Vibration influence on polycrystalline structure and internal friction of the material deposited by welding

M. A. LUCA, T. PISU MACHEDON [*]
Faculty of Science and Materials Engineering " University Transilvania Brasov" "B-dul Eroilor Nr.29, Brasov500036, Romania

The paper presents some aspects concerning the influence of low-frequency sinusoidal mechanical oscillations on the aspect of the surfaces made by welding-loading operations, as well as of the microstructures, density and logarithmic decrement. The results obtained and presented can be used for the development of some welding-loading technologies, both of the construction steels with good weldability and of the alloyed steels with higher carbon content, that are not being currently welded. Under the action of the vibrations applied during welding, surfaces with fine, uniform, and maximum drawdown of 0.2mm are realized. Also, it increases the density of the material deposited, tensions and the friction of the basic material go down.

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1. Introduction

In the specialized literature it is highlighted the favorable influence of the vibrations generated during welding on the physical-mechanical joints realized [1,2]. Mainly, through the generation of mechanical oscillations in the area subject to welding it is realized a reduction of deformations, of the toughness and of the internal tensions, as well as the increase of the tenacity of the thermally influenced area [10]. Also, a superior diffusion in the transition area belt-basis material is registered.

Other works present the influence of vibrations on the casting-crystalizing processes [3,4,5]. In these conditions microstructures with fine granulation are obtained due to the forced germination conditions, reduced porosity and superior mechanical features.

The application of vibrations during the effectuation of the thermal treatments determines the change of transformation mechanisms into solid state [6,7,8,9,12]. Upon hardening in mechanical oscillation field it is registered an increase of the depth of the martensitic layer, the finishing of the acicular martensite and the reduction of the residual austenite. This influence was highlighted through the application of some low frequency mechanical oscillations included in the field 25...800Hz also with excitation powers, relatively reduced. In the case of excitation with high energies, upon exceeding a level of accelerations, there appears in the deepness of the material and excitation of the tensions. Thus, it is registered both an increase of the depth of the reinforced layer and an increase of the tenacity in the core of the products.

In the conditions of effectuation of the return or de-tensioning in the field of mechanical oscillations, it was remarked on various improvement steels and tools an acceleration of the diffusion processes [11]. The stimulation of diffusion and relaxation allows an important reduction of the duration of the thermal treatment, respectively an increase of tenacity. Also, under the action of the mechanical oscillation field applied during the return of the steels with high carbon content or alloyed, it is registered an important diminishment of the content of residual austenite.

2. Experimental

2.1. The Material Subject to Research

The researches aimed at a steel, which generally is not subject to welding, with the wish to find technological solutions which are easy for welding-charging operations. For that, the steel C45U was chosen. Knowing the limits within which the chemical composition of the steel can vary and using the relation for establishing the equivalent carbon content, I.I.W:

$$C_e = C + \frac{Mn}{6} + \frac{Cr + V + Mo}{5} + \frac{Cu + Ni}{15} \quad [\%]$$

it results , Ce = 0,5...0,63%, namely the steel enters in normal conditions in the category of those with strictly conditioned welding. For welding, the semiautomatic welding procedure with gas protection was chosen.

2.2. Experimental Conditions

For experiments test pieces with the sizes 160x50x8mm, with un-penetrated split with the depth of de 6mm and opening angle of α=40° were used. 10 test pieces were realized, A,B,C,D,F,G with split base of 1mm and H,I,J,K with split base of 2.5mm. Un-penetrated test pieces were used so that as a result of the realization of the joints there should result conclusions concerning both the realization of the joints and of the loading deposits.

Test pieces A and H were welded without pre-heating and without vibration. These test pieces were considered

witness test pieces, with respect to which the various influences of the mechanical oscillations were evaluated.
Test sample B was welded without vibration, but with pre-heating, and after welding a post-heating was immediately made, followed by a slow cooling:
- Pre-heating, Tpre = 300°C;
- Post-heating, Tpost = 600°C;
- Maintenance, tmenţ = 20 min.;
- Cooling, vrac = 50°C/h.

Test pieces C,D,F,G,I,J,K were welded with various welding parameters and oscillation amplitude. In table 1 there are presented the welding and excitation parameters of the test pieces.
The welding conditions were the following:
- The diameter of the addition material, ds=1,2 mm;
- Addition material, SG2;
- Protection gas, CORGON 18.

In figure 1 there is the assembly of the equipment used for the realization of the test pieces, made up of:
- welding device, type Digi Plus SAF-PRO 320;
- advance installation with the adjustable speed of the pistol;
- vibrating platform;
- low frequency generator;
- power amplifier;
- electrodynamic exciter.

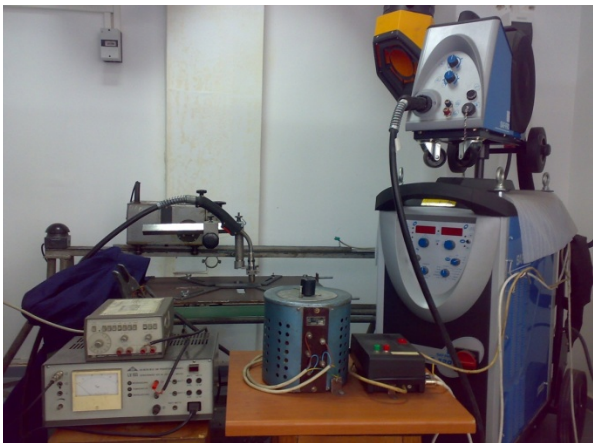

Fig. 1. The assembly of the equipment used for the realization of the test pieces

In Table 1 there are presented the parameters of the welding statuses which were applied, as well as the features of the oscillations generated in the test pieces during welding: the frequency, the horizontal acceleration, the vertical acceleration. Depending on the output tension in the power amplifier, the power of the electro-dynamic exciter can be evaluated; at 20V voltage the power of the exciter is 100W.

Table 1 Welding and vibration parameters of the test pieces

Epr	U_S [V]	I_S [A]	v_s [cm/min]	v_{as} [m/min]	E_l [kJ/cm]	Q [l/min]	f [Hz]	U_{ex} [V]	a_z [m/s^2]	a_x [m/s^2]
A	17,6	175	28	5,2	5,6	13,5	-	-	0	0
B	17,0	200	28	5,2	6,2	13,5	-	-	0	0
C	17,3	172	28	5,2	5,4	13,5	40	5	0,8	2,9
D	17,4	174	28	5,2	5,5	13,5	40	10	1,2	4,9
F	17,6	204	28	5,2	6,5	13,5	40	20	2,2	7,3
G	17,8	207	28	5,2	6,7	13,5	80	20	0,4	2,7
H	15,4	185	15	4,5	9,7	15,5	-	-	0	0
I	15,8	186	15	4,5	10	15,5	750	10	10,4	2,9
J	15,4	185	15	4,5	9,7	15,5	750	15	13,6	4,3
K	15,8	178	15	4,5	9,6	15,5	750	20	5,2	7,1

3. Results and discussion

3.1. Macroscopic Analysis

In figure 2 there is presented the backside of the test pieces welded by loading, respectively the opposite side of the belt made. One can notice that the influence of mechanical oscillations influenced the thermal field. The distribution of the temperatures can be evaluated according to the return colors visible on the backside of the test pieces. . out of this analysis must be excluded test piece B, which at the end of the welding suffered a post-heating at 600°C and thus the colors, which nuance the thermal field, are no longer relevant. It is noticed a big difference between test pieces A...G and H...K, which is due to the different linear energies with which the welding was made.

The most important remark results from the comparison of the aspect of the test pieces H...K. At test piece H, which was not vibrated during welding, it is not noticed the break-up tendency. At test pieces I, J and K, vibrated with the frequency of 750Hz, appropriate to a superior degree harmonics, it is noticed a much bigger break-up, with the tendency of flowing of the melting. The maximum effect is registered at test piece J, which during welding suffered a maximum vertical acceleration (ay = 13,6 m/s2).

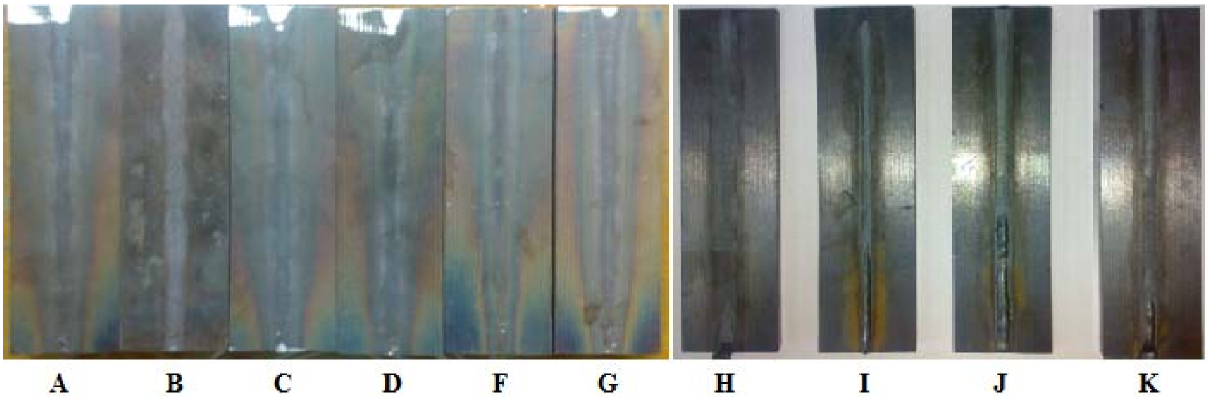

Fig. 2 Thermally influenced areas (backside of the test pieces)

In Fig. 3 there is presented the aspect of the surface of the belts realized by welding. It is noticed that the test pieces which were vibrated during welding have more dense and uniform scales. It is thus forming the idea that under the action of vibrations welding belts, respectively, layer deposits with more uniform height may be realized. This thing can be valorized in the case of various matrixes or other tools meant for plastic deformation, with the active surface loaded by welding with various tough addition materials. It is noticed that the vibration with the frequency of 750Hz and vertical acceleration more than 10 m/s^2 or horizontal acceleration of more than 7 m/s^2, determines the formation of some drawdown scales of max. 0,2mm. It was noticed that the use of other vibration statuses, at frequencies of more than 1500, 3000Hz, did not determine the finishing of the scales.

The most favorable aspect has test piece K, which during welding was subject to a maximum horizontal acceleration (a_x = 7,1 m/s^2). From the examination of the belts realized one should retain the fact that at test piece J it is registered the presence of some gas bubbles on the surface of the belt. This thing is due to the fact that, under the action of vibrations with high vertical acceleration, there is a more advanced degassing of the melt material. It is less probable that these gas inclusions, visible on the surface of the belt, should be formed under the action of oscillations or should have their origin in the protection gas environment.

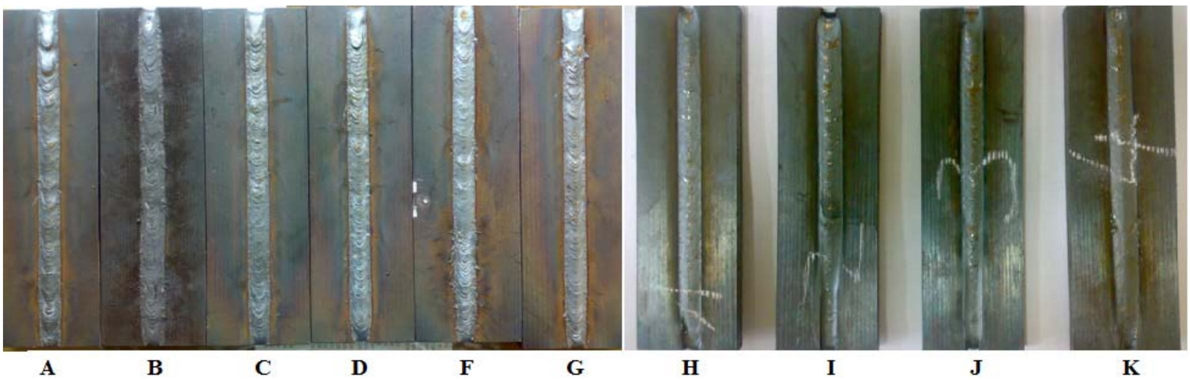

Fig. 3 The aspect of the belts realized with various welding-vibration statuses

In Fig. 4 there are presented the macrostructures on test piece sections. At test pieces A and B, which were not subject to vibration during welding and which were welded with a small linear energy, it is noticed a non-penetration at the root of the split. One must mention that at the first six test pieces splits with a very narrow split T (1mm) were intentionally made, and this, in order to highlight the influence of vibrations on penetration at the base of the split. Test piece H, which was not vibrated, but which had a wider split base and was welded with a bigger linear energy, does not have root defects.

Examining the macrostructure of the test pieces with narrow base of the split, C, D, F and G, it is noticed an appropriate filling of the root, a fact that proves that under the action of oscillations, irrespectively of the frequency, but at vertical oscillations that exceed 0.5m/s^2, the penetration is assured also in the splits with very narrow roots.

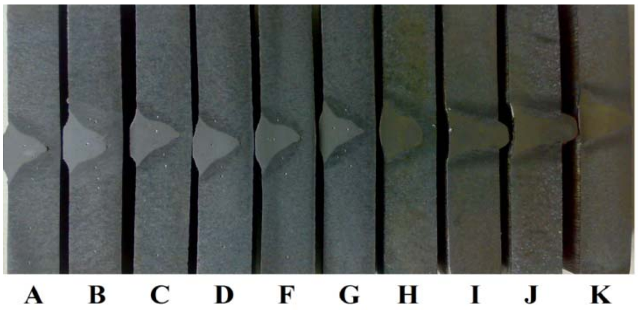

Fig. 4 The macrostructure of the belts realized with various welding statuses.

The effect of vibrations on penetration is very clearly highlighted on the sections of the welded test pieces with a linear energy higher than (9,6...10kJ/cm). At test piece H, which was not vibrated during welding, the filling of the split is appropriate, but at test pieces I, J and K, which were vibrated, it is noticed the break-up tendency and gravitational flowing of the melt material. From here, there results the idea that through the increase of the welding and wire advance speeds and keeping the tension and the intensity of the current unchanged one can avoid the break-up of the root. In these conditions it is realized an increase of productivity and the reduction of energy consumption, because the energy consumed for generating mechanical oscillations is negligible as compared to the one needed for welding.

Another way for the reduction of the energy consumption is the realization of some narrow splits, with smaller deposits of addition materials, the appropriate penetration at the base of the split being assured by the generation of mechanical oscillations in the products subject to welding.

3.2. The Density of the Deposited Material

For the analysis of the porosity, out of the area of the belt samples were taken out which include also a very small part of the thermally influenced area, as well as the root of the split. The volume of these samples is of 1.7...1.8 cm^3 and it was determined through the measure of the displaced liquid volume. The weight was established with the analytical balance. In figure 5 there are presented the densities of the deposited material.

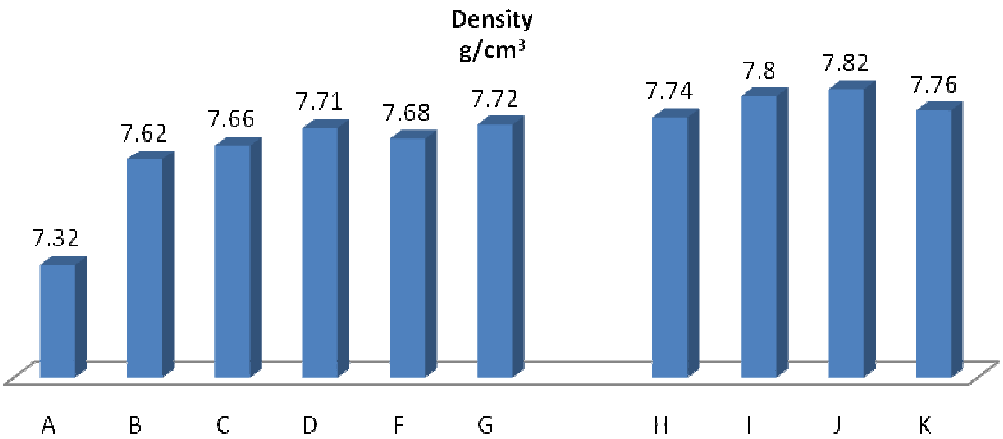

Fig. 5 The density of deposited material

From the analysis of the results presented in figure no. 5 it is noticed an obvious difference between the belts realized through the short or intermediary arch belts, respectively with different linear energies. In the conditions of welding in V-split, with, cu $\alpha=40^{o}$ and with a narrow root of the split (b=1mm), through the use of the welding status with reduced linear energy, it is noticed an insufficient penetration. Because of this reason, at the root of the belt there remain porosities which affect density.

The maximum porosities are registered at test pieces A and B, which were welded without vibrations. It results that the shape of the split and the parameters used for welding are inappropriate. Using the same split and approximately identical welding parameters, under the action of vibrations, irrespectively of frequency or amplitude, it is noticed an important increase of belt compactness. Maximum densities are registered at test pieces D and G, but more reduced than that of test piece J. One may draw the conclusion that under the action of vibrations an increase of penetration at the root of the narrow splits is registered. But this remark has an important economic importance. Through the use of some narrow splits the addition material consumption reduces and implicitly the consumption of energy necessary for the realization of the joint. Thus there appears the problem of optimization of the shape and of the sizes of the split, according to the parameters of the welding status and the vibration conditions. It should be mentioned the fact that for vibration generation the energy consumption is very small, comparable to the one used for welding.

Upon welding the test pieces H, I, J, K it was used an intermediary welding status, and the width of the split soot was increased. It is noticed first an increase of the belt compactness, due to a greater penetration. The microscopic research of the sections of these text pieces highlighted a very good melting in the area of the root. Test piece H, which was not vibrated, has a more reduced density (ρ=7,742 g/cm^3). This thing is due to the presence of some porosities (inclusions of gases and micro-cavities) which could not be highlighted by microscopic research. The other test pieces, which were subject to the action of vibrations, have higher densities, a fact which confirms the effect of vibrations on the increase of belt compactness. The maximum density is registered at test piece J (ρ=7,821 g/cm^3), which was subject to the greatest acceleration on the vertical direction. At this test piece it was also registered the smallest logarithmic decrement. From here, it may be deduced that the presence of porosities determine the increase of internal friction, and from the analysis of the aspect of the resonance curves one can appreciate the condition of tensions in the material, together with the highlighting of porosities.

3.3. The Determination of Internal Friction

The main causes of internal friction into the solid body are due to some irreversible processes of thermal, magnetic or atomic nature. The internal friction is mainly dependent of temperatures and the conditions of use of the test pieces. In the case of cyclic strains the internal friction is influenced by the frequency and the amplitude of oscillations. Mainly, the internal friction is influenced by:

- The tension condition in the material;
- The capacity of relaxation of the existing tensions;
- The presence of imperfections in the crystalline network;
- The movement of dislocations under the action of external forces;
- The cloggy behavior of the limits of the crystalline blocks and seeds;
- Phenomena of the thermal- and magnetic-elastic nature under the action of some external forces.

The evaluation of the internal friction can be made from the analysis of the resonance curve of a test piece excited by a harmonic perturbation force (fig.6). For the determination of the internal friction with the aid of forced vibrations, it is calculated the logarithmic decrement. (δ), with the relation :

$$\delta = \frac{2\pi\Delta f}{f_r}\,\frac{1}{\sqrt{\left(\frac{Xmax}{X}\right)^2 - 1}}$$

where Δf, represents the variation of the frequency of the perturbation force, which causes the diminishment of the resonance amplitude, X_{max}, up to the values of X_1, respectively, X_2. The amplitudes X_1 and X_2 will be allowed to be chosen according to the following criteria:

When the amplitudes correspond to the half of the power of oscillations;

$$X_1 = X_2 = \frac{X_{max}}{\sqrt{2}} = 0{,}707X_{max} \quad (a)$$

When the amplitudes reach half of the value measured at resonance;

$$X_1 = X_2 = \frac{X_{max}}{2} = 0{,}5X_{max} \quad (b)$$

In order to obtain a bigger evaluation precision, frequencies of f_1 and f_2, for $X_1 = X_2$, in both parts of the resonance frequency are measured, a situation from which it results:

$$\delta_{(a)} = \frac{\pi\Delta f}{f_r} = 3{,}14\,\frac{f_2 - f_1}{f_r}$$

$$\delta_{(b)} = \frac{\pi\Delta f}{\sqrt{3}f_r} = 1.815\,\frac{f_2 - f_1}{f_r}$$

In the case of materials with small amortization, as well as the test pieces analyzed in this work, it is recommended the use of the criterion b), because due to the very sharp resonance curve the measurement of the frequencies f_1, f_r, f_2, assures more reduced measurement errors. In figure 4 it is schematically presented a resonance curve and the necessary measures for the calculation of the logarithmic decrement.

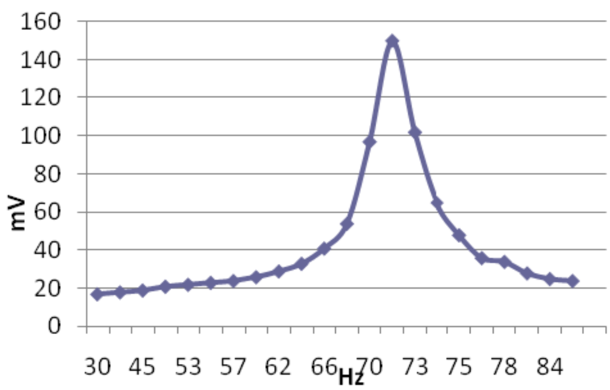

Fig. 6 The Resonance Curve.

The internal friction is especially influenced by the material microstructure and the level of the internal tensions. The trying conditions also influence the results of the determinations. The temperature, the amplitude and the frequency of the oscillations influence the results of the determinations. A special importance has the system of test piece fixing, the positioning of the exciter and of the transducer for oscillation amplitude measuring. The research imposes the creation of some more stable and reproducible experimental conditions.

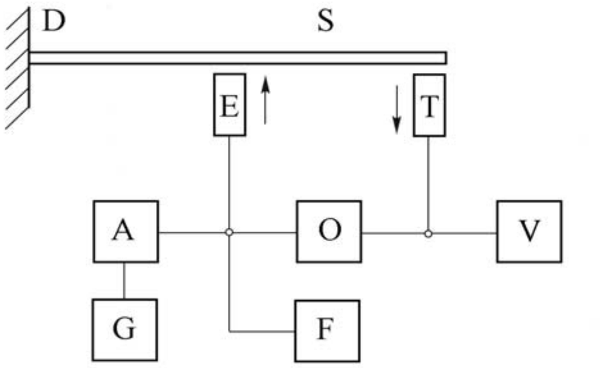

Fig. 7 The plan of the system of measurement of the sizes necessary to determine the logarithmic decrement, from the analysis of the resonance curves.

In Fig. 7 it is presented the plan of the assembly realized for the construction of the resonance curves necessary for the determination of the logarithmic decrement.
D – device; S – test sample;
G –frequency generator;
A – power amplifier;
E – electromagnetic exciter;
T – frequency + amplitude transducer;
F – frequencymeter;
V – voltmeter;
O – oscilloscope

Table 3 Frequency, oscillation acceleration and logarithmic decrement

Test piece	**A**	**B**	**C**	**D**	**F**	**G**	**H**	**I**	**J**	**K**
Welding	Short-circuit (short arch)						intermediate			
f [Hz]	-	-	40	40	40	80	-	750	750	750
a_z [m/s^2]	-	-	0,8	1.2	2,2	0,4	-	10,4	13,6	5,2
a_x [m/s^2]	-	-	2,9	4,9	7,3	2,7	-	2,9	4,3	7,1
δ x10^{-2}	6,41	4,13	5,53	4,75	5,11	6,24	7,72	6,18	4,21	7,02

It is noticed that test pieces A and H, which were welded without vibration, have a high internal friction. Test piece H, welded with a higher linear energy, has a maximum value of the logarithmic decrement, respectively of the internal tensions. This thing is due to the fact that through the use upon welding of a higher linear energy, the thermally influenced area is more extended.

Test piece B, welded without vibration, but with pre- and post-heating, as it was expected, has the smallest value of the logarithmic decrement, respectively the smallest remaining internal tensions.

At all the test pieces vibrated during welding there are registered smaller values of the internal friction, as opposed to test pieces A and H, which are considered as a reference for welding in short-circuit and intermediate status. The minimal value being registered at test piece J, the one which subject to the maximum vertical acceleration. It can be noticed that the logarithmic decrement registered at test piece J is very close to the one of the test piece B, which had a pre- and post-heating.

Through the determinations made, it is highlighted the fact that though welding in mechanical oscillation field there results a condition of smaller remaining tensions. Thus, in certain conditions of frequency and accelerations, pre- and post-heating imposed to certain steels with conditioned weldability can be eliminated. Thus, it is predictable the welding of some steels considered as non-weldable, in the conditions of a pre and post-heating and a vibration during welding.

4. Conclusion

The generation of some mechanical oscillations in the products subject to welding-loading operations has favorable effects:

- There are realized surfaces of the deposited material, with finer and more uniform scales, in the conditions of generation of some oscillations with frequencies of 500...800Hz and horizontal accelerations of more than 5 m/s^2;
- The penetration at the level of the root of the split increases and thus the section of the split can be reduced or the welding speed may be increased;
- It is reduced or removed the risk of formation of root defects, in the conditions of realization of vertical accelerations of more than 0.5 m/s^2;
- It is realized an increase of the compactness of the welding belt through the reduction of the gas inclusions, in the conditions of the generation of some sufficiently big vertical accelerations;
- The reduction of internal friction and the increase of the module of dynamic elasticity;
- Finishing of the granulation of the deposited material;
- The reduction of the fragility of the thermally influenced area, through the finishing of the Widmanstatten-tyoe structure;
- The reduction of the internal tension and of the hardness from the thermally influenced area.

Acknowledgement

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*Corresponding author: tmache@unitbv.ro