EFFECT OF VIBRO-IMPACT STRENGTHENING ON THE FATIGUE STRENGTH OF METALLIC SURFACES

M.A Djema [1, a], K Hamouda [2], A.P Babichev [3], Dj. Saidi [4], Dj. Halimi [1]

[1] *Laboratoire Fiabilité des Equipements Pétroliers & Matériaux (LFEPM), M'hamed Bougara University. Boumerdes, Algeria*

[2] *Houari Boumediène University of Sciences and Technology, Algeria*

[3] *Don State Technical University, Russia*

[4] *polytechnic national schools, Algiers, Algeria*

[a] *djema_amine@yahoo.com*

Abstract:
One of functional parameters which have a big influence on the reliability of machine is the surface quality of mobile and immobile parts. The quality working ability of the surface in contact is depending of their surfaces strength. In this regard, we used vibro-mechanical treatment to increase the hardness of the contact surfaces which is considered as formed surface of plastic deformation. The formed plastic deformation surface is also a kind of micro relief surface, characterized by multitude closed and superimposed on each other traces of contact with the particles working environment cultivated surface. The quality of the surface resulting from the vibro-impact treatment, provide a sufficiently high wear parts.

This paper presents experimental results of using the vibro-impact surface treatment on the fatigue behavior of different materials such as steels, aluminums and titans alloys. The objective of this study is to improve performance functional surfaces in contact by choosing optimal hardening parameters.

Keywords: reliability, strengthening, plastic deformation, micro relief, vibration frequency,

1. INTRODUCTION

The theoretical formulation of the problem in vibro-impact treatment studies and its varieties, mainly consists in determining the basic parameters that accompanying the working environment process impact of a single particle on the work piece surface. Those basic parameters are velocities - V, acceleration –a, micro impacts force-F, the greatest contact pressure- p_{max} ,stress-δ_{max} ,and temperature in the region of micro impacts action-T. So using these basis parameters, it is easy to establish the technological capabilities process, its laws and developing new ways to effectively use the vibro-impact treatment technology [1]. These kinematic and dynamic parameters vibro- impact treatment largely determine the changes undergone by the part during processing.and the quality of the surface resulting provide a sufficiently high wear parts.

2. THEORETICAL BACKGROUND

the physical nature of the investigation process, is based on multiple dynamic effects of a large number of fluid particles on the surface working environment of the work piece, cause plastic deformation or destruction of the elementary parts of the surface layer of the processed material, under the efforts of a single particle impact on the surface working environment of parts.

The theoretical process was described in woks [2]. And according to the mentioned works rate of fluid particles in an arbitrary point of the section of the working chamber can be determined by the formula

$$V_{rp} = V_{pk} Kv; \qquad (1)$$

Where $Kv = 0{,}9877^{L}$,

V_{pk} - velocity of the working chamber point;

$$V_{pk} = \sqrt{A_x^2\omega^2 \sin^2 \omega f + A_y^2\omega^2 \cos^2 \omega t}\ , \tag{2}$$

A_x and A_y – respectively, the amplitude of the oscillations of the working chamber point in the horizontal and vertical planes;

ω - angular frequency of the working chamber;

t – Time;

Kv – loss coefficient of the particle velocity of the working environment as we move away to a distance L from the walls of the working chamber.

The acceleration of particles moving fluid can be calculated according to:

$$a_x = A\omega^2 \cos \omega t;$$
$$a_y = A\omega^2 \sin \omega t. \tag{3}$$

The value of impact force can be varied within wide limits, depending on the modes of vibration exposure and the characteristics of the working environment. The functional dependence of the efforts of the particles dynamic effects on the working environment surface of work pieces and the conditions of the process described by the equation[3]:

a) case freely processing loaded parts:

$$F_{св} = 6V_{грс}\left(\frac{1}{K} m_1 \delta_s R K_m K_Д B\right)^{0,5}; \tag{4}$$

b) Case processing fixed parts:

$$F_{зак} = 6V_{грс}\left[\frac{1}{k} m_1 \delta_s R K_m K_Д \left(1 - \frac{3}{8} K_1\right)\right]^{0,5}, \tag{5}$$

Where

m_1 –particle mass of the working environment

δ_s – Yield strength of the working environment

R – Particle radius of the working environment

K_m – coefficient of added mass;

$K_д$ - coefficient taking into account the properties of deforming the walls of the chamber

K –coefficient of the repeated impact

K_1 – coefficient of recovering

B – coefficient taking into account the amount of impact energy, going to rebound, and the movement of the work piece.

The pressure contact developed in the area of the micro impacts can be calculated by the equation [4]:

a) case freely processing loaded parts

$$p_{к.св} = \frac{F_{св}}{6Пав}, \tag{6}$$

b) Case processing fixed parts:

$$p_{к.зк} = \frac{3F_{зк}}{2Пав}, \tag{7}$$

Where a and в –semiaxes dimensions of the contact area

$$a = \nu_1 \left[3F(\nu_1 + \nu_2)/8\sum \rho \right]^{1/3}; \qquad (8)$$
$$в = \nu_2 \left[3F(\nu_1 + \nu_2)/8\sum \rho \right]^{1/3},$$

Where

ν_1 and ν_2 – coefficient of elasticity, which characterizes the elastic properties of the colliding bodies material;

$\Sigma\rho$ - the value sum of the inverse principal curvature radius of contacting surfaces.

Under vibro-impact treatment, most characteristic is the collision of a spherical surface with the plane when *a* = *в*. In this case the formula (8) simplifies to:

$$a = в = 0{,}0677(Fd_ш)^{1/3} \qquad (9)$$

Where

d_m – ball diameter (particles of the working environment).

To determine the collision energy can be used by the equation

$$Эу = HBd^4 / 6d_ш \qquad (10)$$

Where HB – hardness of work piece.

Temperature in the region of micro impacts action calculated by the formula:

$$T = \frac{2m_1 V_{грс}^2 R(1 - K_1^2) K_m K_Д}{427 C_T \gamma m П 24} \qquad (11)$$

Where

Cт – specific heat of the work piece material

ρ - density of the part material

n – Coefficient of performance.

As shown by special experiments on the dynamic effects of abrasive grains on the surface of specimens made of steel (St3, 45,SH15), iron (MF12, MF8,), brass (LS59, L63) and aluminum (A 17,AK6),when the value of impact parameter of the process, appropriate the range efforts of the dynamic interaction of the particles of the working environment and work pieces in the chamber of the vibration machine, the destruction traces observed on the surface of the specimens in the form of craters-grooves (on metal) or coating damaged [5]. At the same combination of process elements, as a sequential application of multiple microimpacts, intensive mixing of the fluid and the workpiece at various orientations, creates the conditions for grinding, finishing and strengthening operations. According to the results of the calculations, as well as numerous studies of impact processes in vibro-impact treatment, performed by high-speed filming, strain gauge and the piezometric devices [5], the value of the collision forces can reach up to 30 N or more. Vibro-impact treatment allows you to create isotropic surface micro parts with the values of the parameter Ra (5мкм ≤ Ra ≤ 0,08мкм), corresponding rough grinding operations, finishing sanding, finishing grinding, fine grinding and polishing.The process duration and achieved results mainly are determined by the characteristics of fluid particles, modes of treatment, composition and volume of process liquid in the working chamber.To change the speed of the process or for other high quality processing results must change at least one of these factors. A change of any of the Vibro-impact treatment parameters,contributing to increased efforts of the dynamic effects of fluid particles on the workpiece surface, accompanied by an increased rate of removal of the original asperities of the parts surface layer (at $Ra_{original} > Ra_{processed}$) (or an increase in this parameter with respect to the original smooth surface,when $Ra_{processed} > Ra_{original}$). Significant influence on the roughness of the forming surface has a grain size of abrasive grains. Sequential reduction of abrasive grain granules provides the transition from coarse sanding operations to the more subtle. Equation describing the dependence of the surface roughness of the abrasive grain may be in the form of the charge of :

$$Ra = N_3^m K \ , \qquad (12)$$

Where N_3 – grain dimension,

m and K – coefficients, depending of treated materials [5].

The surface contact of piston pin with 50% after centre less grinding brought VT to 95%. For practical results evaluation of an optimal roughness, tests on friction and wear of the samples were done, the working surfaces of which are processed by different technological schemes. The surface after vibro-impact treatment has an actual area of contact with the sample-calibre in 2.5 - 4 times higher than after grinding. Practical validation of the results of research done on certain products: For example, finishing and hardening of valve plate compressor finishing, polishing and hardening of the roller rings; grinding and polishing of parts of sewing machines, grinding and polishing of parts of printing machines and some others. The formation of regularization micro relief creates prerequisites for the standardization of its elements, the radius of the rounded ridges and troughs roughness, slope angle forming the protrusion, the length of the line profile significantly associated with the operating characteristics of parts. For example, the creation of regularization micro relief on the working surface of parts of friction pairs can substantially (1.5 - 4 times) to increase durability, as well as the running-in ability of parts; improves smoothness and in some cases slightly reduces the noise; increases the creep resistance and increases the contact stiffness; significantly increases the tightness of the sealing steam hydraulics. Significantly increases the strength of the fixed compounds. Regularization micro relief allows in some cases to reduce the demands on surface roughness, and eliminate labour-intensive operations such as finishing, scraping, honing, polishing and coating [6]. The formation of regularization micro relief performed many contact vibrating percussion instrument- ball - rod hardener (BRH).In this case, a large number of concurrent indenters at a sufficiently high oscillation frequency shock pulses determines the samples contact surface made by hardened steel after surface grinding and vibro-impact treatment with the sample surface calibre of the same steel after finishing and polishing.The sample surfaces after vibro- impact treatment were more resistant to wear under sliding friction than after grinding. In conditions of dry friction with the surface of the samples after the vibro- impact treatment proved to be less durable than the ground. This can be explained by the fact that the surface after vibro- impact treatment carries a set of asperities oriented in different directions, which increases the adhesion of two surfaces of their contacts with their mutual movement. This is indicated by a higher torque and friction coefficient. The residual stresses depth distribution could be up to 400 microns and more [7].

3. RESULTS AND ANALYSIS

Below are the results of studies of the effect VT on fatigue strength is enough common materials for the parts. Samples of steel 40HNMA (heat-treated $\sigma_n = 160 \pm 10$ kgf/cm2) were subjected to treatment, structural aluminium alloy AVT - 1 and the titanium alloy VT4 – 1. As the manufacturing environment used balls made of hardened steel ShKh-15 mm, $d_m = 8$mm, and the amplitude and vibration frequency, respectively: A=2.5-4.5mm, $f = 34$ Hz, processing time T=15-120min. Test Base $N_ц = 10^7$ cycles. In each batch is a tested 10-14 sample.

As the tests results showed, the vibro-impact treatment of the samples of aluminium alloy AVT - 1 during 20 min, with A = 2.5mm led to an increase in the endurance limit by 11 % (curves 2 and 3, fig 1). The subsequent increase in treatment duration to 45 min increased the endurance limit of samples up to 18.10^7N/m^2, ie to 28% as shown in (curve 1,fig 1).

1-hardened during 45min

2-hardened during 20min

3- Periodic component of efforts due to beating of the roller relative to the surface pads.

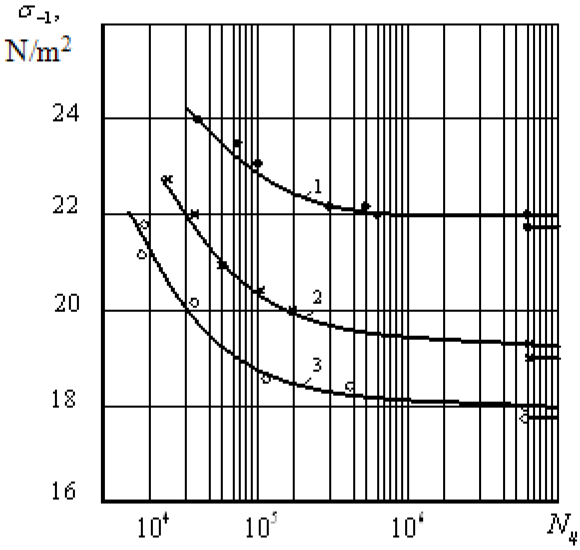


Fig1: Effect of vibration impact on enhancing the fatigue strength of aluminium alloy AVT-1 samples.

1. Hardened for 120 min; 2 –origin

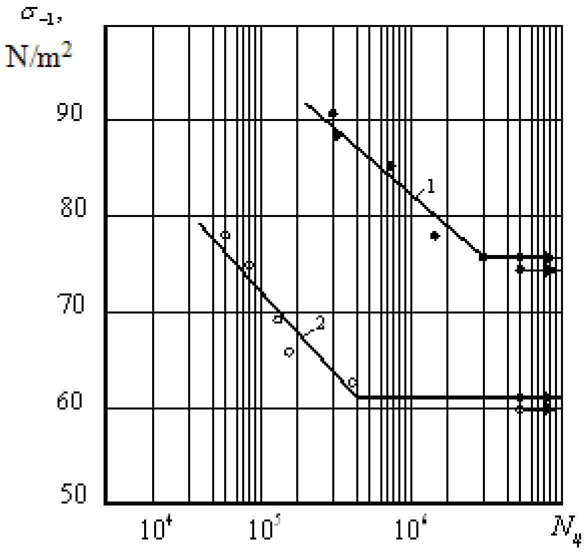
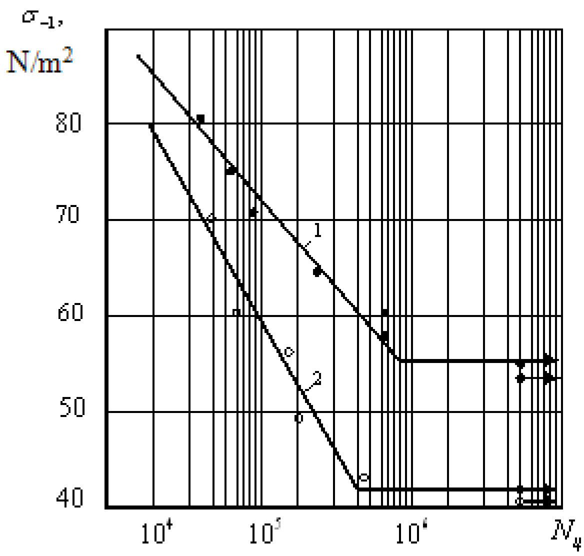


Fig 2: Effect of vibration impact hardening on fatigue strength Steel *40HNMA samples*



1 - Hardened for 60 minutes; 2 –origin

Fig3: Effect of vibration impact hardening on fatigue strength *Titanium alloy VT4-1 samples*

For a similar program carried out tests on samples of steel 40 HNMA. The greatest increase in endurance limit of samples, hardened with A = 2.5 mm was obtained by processing time T = 120 min. (Fig. 2) and is 21% (from 62 kgf/mm2 to 75 kgf/mm2). As is the case with samples of aluminum alloy AVT - a further increase in the duration of the process and the amplitude a noticeable effect in increasing the fatigue strength is not revealed. Fig. 3 shows the results of fatigue tests of the original and hardened specimens of titanium alloy VT4 – 1. The greatest increase in endurance limit of 28% achieved in the processing for T = 60 min. and the oscillation amplitude A = 2.5 mm. Increased longevity was 26%.

4. CONCLUSION

Each set of Vibro impact treatment parameters is characterized by rational treatment duration, within which there is an effective reduction of the surface asperities details.

Vibro impact processing is accompanied by an increase in the micro hardness $H\mu$ of the surface layer. Depending on the characteristics and condition of the processed material, the micro hardness $H\mu$ increase up to 20-35% at a thickness (depth) of the hardened layers 20-450 microns and more. For hardened steels most noticeable change of micro hardness and structure of the surface layer observed in the vibro-impact process in the medium of hard spheres (Fig. 2).

In the process of vibro-impact process in the surface layer formed by relieving the residual stresses with a maximum at the surface. This is explained by the nature of the contact and shears deformation of the surface layer and relatively low temperatures in the zone of collision did not cause relaxation of residual stresses. This distribution character of residual stress enhances endurance limit of parts. The vibro-impact process has a significant impact on the quality of the surface layer and on the fatigue strength of surfaces parts.

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