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The probability density of stress intensity factor in S355 Steel

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Abstract: *In many industrial fields, such as aircraft industry, automotive or under pressure reservoirs… pieces and organs ar subjected to different types of solicitations; thermic, mechanic or even cyclical load. This type of cyclical loads causes a progressive degradation of material's characteristics, leading thereafter to a brutal rupture; it is the fatigue phenomenon. The work presented in this paper is a contribution to the characterisation of the fatigue dammage risks, and the evolution of cracking mechanisms under cyclical load of a S355 steel piece used for under pressure reservoirs, having as crucial aim, the study of the stress intensity factor and giving a contribution to the determination of the stress intensity alert factor, which usually precedes the sudden rupture of a component, in order to estimate the life expectancy more precisly, based on a probabilistic method using the Weibull distribution*.

Keywords- *Fatigue crack initiation, Weibull distribution, Life expectancy*.

I. INTRODUCTION

Among the causes of service failures, the most common ones are due to fatigue of parts under the action of progressive loads or deformation, which lasted until the remaining cross section can no longer sustain the applied force. This causes the sharp break and can cause several accidents. Therefore, since we know the existence of these progressive cracking, we studied the propagation of fatigue cracks, to prevent accidental breakage.

The cyclic stresses applied to a mechanical part result in the appearance of localized damage in a zone of stress concentration [1], and the structural resistance of the part decreases continuously during the solicitation. This decrease is even higher than the number of cycles increases. Indeed, the damage is an irreversible physical process due to the presence of defects in the material [2]. The problem of stress concentration can be very important [3]. The stress concentration in a part depends on the quantity, size, nature, and the distribution of defects or inclusions in the material, and their forms in relation to the direction of stress [4]. The general experience shows that the crack initiation results from the concentration of plastic deformation that occurs in a small field of finite dimension [5]. Our mean goal is to study the stress concentration in a notched piece of S355steel. We are particularly interested by the determination of alert critical stress intensity factor, which spread beyond the brutal of a fatigue crack originates.

I. Materials and Methods

II.1 MATERIAL

The material used in our test program is S355 steel, whose chemical composition is reported in Table 1.

Table1: Chemical composition of steel S355

	Composition (%)					
S355	**C**	**Mn**	**P**	**S**	**Si**	**Cu**
	0,29	0,80-1,20	0,09	0,05	0,15-0,30	0,20

Static tensile tests were conducted on smooth specimens, the results reported in Table 2 give the mechanical characteristics of the S355 steel.

Table 2: Mechanical properties of steel S355

Specification	**Properties**		
S355	**σ_u (Mpa)**	**σ_e (Mpa)**	**E (Gpa)**
	621	**372**	**200**

II.2.TEST TUBE

The tests were conducted on flat test doubly notched whose dimensions are shown in Figure 1 below.

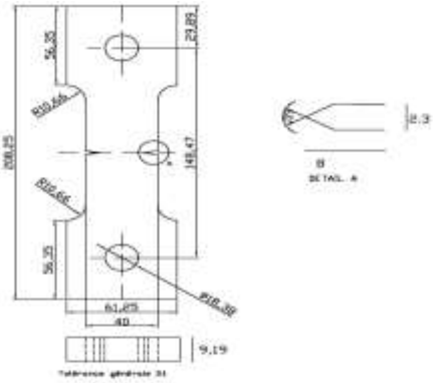

Fig 1: Dimensions of the test tube (mm).

II.3. Test to Determine the Lifetime to Failure.

Fatigue tests with constant amplitude were performed on samples of S355, under different stress levels; 352, 282 and 248 MPa. These tests aim to determine the number of cycles to failure (N_f) [6].

II.4. Stress Intensity Factor

The stress intensity factor is calculated from the following equation [10].

$$\Delta K = 1{,}12 \Delta\sigma (\Pi a)^{0,5} * f$$

With

$$f = 2/\Pi * b/a * tg(\Pi/2 * a/b))^{0,5}$$

ΔK: Stress intensity gap; (K_{Imax} - K_{IMIN}) in MPa √ m.

$\Delta\sigma$: cyclic of stress gap; (σ_{max}-σ_{min}).

a: crack length in mm.

f: correction factor taking account of the crack length a and b the width of the specimen (b in mm).

II. Results and Discussion

III.1. the Probability Density Function Of Stress Intensity Factor

The Weibull distribution [7] is suitable to model structures with a large number of small defects. It was first used in the study of material fatigue. It was very useful in studying the distributions of failure of vacuum tubes and is currently an almost universal use in reliability [8].

A continuous random variable x is distributed according to the Weibull distribution when its probability density function is characterized by:

$$\mathbf{f(x)} = \frac{\beta}{\eta} . \left(\frac{x-\gamma}{\eta}\right)^{\beta-1} \exp\left[-\frac{x-\gamma}{\eta}\right]^{\beta} \quad \textbf{(1)}$$

With

γ = origin offset,

β =shape parameter,

η = scale parameter.

Its distribution function is expressed by:

$$\mathbf{F(x)} = 1 - \exp\left[-\frac{x-\gamma}{\eta}\right]^{\beta} \quad \textbf{(2)}$$

From (1), Marshal [9] demonstrated that the probability density of the rupture is depending on the stress intensity factor

$$f(K)_K = \frac{2K}{K_m^2} e^{-\left(\frac{K}{K_m}\right)^2} \quad (3)$$

Where $K_m = \alpha \Delta\sigma \sqrt{\pi a_m}$
$\Delta\sigma$: variation of the applied stress
K_m: stress intensity factor y

The calculations for S355 steel were made from the relation (3). We give a representation in Figure 3.

The results given in Figure 2 show the probability densities calculated for the three parameters in crack length.

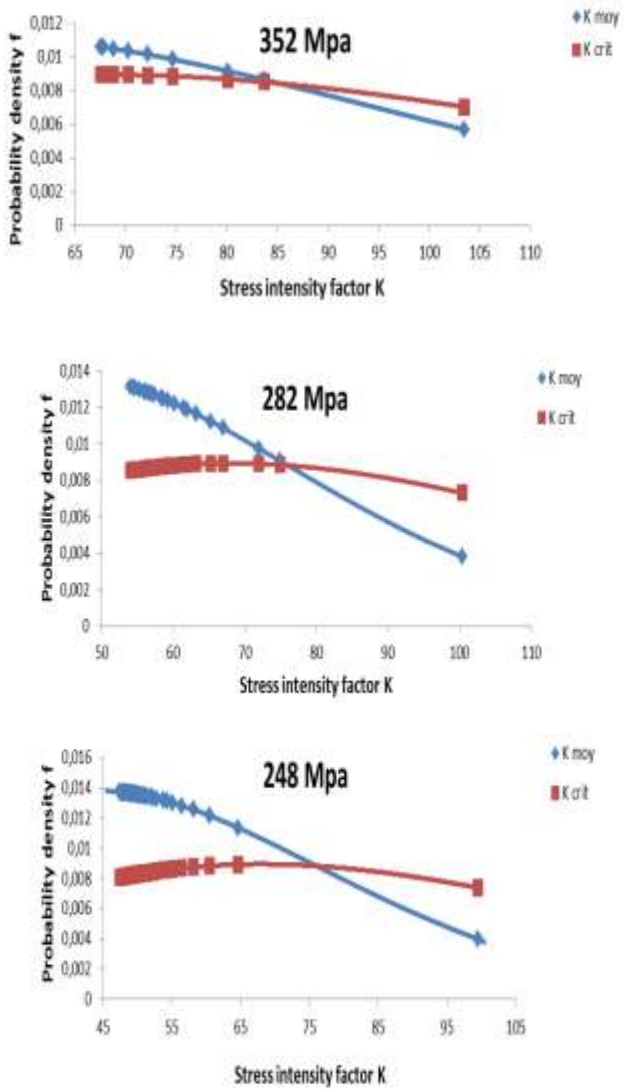

Figure 2: The probability density function for the stress intensity factor for three stress levels $\Delta\sigma$ = 352MPa, 282MPa, 248MPa.

The probability density to the rupture of the specimen calculated with the mean stress intensity factor K_{moy} significantly decreases gradually as K increases, while that with K_{crit} remains almost constant up to values close $K_{rupture}$ where we notice a slight decrease. On the other hand, the two curves are cut to a value of stress intensity factor that we named K_{alerte} (stress intensity factor Alert) from which the sudden propagation of the crack take place, the K_{alerte} becomes important by increasing the applied load.
We also note that the curve representing the probability density is narrowed when the applied stress increases (see Figure 2).

III.2. COMPARISON OF PROBABILITY DENSITIES

We represent a comparison between the different values of the probability density for the three applied loads, and for two parameters namely K_{moy}, K_{crit}

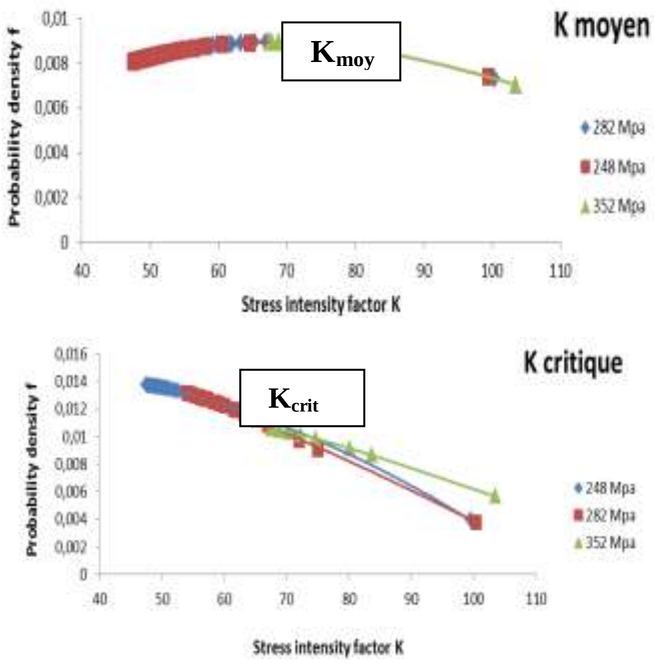

Figure 3: probability density as a function of stress intensity factor for three stress levels Δσ = 352MPa, 282MPa, 248MPa

For the average critical (the probability density calculated with the critical crack length) the shape of the curve follows the value of the amplitude of the load, ie of a probability density corresponds to a significant large amplitude, but, the three curves converge them at the end of life cycle of the part. This is because the calculated values of the probability density are taken from the critical crack length at which the sudden propagation of the crack arises.

Contrariwise the curves given by the probability densities calculated from the average crack length and initation are confused no matter the load, it seems normal because there we work beyond the stage III, in an area where the crack propagation is controllable.

III. CONCLUSION

Our results show that we can neglect the propagation phase when we are conducting tests with a large number of cycle. Our results show that when the defect size approaches a critical value, the probability of rupture depends on the level of applied load, on the other side, this probability is independent of load level values as low as the default in phase of slow initiation or propagation.

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