Bulletin of the *Transilvania* University of Braкov ÅVol. 9 (58) No. 2 - Special Issue ï 2016
Series I: Engineering Sciences

THE INFLUENCE OF SUPERFICIAL LAYER PARAMETERS ON FATIGUE STRENGTH

V. MEREUȚĂ[1] S. CIORTAN [1]

Abstract: *In this paper, was studied the evolution of roughness surface finish and the Vickers micro hardness, for S355JR steel grade samples, under a constant amplitude fatigue loading. Several bending fatigue tests were carried out using flat specimens. This paper is aimed the appreciation of the metallic surface integrity evolution subjected to the fatigue processes on the basis of the links between the surface roughness evolution, as geometrical aspect, and the micro hardness evolution as physical aspect.*

Key words: *surface roughness, micro hardness,* $\sqrt{area_R}$ *parameter, fatigue.*

1. Introduction

The quality of the surfaces of the mechanical structures as a parameter of their integrity, resulted after the processing, plays an important role in determining the behavior to variable loads [1]. The deterioration process by fatigue takes place by the initiation and the evolution of the cracks having as primary source the parameters that characterize the integrity of the surfaces.

The experimental researches [2], [3], [4] have shown that during the fatigue process the surfaces modify their integrity state following the evolution of the parameters that define it.

The cracks made by fatigue are initiated, mainly, in the superficial layer of the material, the integrity of the surface having a considerable influence on this process. The structural discontinuities, such as: micro cavities, cuts, (such as it may be considered the roughness) can be considered as prime of the fatigue cracks [5].

As it was shown, in the process of the variable loads, the irregularities of the surfaces do not remain at the constant value resulted following the processing, evolving together with the number of the solicitation cycles, until a value at which these lead to a high degree of concentration of the tensions, from which starts the process of evolution of the fatigue crack [6].

On the basis of the fact that the surface defects can be considered primes of the initiation of the fatigue cracks, the studies of Murakami and others [7÷10] have shown that the resistance limit to fatigue can be determined mathematically.

So the relation that allows the determination of the fatigue strength has the form:

[1] ñDunŁrea de Josò, University of GalaŞi.

$$\sigma_w = \frac{1{,}43(MH_V + 120)}{\left(\sqrt{area}\right)^{1/6}} \qquad (1)$$

where,

MH_V - is the Vickers micro hardness;

$\sqrt{area}$ - the parameter defined as the size of the defect is projected on the perpendicular plan on the application direction of the load.

It must be seen the fact that the equation (1) can be used for steels, as well as for other materials, such as copper and aluminum, being variable in the case of the surface defects. For the internal defects the coefficient 1,43 must be replaced with the value 1,56. The validity of the equation proved to be a series of Vickers micro hardness (HV), comprised between 70 MPa and 720 MPa.

Murakami modified then the equation (1), so that the roughness parameters can be used at the determination of the fatigue resistance, so the micro geometry of the surface can be considered as a surface defect [10]. So it was elaborated an equivalent equation that will take into account the amplitude parameters of the roughness R_y and R_p resulting the equations (2) and (3).

For, $\frac{a}{2b} < 0{,}195$:

$$\frac{\sqrt{area_R}}{2b} \cong 2{,}97\left(\frac{a}{2b}\right) - 3{,}51\left(\frac{a}{2b}\right)^2 - 9{,}47\left(\frac{a}{2b}\right)^3. \qquad (2)$$

For, $3 > \frac{a}{2b} > 0{,}195$:

$$\frac{\sqrt{area_R}}{2b} \cong 0{,}38, \qquad (3)$$

where,

a - is the roughness parameter R_y, defined as the maximum depth of the roughness;

b - represented by the amplitude R_p, defined as the distance from the top of the roughness to the median line.

In this paper the model Murakami will be used in the evaluation of the evolution of the resistance to instant fatigue, considering the roughness as evolution surface defect during the fatigue process.

2. Experimental determinations and materials

Experimental tests followed roughness parameters evolution and the micro hardness evolution during the variable loads.

Bending fatigue tests were carried out using a flat specimen (Figure 1) of steel grade S355JR, with the following mechanical characteristics presented in Table1(mechanical properties of grade S355JR)

Table 1

Minimum yield strength (MPa)	Tensile strength (MPa)	Minimum elongation [%]
Nominal thickness <16 (mm)		
355	470-630	22

The surfaces of the flat specimens were processed at three values of roughness (R1 ï Ra = 0,05÷0,1µm, R2 ï Ra = 0,2÷0,3µm, R3 ï Ra = 1,0÷2,0µm). The flat cantilever samples were subjected to plane bending fatigue loading

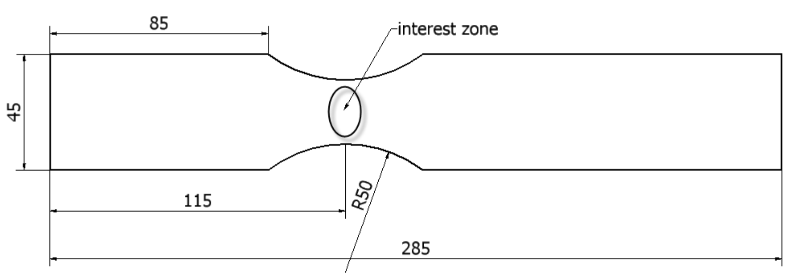


Fig. 1. *Dimension of plate specimen*

During the tests for the three levels of roughness and three levels of symmetrical variable loads was registered the time evolution of roughness parameters.

Determination of the roughness parameters evolution was performed using Profilometer PRO500 3D (with stylus), assisted by a dedicated soft SPIP (The Scanning Probe Image Processor).

The surface roughnesses, of all steel plates, were measured for all the three kinds of surfaces in the three points, because a single 3D measurement with Profilometer PRO500 is not sufficient for qualifying the surface quality. There were investigated a maximum areas of 500εm x 500εm with PRO 500, all records have been done with 100 point on each line. Measurements were made for evolution in time of the roughness parameters Sy, Sp .

In order to study this type of behavior, at three levels of load cycles $N1=9x10^4$, $N2 =1.3x10^5$, $N3 =1.8x10^5$, were made experimental determinations of micro hardness on flat specimens (Figure 1), using a Vickers Hardness Tester.

Three measurements were done, the average values obtained are considered as micro hardness of each tested sample. The minimum distance between the centers of the measuring points was approximately three times the value of the diagonal of the impression, in order to avoid any influence of the previous measurements.

The micro hardness value was calculated with the relation [11]

$$MH_V = 1{,}854 \cdot \left(\frac{F}{d^2} \right) \tag{4}$$

where,
MH_V is the Vickers micro hardness;
F is the applied load and d is the diagonal length of the indentation.

3. Results and discussion

On the basis of the above mentioned reasons, regarding the behavior to fatigue considering the roughness as surface defect, it was followed the establishment of the influence degree of the factors that determine the evolution of the resistance to instant fatigue, in the conditions of some different processing levels of the variably load surface.

For the improvement of the Murakami model, which used the 2D roughness parameters, the 3D roughness amplitude parameters were used.

It was proposed the use of the 3D roughness amplitude parameters because these parameters offer a better characterization of the surface in comparison to the 2D ones [12], offering more precise information about the local state of the micro geometry of the surface.

In this paper, the determination of the roughness amplitude parameters has been made all time during the try.

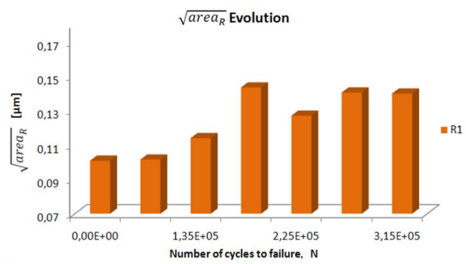
It was seen that the report $a/2b$ is between the interval 0,193÷3, which leads to the fact that the parameter $\sqrt{area}$ will be calculated with the relation [10]

$$\sqrt{area} = 0{,}38 \cdot 2b \tag{5}$$

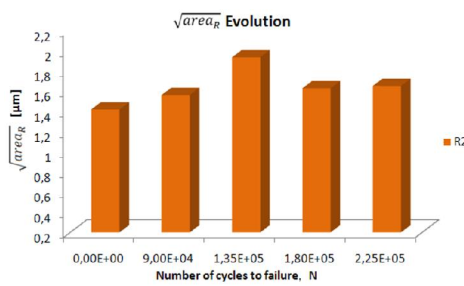
where $2b$ represent the roughness amplitude parameter S_p.

On the basis of the experimental values it was followed the evolution of the parameter $\sqrt{area_R}$ (Figure 2), for all the three roughness levels. From the analysis of the experimental data it can be seen the fact that the parameter $\sqrt{area_R}$ evolves together with the solicitation duration and with the roughness level. It can be seen that no matter the roughness level this parameter keeps the same character of the evolution.

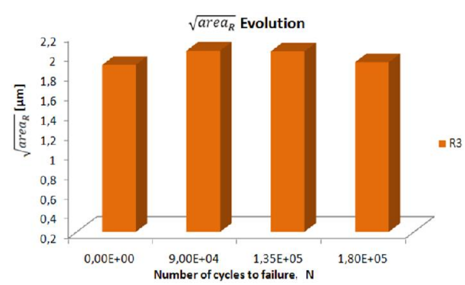
The parameter $\sqrt{area_R}$ has an evolution route together with the solicitation duration, reaching a maximum value followed by a decrease of this value. It is seen the fact that the number of cycles at which the maximum value is recorded varies according to the sample processing level. Together with the increase of the processing level the number of cycles until the reach of the maximum value, is higher.



a)



b)



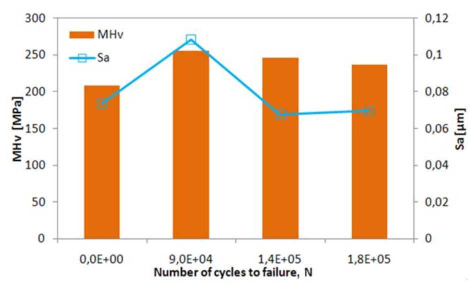
c)

Fig. 2. *Evolution of* $\sqrt{area}$ *and* S_a*, S=345MPa: a) R1 roughness, b) R2 roughness, c) R3 roughness*

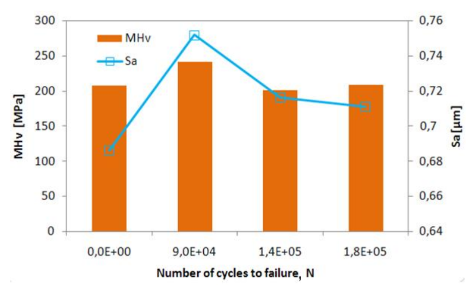
Regarding the micro hardness of the superficial layer, it was recorded an evolution of it, during the variable load, for the three processing levels of the specimen samples.

High values are recorded together with the increase of the finishing level of the surface, following the cold straining process which takes place during mechanic processing.

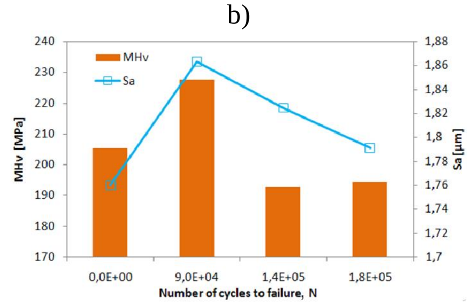
In figure 3 it is presented the micro hardness evolution according to the numbers of load cycles for the three processing levels of the specimen samples surfaces (R1, R2 and R3).



a)



b)



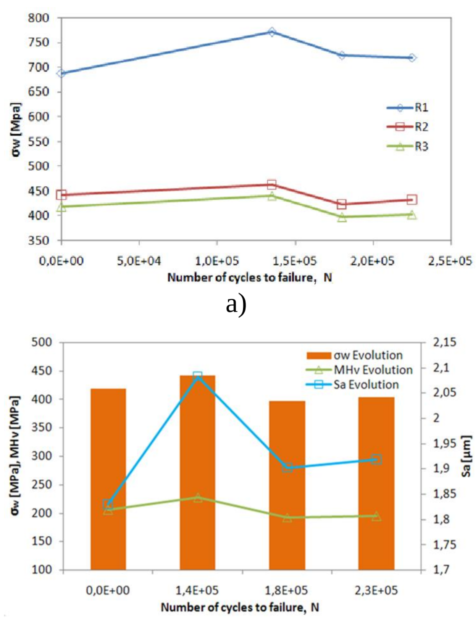
c)

Fig. 3. *Vickers micro hardness evolution: a) R1 roughness, b) R2 roughness, c) R3 roughness*

According to the relation of Murakami, the evolution of the parameters $\sqrt{area_R}$ and MH_V during the solicitation leads to the instant modification of the resistance limit to fatigue.

So, in figure 4 it is presented the evolution of these characteristics for the three roughness levels, at the load level, S2=450MPa.

It is seen, (Figure 4), a fluctuation in the evolution of the resistance limit to fatigue, according to the roughness level, the highest resistance to fatigue, being as it was expected, at the lowest roughness (high degree of finishing of the surface).



a) b)

Fig. 4. *The evolution of the fatigue limit: a) R1, R2, R3, roughness b) S_a and MH_V influence (R3 roughness)*

Regarding the share of the influence of the parameters $\sqrt{area_R}$ and MH_V, on the evolution of the instant resistance to fatigue it is seed (figure 3.b) that for the same level of roughness the parameter $\sqrt{area_R}$ has a higher influence comparatively to the influence of the micro hardness. It was seen that the influence degree of the parameter $\sqrt{area_R}$ increases together with the increase in the level of the roughness.

3. Conclusion

The use of the 3D roughness amplitude parameters, in the analyzed models, leads to the increase of the precision degree of the experimental determinations.

The roughness of the surface can be considered as surface defect evaluated by the means of the parameter $\sqrt{area_R}$ .This parameter can be used in the analysis of the behavior to fatigue of the materials.

The parameter $\sqrt{area_R}$ and the micro hardness MH_V, develops during the fatigue process leading also to the instant modification of the resistance to fatigue σ_w. The evaluation of the influence degree of the parameters $\sqrt{area_R}$ and MH_V, on the evolution of the instant resistance to fatigue, demonstrate that for the same roughness level the parameter $\sqrt{area_R}$ has a higher influence. The influence degree of the parameter $\sqrt{area_R}$ increases together with the increase in the level of the roughness.

References

1. Frene, J., O. Bonneau, H. Zaidi, M. Arghir, *Wear Damage in Tribology. Historical Aspects and Present Knowledge*, J. of Balkan Tribological Association, 2008, 14 (3), 331.
2. MereuŞL V., Gheorghieк C., Palaghian L., *Roughness as small surface defects and microstructure changes in fatigue process*, The Annals of University

"Dunarea de Jos" of Galati, Fascicle VIII Tribology, vol.1, ISSN 1221-4590 Issue 1, 2011, p. 52-57.

3. MereuŞL V., Gheorghieк C., Ciortan S., Palaghian L., *Assesing the link between surface processing and fine structural parameter in fatigue damage evolution using neural network*, The Annals of University ĂDunarea de Josò of Galati, Fascicle VIII Tribology, vol.2, ISSN 1221-4590 Issue 1, 2011, p. 32-36.
4. MereuŞL V., Alexandru P., Palaghian L., *Microhardness a possible characteristic of fatigue damage of metallic surfaces*, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, Volume 22, No. 1, ISSN 1726-9679, 2011, pp. 905-906.
5. Michael D. S., *The physics of fatigue crack initiation*, International Journal of Fatigue 57, 2013, p. 58ï 72.
6. Deng G., Nagamoto K., Nakano Y., Nakanishi T., *Evaluation of the effect of surface roughness on crack initiation life*, ICF12, 2009, p. 1-8, Natural Resources Canada, Ottawa, Canada.
7. Takahashi K., Murakami Y., *Quantitative evaluation of effect of surface roughness on fatigue strength*, Engineering Against Fatigue, 1999, pp. 693-703, A.A. Balkema, Ed., Sheffield, UK.
8. Murakami Y., Endo M., *Effect of defects, inclusions and inhomogenities on fatigue strength*, International Journal of Fatigue, Vol.16, No. 3, 1994, p. 163-182.
9. Murakami Y., Endo M., *The effects of small defects on the fatigue strength of hard steels*. Materials, Experimentation and Design in Fatigue, Warwick University, England, 24-27 March, IPC Science and Technology Press Ltd., Guildford, 1981, p. 431-440.
10. Murakami Y., *Effect of surface roughness on fatigue strength*, *Metal Fatigue: Effect of Small Defects and Non Metallic Inclusions*, Elsevier, Kidlington, Oxford, UK, ISBN 0-08-044064-9, 2002.
11. Wen, W., Qi*, J. W., &* Qin, W., *Indentation size effect in micro hardness measurements of Hg1-xMnxTe,* Trans. Nonferrous Met. Soc. China 19, 2009, p. 762-766.
12. MereuŞL V., Palaghian L., *Comparison between two methods in assessing the surface quality for different manufacture process*, Annals of DAAM for 2010&Proceedings of 21 st. International DAAM Symposium 20-23 oct. 2010, Zudar Croatia, ISSN 1726-9679, 2010, p. 1459-1460.