Analysis of Resonance Curves for Spot Welding Technology Optimization

MACHEDON Elena
Transilvania University of Brasov, Romania, elena.machedon@unitbv.ro
LUCA Mihai Alexandru
Transilvania University of Brasov, Romania, luca.mihai@unitbv.ro

Abstract
Spot welding is a complex technological process in which the interaction occurs between the electrical, thermal, mechanical and metallurgical phenomena. Different researchers around the world are studying the problems generated by dilatations and contractions in welded joints and the microstructure changes that cause dangerous internal tensions or unacceptable deformations that affect the quality and reliability of welded products. Were experimented, developed and tested various welding conditions and different materials using both theoretical and experimental methods [1…5]. In this paper are shown the results obtained by dynamic tests applied on specimens subjected to spot welding. The specimens made out of sheet metal for pressing were welded with two different welding regimes. The number and succession of the points execution has varied. In these conditions different internal tensions and deformations was result. For each test specimen to the basic harmonic excitation, the resonance curve was built. Based on the evaluation of resonance curves, the logarithmic decrement was determined for evaluation of internal friction. Experiments have shown that in certain technological circumstances results a lower or bigger internal friction, respectively lower or major internal tensions. The proposed test method is useful for choosing the optimal manufacturing variants when conducting the approval of a new product or when it comes to a reliability analysis.

Keywords
spot welding, resonance curve, internal friction, logarithmic decrement, vibration analysis

1. Introduction

Spot welding is generally used for assembly of components made of sheet metal with a thickness of up to 10 mm. The method is applied especially in the construction of motor vehicles and consumer goods. The quality and reliability of spot welded structures is influenced by:

- Design elements: geometry, shape and dimensions of the welded structure, material thickness;
- Material: chemical composition, surface condition;
- Equipment used: automation level, schedule parameters stability, electrodes wear state;
- Applied technology: components immobilizer system, current intensity, welding time, pulse shape, pause time between pulses, cooling driving, distance between the welded points, succession of the points execution etc.

The succession where the welding points perform has a large influence on the assembly resistance, dimensional stability, residual stresses and deformations. In Generally the joints quality checking currently being carried out by methods that are not always conclusive, respectively by visual examination of the assembly and testing of shear specimens with 1, 2 or 4 welded points.

The residual stresses state in a material or in a welded structure can be evaluated by analyzing of the assembly resonance curve. The resonance curves are experimentally drawing, and with their help can be established the internal friction in the material by the logarithmic decrement calculating. The internal friction is reduced when in the tested assembly stored energy is low and in this case the internal stresses are small and the physicochemical stability of the tested object is higher [6, 7, 8].

The advantage of research conducted in order to evaluate the internal friction is the fact that the results relate to the assembly overall status, respectively of the tested object in its entirety and in these circumstances the risk from accidental influence of local defects is much lower.

2. Internal Friction Measurement

The main causes of internal friction into the solid object are due to some irreversible processes of thermal, magnetic or atomic nature. The internal friction measurement is mainly dependent of the temperature and test conditions of the test pieces. In the case of cyclic stresses generated by forced vibration, the internal friction is influenced by excitation conditions, respectively of the oscillations frequency and amplitude. The internal friction is influenced inclusive by the material microstructure and the technologies previously applied [9, 10]:

- The material internal tensions;
- The relaxation capacity of the existing tensions;
- The presence of imperfections in the crystalline lattice;
- The dislocations movement under the external forces action;
- The viscous-elastic behavior of the limits of the crystalline blocks and grains;
- Thermal- and magnetic-elastic phenomena that are produced 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 sample excited by a harmonic perturbation force (Figure 1). For the determination of the internal friction with the aid of forced vibrations, it is calculated the logarithmic decrement (δ) with the relation:

$$\delta = \frac{2\pi \cdot \Delta f}{f_r} \cdot \frac{1}{\sqrt{\left(\frac{X_{max}}{X}\right)^2 - 1}} \qquad (1)$$

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;

$$X_1 = X_2 = \frac{X_{max}}{\sqrt{2}} = 0.707 \cdot X_{max} \quad \text{(a)} \qquad (2)$$

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

$$X_1 = X_2 = \frac{X_{max}}{2} = 0.5 \cdot X_{max} \quad \text{(b)} \qquad (3)$$

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

$$\delta(a) = \frac{\pi \cdot \Delta f}{f_r} = 3.14 \cdot \frac{f_1 - f_2}{f_r} \cdot \delta \qquad (4)$$

$$\delta(b) = \frac{\pi \cdot \Delta f}{f_r \cdot \sqrt{3}} = 1.815 \cdot \frac{f_1 - f_2}{f_r} \qquad (5)$$

In the case of materials with small damping, for example metallic materials, 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 1 it is schematically presented a resonance curve and the necessary measures for the calculation of the logarithmic decrement.

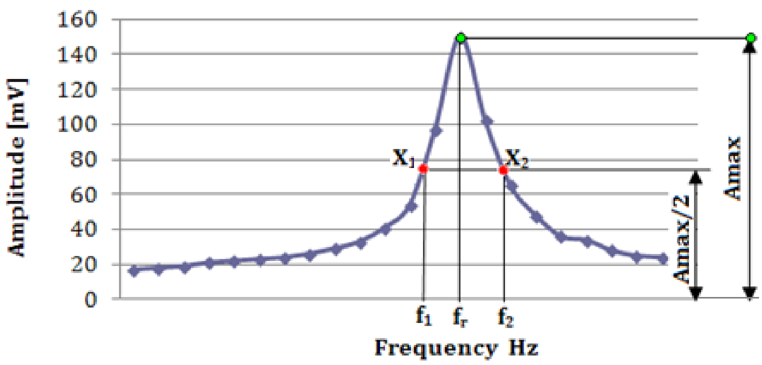

Fig. 1. Resonance curve

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

Figure 2 presents the mounting scheme achieved to plot of resonance curves which is necessary to calculate the logarithmic decrement.

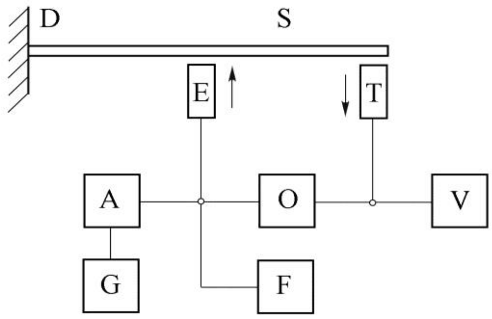

Fig. 2. Equipment scheme used to construct of resonance curves
D – fastening device; S – test sample; G –frequency generator; A – power amplifier; E – electromagnetic exciter; T – measurement transducer; F – frequency meter; V – voltmeter; O – oscilloscope

By varying the frequency of the sinusoidal current produced by the frequency generator the sample oscillates with different amplitudes and the electromagnetic transducer generates a variable voltage recorded by the digital voltmeter. When the specimen oscillates at resonance, the measured voltage is maxim and the corresponding frequency is indicated with precision by numerical frequency meter. By change of the frequency around the resonance point, the oscillations amplitude decreases and will be denoted the amplitudes X_1 and X_2 corresponding to the frequencies f_1 and f_2.

3. Welding of Test Specimens

For specimens was used etched metal sheet for pressing used in the automotive industry, that has a thickness of 1.2 mm. Spot welding was conducted on a spot welding installation “TECNA” with pneumatic actuated by "Synchronous tyristor drive - TE90 Mark II". The welding current limit is between 1500 ... 2000 A and is controlled by the processor of the control unit.

Ten specimens were conducted in five different weld points succession and were selected two values of the welding current. All adjustments were performed as recommended in the welding installation manual [11]. Adjusting parameters are shown in Table 1, and in Figure 3 are shown the order and number of the welded points.

Table 1. Programmed parameters

Parameter	Range	Program A	Program B
Squeeze	01 - 99 cycles	30	30
Weld time	01 - 99 cycles	40	40
Current	00 - 99 %	55	50
Hold	01 - 99 cycles	49	49
Off time	01 - 99 cycles	28	28
Comp. off / Comp. on	00 - 01	0	0
Single / Repeat	00 - 01	0	0
Weld time 2	00 - 99 cycles	0	0
Current 2	01 - 99 %	0	0
Slope	00 - 29 cycles	10	10
Cold	01 - 50 cycles	0	0
Impulse number	00 - 09	0	0

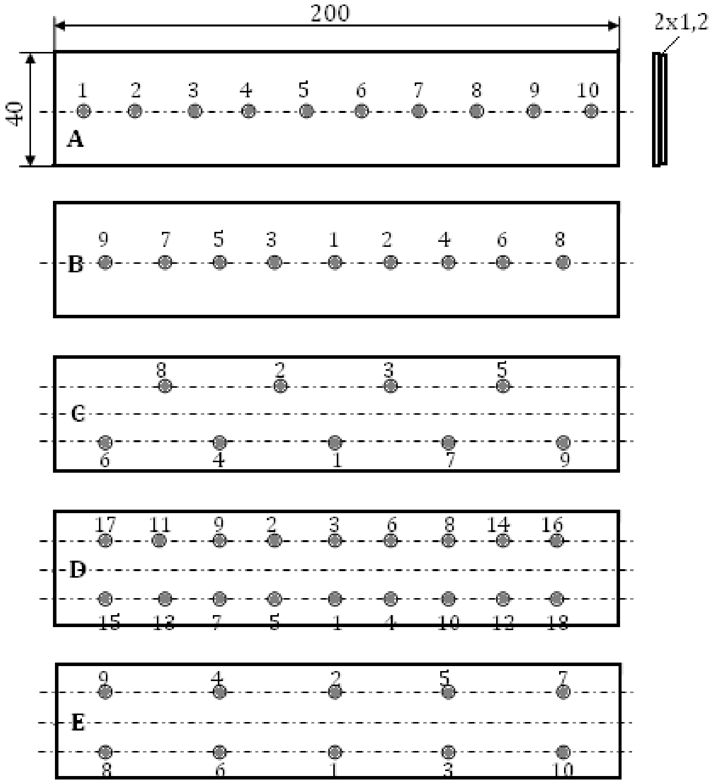

Fig. 3. Welded points position and the execution order

The control unit of the welding apparatus no accepts choosing of inadequate welding regimes. If they occur inconsistencies is announced "Error" and is necessary reprogramming.

4. Experimental Results and Conclusions

In Table 2 shows the frequency which resulted from the resonance curves analysis and these values have facilitated the calculation of the logarithmic decrement of the test specimens that were welded under different conditions. This research aims to identify the succession of the execution of weld points so as to obtain a welded assembly to present minimal residual internal stresses respectively the lowest internal friction.

Table 2. Results of the resonance curves analysis

Sample number	Welding current [%]	Sample type	Frequency [Hz]			Log. decr. $\delta \times 10^{-2}$
			f_1	f_r	f_2	
1	**55**	A	41.2	42.2	43.1	4.50
2		B	40.5	41.5	42.7	9.73
3		C	42.4	43.0	43.7	4.27
4		D	40.2	42.6	44.6	10.28
5		E	41.3	41.5	42.1	3.53
6	**50**	A	42.6	43.1	44.5	4.41
7		B	42.1	43.1	43.9	7.68
9		C	42.3	42.5	43.2	3.88
8		D	39.9	41.6	43.9	9.61
10		E	40.9	41.2	42.0	4.90

By the results analyzing it follows that the highest internal friction of welded specimens are recorded in both welding regimes to variants B and D, and the lower internal friction of welded specimens are recorded in variants C and E. Interim results are obtained when welding in the variant A.

When welding in D version, logarithmic decrement due to high point density is too large, which is why the stress relaxation that occurs in the welded areas is hindered to cooling and so there is a high value of logarithmic decrement. Thus, the design of welded structures should be avoided unduly increasing the point density.

Unexpected behavior both test specimens B. The specimens 2 and 7 show a relatively high logarithmic decrement because the welded points are too close together and the order in which the welding has been carried out no allow stress relaxation and thus remain not deformed and thus the specimens are kept relatively high residual stress. The specimens 1 and 6 are carried out in line and they have the same pitch but finally presents a large deformation, an arrow in the middle of 1.5 to 1.7 mm. This proves that in case where welding is performed in successive points, reducing the internal stress is carried by a pronounced deformation.

From the results analysis it is recommended to the welding in the variants C and E leading to a reduced logarithmic decrement, internal tensions and low deformations.

Experiments have shown that in certain technological circumstances results a lower or bigger internal friction, respectively lower or major internal tensions. The proposed test method is useful for choosing the optimal manufacturing variants when conducting the approval of a new product or when it comes to a product reliability analysis.

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