical composition and the tensile properties are given in tables I and II.

One can observe that the material B presents a yield strength slightly lower than that of the material A (very likely a cold work effect), but an ultimate tensile stress slightly higher; consequently it presents a higher work hardening coefficient.

IV.1.2 - Specimen

The specimens used were hourglass specimens with a diameter of 10 mm for material A, and a diameter of 8 mm for material B.

They have been cut at half thickness of the plates, perpendicular to the major rolling direction.

IV.1.3 - Experimental device

Tests have been performed on a MTS servohydraulic fatigue machine of 10 tons , controlled by a mini computer PDP 11/04. A view of the installation is shown on figure 1.

Details of the device used to perform high temperature fatigue tests are shown in figure 2.

The software used, provides random signal by means of the SRFFT program based on Markov matrix, as described previously.

Tests can be performed using 3 irregularity factors : I = 30 %, I = 70 %, I = 99 %. Examples of random signals recorded and applied to specimen are shown on figure 3.

IV.2 - Experimental results

IV.2.1 - Object

The experimental work aims at determining the random fatigue S-N curves relative to 3 irregularity factors : I = 30 %, 70 % and 99 %.

This enables one to obtain directly or by interpolation, fatigue data under random solicitations, corresponding to a great variety of gaussian spectrums that can be found.

Because of the scattering of the fatigue life times for high cycle fatigue, one needs to use statistical methods to establish these curves :

- In the endurance region : the stair case method is used to determine fatigue limit (50 % probability failure), using at least 10 specimens.

- In the non endurance region : the Henry's straight line method is used to determine N_σ such as 50 % of specimens are failed for $N < N_\sigma$ for 2 or 3 stress levels, using at least 10 specimens by level. The total programme needs a great number of tests, but when some reference curves have been established, it allows to study the effect of several parameters on fatigue with a smaller supplementary number of tests. The data available, presently, deal with endurance region.

IV.2.2 - Tests at 550 °C (material A)

Fatigue limits have been determined at 5.10^6 cycles, for I = 30 % and 70 %, in the following conditions :

- cycle number = 5.10^6
- load control
- mean stress = 0 (spectrum set on 0 mean stress)
- frequency = 20 or 40 HZ
- step variation = 15 MPa

The stress here considered is the maximum stress of the spectrum.

The results are :

$\sigma_{D\ (max)}$ = 367 MPa for I = 30 % (13 specimens)
$\sigma_{D\ (max)}$ = 325 MPa for I = 70 % (15 specimens)

<u>Remark</u> :

In this paper, we always use the concept of random fatigue limit (at 5.10^6 cycles), but in fact, this value is only a conventionnal fatigue limit, because, as shown by some researchers [7], the actual fatigue limit in random loading is obtained only for a very high number of cycles, as only some cycles reach the maximum value, whereas, for constant amplitude fatigue, the endurance limit is reached near 5.10^6 cycles for this steel.

IV.2.3 - Temperature effect (tests at 300 °C on material B) and steel origin effect

Beginning of stair-cases have only been performed in a first time, to examine if there is an evident effect of temperature between 300 °C and 550 °C.

Tests have been performed in the same conditions as for 550 °C (except the frequency is always 40 HZ), for I = 30 %, 70 % and 99 %.

The "estimated" values of random fatigue limits are :

$\sigma_{D\ (max)} \simeq$ 387 MPa for I = 30 % (6 specimens)
$\sigma_{D\ (max)} \simeq$ 308 MPa for I = 70 % (6 specimens)
$\sigma_{D\ (max)} \simeq$ 287 MPa for I = 99 % (6 specimens)

IV.3 - Results analysis, discussion

Random fatigue limits ($\sigma_{D\ max}$), versus irregularity factors, at 550 °C (material A) and at 300 °C (material B), have been brought in a diagram (Figure 4).

Fatigue limits σ'_D related to fatigue tests under constant amplitude loading (I = 100 %), at 550 °C (materials A and B) and 300 °C (material B), have also been indicated, as well as the ultimate tensile stresses R_m (which can be assumed to be the endurance limit for I = 0 %, in absence of creep), at 550 °C (materials A and B) and at 300 °C (material B) (Table III).

1°) It seems reasonable to use a linear relationship to fit the data of $\sigma_{D\ max}$ against I, including R_m (I = 0).

However, as there are no random fatigue tests for I = 100 % at 550 °C (material A) and as there are only a moderate number of tests at 300 °C (material B), this relationship has to be confirmed by other tests.

2°) This relationship being drawn in the diagram, one can make some comments. By extrapolation, for I = 99 %, it is found that the random fatigue limit $\sigma_{D\ max}$ for material A, is fairly higher at 550 °C than for material B at 300 °C. The same behaviour is observed for fatigue tests under constant amplitude loading : the fatigue limit σ'_D for material A is higher at 550 °C than at 300 °C for material B.

One can be surprised by this result, but one can make some remarks :

- the ratio of fatigue limit over yield stress $\sigma'_D/R_{p\ 0,2}$ is increasing with temperature.

- in other hand, the yield stress is decreasing with temperature and material A has a higher yield stress than material B.

So the conjunction of these two phenomena can explain that the endurance limit for material A at 550 °C could be higher than that of material B at 300 °C.

3°) The results show that there is a correlation between random fatigue limit and the ultimate tensile stress for the low values of the irregularity factor. This explains why the random fatigue limit at 300 °C is higher than that at 550 °C for I = 30 %.

The relationships between the random fatigue limit and the irregularity factor are :

T = 550 °C (material A): $\sigma_{D\ max}$ (MPa) = - 1,25 I (%) + 410

T = 300 °C (material B): $\sigma_{D\ max}$ (MPa) = - 1,80 I (%) + 450

4°) The whole results show that the knowledge of the random fatigue limit for one value of irregularity factor and the knowledge of the tensile curve seem to be a good guide to determine random fatigue limit versus irregularity factor, following the relationship : $\sigma_{D\ max} = - \alpha I + R_m$.

5°) Comparison between random fatigue results and constant amplitude fatigue results :

Comparison can be made by means of the RMS value, for I = 99 % (Figure 5), (table III), dealing with the relationships :

$\sigma_{D\ RMS} = \sigma_{D\ max} / 5,256$ (random fatigue)

$\sigma'_{D\ RMS} = \sigma'_D / \sqrt{2}$ (fatigue under constant amplitude loading).

It can be seen, that random fatigue gives more damage than fatigue under constant amplitude stress, considering the RMS value.

The relationships obtained for the RMS value versus irregularity factor are :

σ_{DRMS} (MPa) = - 0,237 I (%) + 76,0 at 550 °C

σ_{DRMS} (MPa) = - 0,342 I (%) + 85,7 at 300 °C.

V - USE OF RANDOM FATIGUE DATA FOR DESIGN METHODS

Two methods can be used :

V.1 - Determination of design-curves under random fatigue.

A method similar to that used for constant amplitude solicitations, can be used. The design curve σ_{max} - N under random loading, is deduced from an experimental mean curve σ_{max} - N corresponding to a probability of failure = 50 %.

But here, the stress used is the maximum stress of a stationary gaussian process and it deals with a given irregularity factor.

In practice, 3 experimental mean curves can be determined, corresponding to 3 irregularity factors : I = 30 %, I = 70 %, and I = 99 %, allowing by interpolation the evaluation of all other values of I.

In this study complete random fatigue curves are not yet available, the method is applied to fatigue data obtained in the endurance region (5.10^6 cycles). Thus the relationship $\sigma_{D\ max}$ = f (I) (Figure 4) is here considered.

Data used are those corresponding to material B at 300 °C.

The design curve deduced from the results by dividing the stress by a factor of 2, is :

$\sigma_{D\ design}$ (MPa) = - 0,90 I (%) + 225 (Figure 4)

The similar relationship using the RMS value instead of the maximum stress is :

$\sigma_{RMS\ design}$ (MPa) = - 0,171 I (%) + 42,8 (Figure 5).

V.2 - Fatigue life prediction by damage calculation

1°) Hypothesis

A damage calculation can be made to predict random fatigue life from data provided by high cycle fatigue tests under constant amplitude loading. When statistic characteristics of the given random solicitation are known, it is possible to deduce the damage value by an analytical calculation, using Miner rule for example.

This damage is estimated from the probability density function of the solicitation by the relationship [13] :

$$D = N_e \int_o^\infty \frac{f_s\ (S_i)}{N_i}\ d\ S_i$$

with :

N_e = number of cycles executed

$f_s\ (S_i)$ = probability density function

N_i = number of cycles corresponding to failure at S_i constant amplitude. If the following conditions are verified :

- gaussian process
- overall mean stress = 0
- I = 100 % ,

using the relationships between S_i and N_i given by S-N curves (fatigue under constant amplitude loading) :

$S_i = c'_f\ N_i^{\ b}$ (1),

one can deduce the S-N curve corresponding to random signal :

$\sigma_{RMS} = C'\ N_T^{\ b}$ (2)

with :

$$C' = \left(\frac{\sigma'_f}{\sqrt{2}}\right) \left(\frac{1}{\Gamma\left(\frac{2+\beta}{2}\right)}\right)^{1/\beta}$$

with :

$\beta = -\frac{1}{b}$ and Γ = gamma function

2°) Application to experimental results of this study

The fatigue limit under random loading $\sigma_{D\ max}$ can be predicted at 5.10^6 cycles using the relationship :

$\sigma_{D\ max} = 5,256\ \sigma_{RMS}$,

σ_{RMS} being deduced from the relationship (2) ($N_T = 5.10^6$ cycles).

$\sigma_{D\ max}$ is corresponding to a probability failure = 50 %, and can be compared to the experimental value of the staircase at 5.10^6 cycles.

For this calculation one needsthe value of σ'_f and b of the S-N curves corresponding to fatigue under constant amplitude loading.

The equations of the S-N curves are :

At 300 °C (material B) : $S = 286,6\ N^{-0,029}$

At 550 °C (material A) : $S = 307,7\ N^{-0,026}$

The calculation gives :

$\sigma_{D\ max}$ (predicted) = 252 MPa at 300 °C

$\sigma_{D\ max}$ (predicted) = 270 MPa at 550 °C

The comparison of predicted and experimental valules, shows that Miner rule provides fatigue limits slighytly lower than experimental values (Figure 4). This has been found by other researchers [7].

To make the damage calculation easier, the commun practice is to choice an equation of the type $\sigma = \sigma'_f\ N^b$, to represent the S-N curve (fatigue under constant amplitude loading).

This is a simplified approach because the fatigue limit exists.

The results of this study suggest that an equation type :

$\sigma - \sigma'_D = \sigma'_f\ N^b$ (giving a better correlation coefficient) should be used.

VI - CONCLUSION

Two methods have been presented to use data given by fatigue under random loading.

The first, by an analog method as those of the existing codes, provides design curves depending on the irregularity factor value.

The results only available in the endurance region, show that the effect of irregularity factor on the random fatigue limit, for a gaussian process, can be described by the fomulae :

$$\sigma_{D\ max} = - \alpha\ I + R_m$$

So the random fatigue limit for large band spectra (low values of I), should be controlled by the ultimate tensile stress R_m, whereas a correlation exists between random fatigue limit and the yield stress for narrow band spectra (large values of I).

The second approach develops a damage calculation using the probability density function of the spectrum and the Miner rule, to predict fatigue lives. The results obtained by this method seem to lead to conservative values of random fatigue limits.

REFERENCES

[1] Z. TAHHAN
Essais de fatigue par la méthode des "blocs programmes"
INSA - Thèse 1979

[2] M.P. LIEURADE
Etude du comportement en fatigue à programme d'assemblages soudés en croix en acier E 24 et E 36 (E 355)
IRSID - RE 231 - 29.10.1974

[3] Fatigue crack growth under spectrum loads
ASTM STP 595 - 1976

[4] Effect of load spectrum variables on fatigue crack initiation and propagation
ASTM - STP - 714 - 1979

[5] E. HAIBACH, R. FISHER, W. SCHUTZ, M. HUCK
Standard random load sequence of gaussian type recommended for general application in fatigue testing; its mathematical background and digital generation.
Intern. Conf. on "fatigue testing and design" - Londres - 4/1976

[6] F. SHERRAT and B.C. FISHER
Extracting fatigue testing and design data from service loading records
J.B.C.S.A. Conference 1972

[7] S.E. STANZL, E.K. TSCHEGG and H. MAYER
Lifetime measurements for random loading in the very high cycle fatigue range
Int. Jl of fatigue, october 1986, p. 195

[8] H.P. LIEURADE
Les essais de fatigue à programme
IRSID RE 188 - Avril 1974

[9] Méthodes d'analyses et de simulation en laboratoire
des sollicitations de service
SFM Groupe de travail IV "Fatigue à programme"
CETIM - SENLIS - 6 mai 1982

[10] C. MAILLARD SALIN, H.P. LIEURADE
Les essais de fatigue sous sollicitations d'amplitude variable
MSRM - Novembre 1982 - p. 617

[11] R. GREGOIRE
Analyse des sollicitations de service
MESRM - Novembre 1982 - p. 581

[12] M. HORSTMANN
Dépouillement statique des mesures de déformation en service
Revue pratique de contrôle industriel
Octobre, Novembre, 1973 - p. 13

[13] Y.S. SHIN
Prediction of random high cycle fatigue life of LWR components
Trans. of the ASME - Vol. 102, November 1980, p. 378

		C	Mn	Si	S	P	Ni	Cr	Mo	Co	Cu	Ta	N_2	B
Plate 45mm Thick Material A	Cast	0.022	1.71	0.28	0.007	0.030	12.5	17.31	2.53	0.16	0.17	< 0.05	0.071	0.0031
Plate 26.5mm Thick Material B	Cast	0.020	1.74	0.48	0.003	0.027	12.35	17.91	2.32	0.14	0.37	< 0.05	0.07	15ppm

TABLE I - Steels composition

	Test temperature (°C)	Yield strength (MPa)	UTS (MPa)	Uniform elongation (%)	Total elongation (%)	Reduction of area (%)
Material A Plate 45mm thick (cut 1/4 thickness)	20	300	581	48	63	83
		290	579	53	65	75
	550	151	410	32	43	60
		157	416	36	47	59
Material B Plate 26.5mm thick	20	275	586	52	64	85
		274	589	52	64	83
	300	174	462	39	50	76
		173	462	36	47	75
	550	146	426	39	47	75
		147	432	38	47	73

TABLE II - Tensile properties of steels tested. Transverse orientation

			I %				
		T (°C)	0	30	70	99	100
Fatigue limit under random loading σ_D max (MPa)	Material A	550°C		367 [69.8]	325 [61.8]		
	Material B	550°C					
		300°C		387 [73.6]	308 [58.6]	287 [54.6]	
Fatigue limit under constant amplitude stress σ_D' (MPa)	Material A	550°C					207 * [146]
	Material B	550°C					183.5 [129]
		300°C					173.5 [122]
Ultimate tensile stress Rm (MPa)	Material A	550°C	413				
	Material B	550°C	429				
		300°C	462				

* (10^7 cycles)

[ ] $\sigma_{DRMS} = \sigma_D \max / 5.256$

$\sigma_{D'RMS} = \sigma'_D / \sqrt{2}$

TABLE III - 316 L (N) steel. Results of fatigue tests under random loading at 5.10^6 cycles.

T (°C)	Material	σ'_D * (MPa)	Rp 0.2 (MPa)	σ'_D/Rp 0.2
20	A	260	295	0.88
	B		275	
300	A			
	B	173.5	173	≃ 1
550	A	207	154	1.34
	B	183.5	146	1.25

* at 5.10[6] cycles

TABLE IV - 316 L (N) steel. High cycle fatigue under constant amplitude loading.

FIG. 1 - General view of the installation for high cycle fatigue under constant amplitude or random loading.

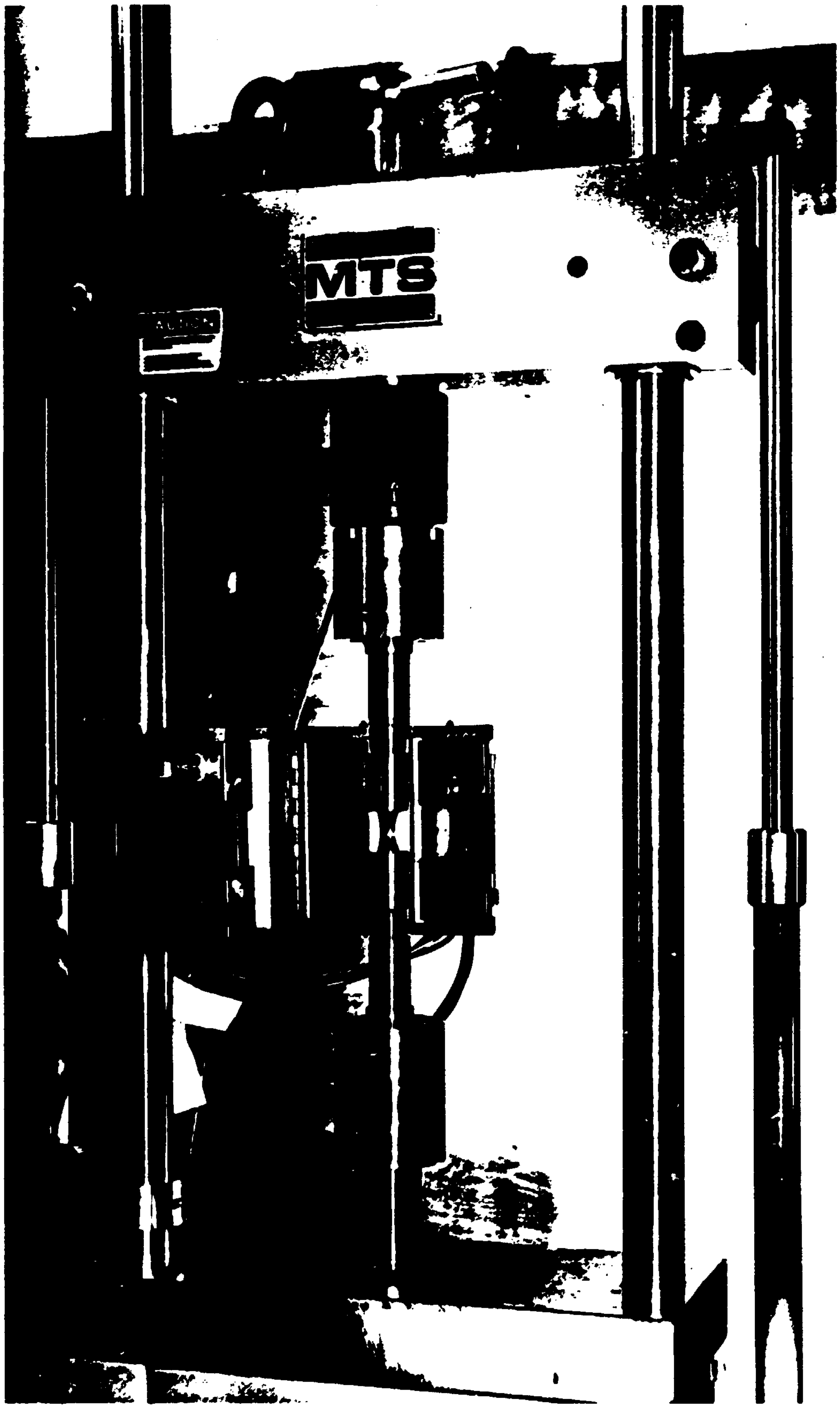
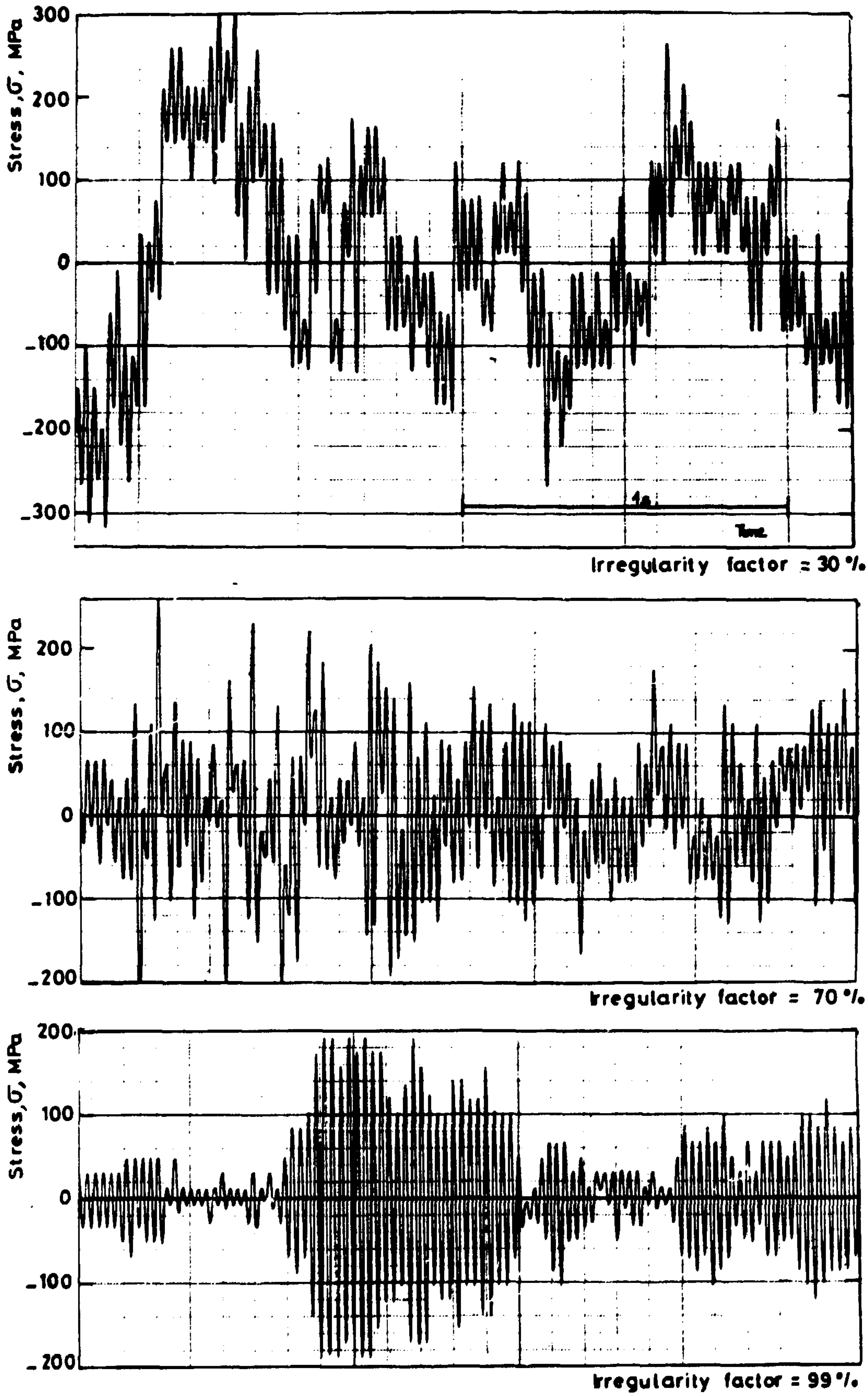
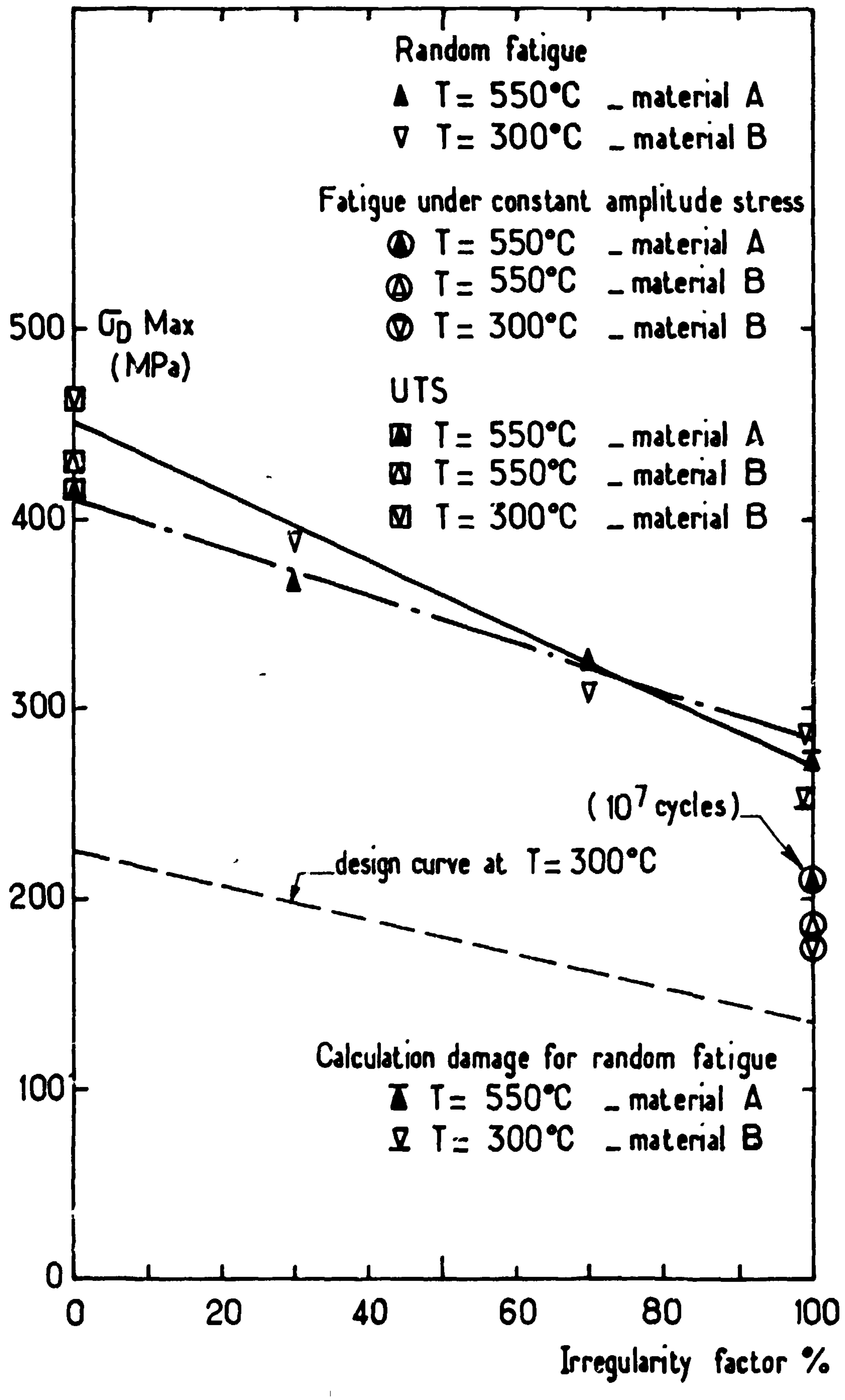


FIG. 2 - Fatigue testing machine for high temperature tests. Hourglass specimen attached to its grips.

GAUTHIER JP - FIG 3 - SCALE 1



GAUTHIER J.P. - FIG. 4 - SCALE : 2/1



GAUTHIER JP_ FIG. 5 - SCALE : 2/1