CONTRIBUTIONS TO THE PROCESS WHERE PLATING DIFUSSION FIELD ULTRASONIC WELDING PLAIN CARBON STEELS

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Abstract. *The plating by welding of steel with a high carbon content can occur in the heat affected area a hardening of the material. In this paper we analyzed weld plating of 5 steels with high carbon content considering the heat affected zone where it can be caused a hardening of the material, thus avoiding brittle material required a series of technological measures such as: preheating, welding with high linear energy, suitable choice of materials, welding in ultrasonic field etc.. Research undertaken for several couples of materials revealed that when plating it occurs: volume diffusion; diffusion at the limits between grains; the exterior surface diffusion.*

Key words: ultrasounds, plating, carbon steel, diffusion

1. INTRODUCTION

Carbon steels do not contain other alloying elements besides carbon and elements required for making and casting: silicon, manganese, aluminum, sulfur and phosphorus in certain concentrations [1].

The mechanical characteristics and behavior of the welding of carbon steels are primarily determined by the carbon content. Figure 1 shows the influence of carbon content on the main mechanical characteristics (HB, KCU, A, RM) [2, 3].

Experimentally it has been found that increasing the carbon content increased by 0,1 % tensile strength of about 90 N/mm^2 and yield strength of 40...50 N/mm^2, and the maximum hardness of is limited, in general, steels carbon and low alloy 350 HV5. This hardness is achieved with a carbon content of 0,22 % and a 50 % martensite structure [4, 5].

2. EXPERIMENTAL

The cladding by welding of steel with a high carbon content can occur in the hardening of the heat affected material. Tensile strength and hardness increase greatly in the area, while the plasticity decreases, so a request, sometimes the internal stresses can occur due to cracking of the material. Figure 2 shows the dependence of the carbon content and hardness of the material structure. Hardness depends almost exclusively on the carbon content of the steel. Therefore, it is considered that the welding of carbon steel with less than 0,22 % C, generally no danger of cracking in the cold (the hardening).

Steels with 0,22 % C than is considered weldability condition to avoid brittle material requiring a series of technological measures, namely: preheating, the cooling rates are reduced, and therefore, the risk of hardening. The temperature of pre-heating depending on the carbon content of the steel, the thickness of the material, the shape of the joint and the welding process. Data indicative of the choice of the pre-heating temperature are shown in table 1. The piece has a thickness greater than the pre-heat temperature should be higher, in terms of a two-dimensional propagation of heat [6, 7].

Table 1. *Choice of temperature preheat*

Content Carbon [%]	Preheating temperature [^{0}C]	The minimum thickness [mm]
0.25	100	50
0.35	100 – 250	10
0.45	150 – 300	5
0.60	300 – 400	5

Figure 3 shows the influence of preheating temperature on hardness in the HAZ, for a given carbon and energy some linear, both classical cladding welding and plating ultrasonic welding field.

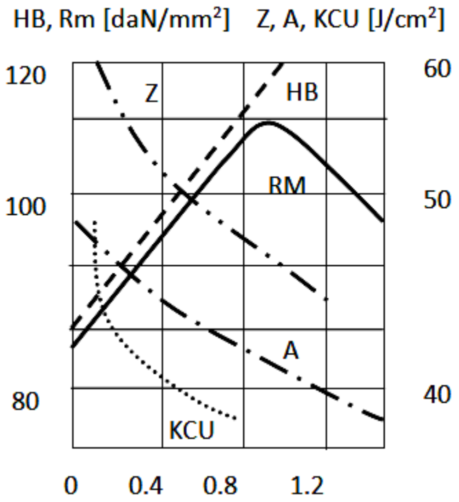

Fig.1. *Influence of carbon content on the mechanical characteristics steels of carbon: HB-hardness; RM-tensile strength; A-plasticity; KCU-tenacity; Z-constriction at break*

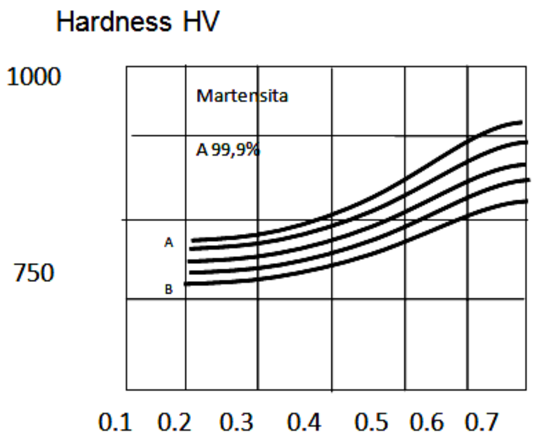

Fig. 2. *Dependence hardness steels the carbon content of the material structure*

- welding of high linear energy. This measure has the effect similar to preheating. Trend hardening decreases with the use of electrodes (wires) or the larger diameter of welding processes are energy intensive (example in the weld line). Figure 4 shows the influence of the linear power and welding speed of hardness, in the case of a carbon steel with 0,44 % C, and 0,53 % C.

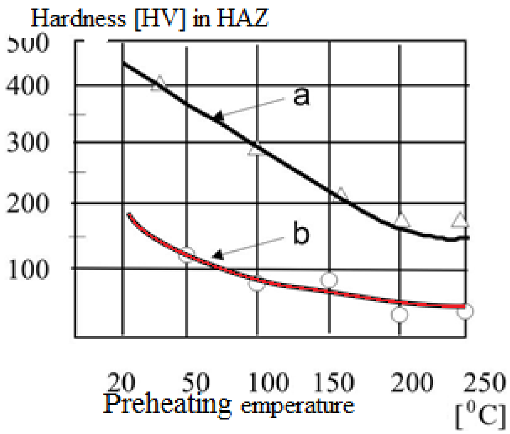

Fig. 3. *Influence of preheating temperature on hardness in HAZ (example for ordinary carbon steel OL 42 and the corresponding linear welding energy) a - ordinary welding; b - ultrasound welding*

The main influence on the hardness maximum electrode diameter for a particular case is illustrated in Figure 5. A pronounced warming of the material can be ensured by the oscillation of the electrode (wire) [9, 10, 11].

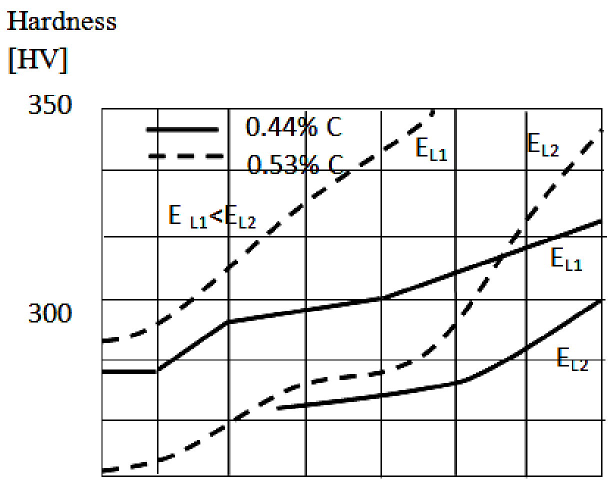

Fig. 4. *Influence of linear energy and welding speed on hardness in the ZIT*

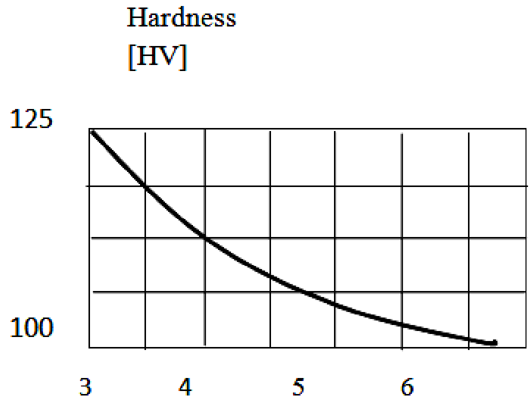

Fig. 5. *Influence of electrode diameter on maximum ZIT hardness*

- forming a seam by suitable choice of high plasticity of material welding (for example, basic coated electrodes). The seam has a higher plasticity, so it can take higher voltages without fissure. Tribute noted that this measure cannot be applied independently of the above measures because it does not influence the hardening heat affected zone.

- ultrasonic welding field. To this end, depending on how ultrasonic energy is introduced into welding bath held a series of events that have positive effects on the characteristics of the deposited layer, thus:

- smooths the welding bath temperature and increases the heat exchange core layer increases the cooling rate up to 800 % in the central area of the bath of welding and 200 % in the edge area; 400% increasing rate of heat release and the heat exchange rate;

- accelerating the diffusion process resulting in thorough mixing of atoms in a stable state to another stable state by the action of cavitation breaths, the pressure of the ultrasonic causing turbulent mixing and boundary film destruction of the liquid phase and the solid phase; stable state to another stable state by the action of cavitation breaths, the pressure of the ultrasonic causing turbulent mixing and boundary film destruction of the liquid phase and the solid phase;

- dendrite structure is completely eliminated fragility decreases while the hardness increases due to obtain a uniform fine grain structure and compact (Figure 6).

The behavior of the welding of carbon steel, however, is affected by the other alloying elements. Their influence on the mechanical properties of the steel compared with the effect of the carbon is shown in table 2.

Silicon is a strong deoxidizer insignificantly influencing mechanical characteristics of carbon steels. For example, 0,1 % and increases the tensile strength by about 10N/mm^2. Lack silicon is an indication that the steel was not calmed.

Manganese increases the tensile strength and yield strength without disturbing workability (1% Mn increases the tensile strength of 120 N/mm^2). Deoxidiser and sulfur is bound by reducing the risk of hot cracking. It is recommended that the ratio Mn/S is greater than 20.

Phosphorus result in an increase in tensile strength and yield strength but worse processability (1 % P leads to an increase in tensile strength of 40 N/mm^2). Phosphorus increases susceptibility to brittle fracture by weakening cold and promotes segregation appearance.

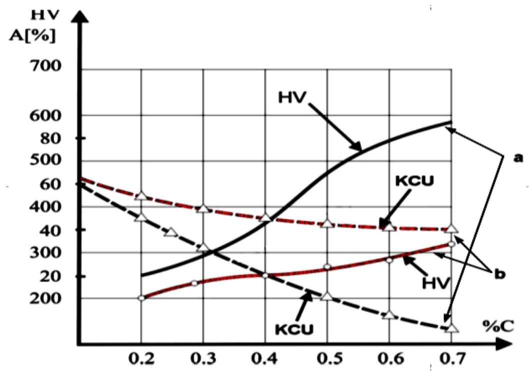

Fig. 6. *Effect of alloying elements on the mechanical characteristics of steel*

Table 2. *Effect of alloying elements on the mechanical characteristic of the steel*

Feature mechanics	The content of elements %, which has the same effect as a 0,1 % C					
	P	Mn	Si	Cr	Cu	Ni
Yield	0.2	0.5	0.4	0.55	0.45	0.8
Tensile strength	0.15	0.8	0.7	0.9	1.0	1.3
Elongation	0.1	0.8	0.5	1.0	0.7	1.5

Sulfur risk of hot cracking stresses. Also influences negatively, deformability and susceptibility to cracking in lamellar disintegration. To higher levels easier machinability by cutting. In general, welding is appropriate to limit the sulfur and phosphorus content in the steel at approx. 0.05 %. The base material has a phosphorus content of sulfur and less, the behavior of welding is improved.

Nitrogen increases the tendency to embrittlement of steel by aging. It is recommended that the steel nitrogen content is less than 0,01 % .

Aluminum is deoxidizer and annihilates the effect of nitrogen lowers the threshold of cold brittleness and provides stability whilst steel . Results in a fine grain structure.

*Coppe*r retard the rate of corrosion of steel in the atmosphere, the content of 0,15...0,5 % . By containing 0,25 % no adverse effects on behavior welding.

The behavior of the welding of carbon steel is influenced in addition to the chemical composition and mode of preparation. From this point of view mentioned peculiarities semi-killed steels behavior welding, cold plastically deformed steels and cast steels [12].

3. CONTRIBUTIONS DIFFUSION PROCESS FOR COATING FIELD ULTRASONIC WELDING OF CARBON STEELS

Plating involves welding filler material existence and part of the base material and liquid and solid after learning a thermal cycle as: heating-melting-solidification cooling. In all phases of the material through which the couple runs with a different intensity diffusion process, which is very intense in the plating process as adhesion to the base material deposited material depends heavily on this phenomenon.

Research undertaken for several couples of materials revealed that when coating occurs:

- diffusion volume;
- diffusion at boundaries between grains;
- diffusion of the external surface.

Displacement of atoms of an element dissolved Ni or Cr in the filler material core network element can be carried out by substitution or interstitial, each way having different mechanisms of realization. In the case of diffusion through the gaps, only some of the interstitial spaces of the network are filled as an interstitial atom has enough free places for neighboring interstitial which can be moved if it exceeds a particular energy barrier which If the ultrasonic activation is much easier than making it possible to move atoms Ni and/or Cr in the base material network.

Depending on the propagation of ultrasonic waves through the material, diffusion can take place through direct exchange of atoms between them, with a change in the circle, the trial can participate Ni and Cr atoms and the other elements. In areas compression due to the propagation of ultrasonic waves passing atom to a vacancy can be done by successive displacement interstitial.

It was found however, that the predominant mechanism of diffusion is given by diffusion through the holidays, where an atom moving in a joined leaving free local vacancy previously occupied, which can displace another atom .

This process of diffusion through the holidays is very much enhanced by ultrasonic waves are mainly not only in the longitudinal waves and transverse waves. The essential condition for diffusion to take place by this mechanism is that the material to be a sufficient number of holidays or at thermodynamic equilibrium melting are over 106 holidays 1014 holidays to ambient temperature .

The tests performed at the electronic microscope showed a high number of vacancies in the filler mixture - based material, and therefore scattering is enhanced from the filler material into the base material.

The amount of mass m, which diffuses through the cross-sectional area ds at constant temperature per unit time can be determined by Fick 's first law , given by:

$$m = - D \left(\left. \frac{\partial c}{\partial x} \right| \right) ds\ dt \tag{1}$$

where in: D is the diffusion coefficient defined as the mass flow to be transported through the unit cross-sectional area ds a concentration gradient $\left. \frac{\partial c}{\partial x} \right|$ in a time period dt equal to unity.

The diffusion coefficient is a quantity that depends on the distance it moving atoms corresponding to lattice parameter and the frequency F, with which these displacements, ie:

$$D = \varphi\, l^2 F \tag{2}$$

where in: φ is the geometrical factor of the network.

The frequency of travel F is composed of a size determined by the temperature and is proportional to the oscillation frequency f atom in a state of equilibrium, about the frequency corresponding to Debye. If ultrasonic activation over the overlap frequency ultrasonic oscillations υ and the probability that an atom to jump to a holiday depends on the energy of the atom to be given for them to move. After driving energy required is U_{LN}, the probability of a jump P atom in a vacancy is given by:

$$P = e^{-U_{LN}/RT} \tag{3}$$

where: U_{LB} is the energy required training vacancies; R-the gas constant.

Bearing in mind what is explained above, the hop frequency F can be determined by a relationship of the form:

$$F = z\ .\ f\ .\ e^{-(U_{LB} + U_{LN})\ .\ /RT} \tag{5}$$

and the diffusion coefficient D, as will become:

$$D = \varphi\, l^2\ .z\ .f\ .\ e^{-(U_{LB} + U_{LN})/ RT} \tag{6}$$

where in: z is the next neighbor of an atom or of a holiday; φ - network geometric factor (φ = 1/12, the face-centered cubic grids, φ = 1/8, in cube networks with constant volume).

For example, in the case of the cubic system, the product φ. z ≈ 1 and relationship to calculate the diffusion coefficient D becomes:

$$D = l^2 . f . e^{-(U_{LB} + U_{LN})/RT} \quad (7)$$

Various concentrations over time in a given area can be determined, using the law of Fick's second given by the expression:

$$\left.\frac{\partial c}{\partial t}\right| = D \cdot \left.\frac{\partial c^2}{\partial x^2}\right| \quad (8)$$

It is clear that between the activation energy for diffusion and the binding energy of atoms in the network to be connected.

It is noted that the strength of the diffusion matrix is represented by the concentration $\left.\frac{\partial c}{\partial t}\right|$ gradient, thus mixing or diffusion is intended for a completely different chemical composition, the possibility of the formation of the necessary connections.

As noted above, the volume diffusion happens especially when the materials are liquid. When completed the curing process begins to dominate scattering at the boundaries between grains. The grain boundaries are based on the increase rate of diffusion because it comprises a construction with less dense and orderly packing of atoms, containing multiple partial holidays, which permits an increase in the frequency of movement of atoms and accelerates the diffusion process.

Experimentally it was found that lower activation energy required for diffusion to the grain boundaries is becoming greater as the temperature decreases, determining an expression of the form:

$$\frac{D_{\lim it}}{D_{volume}} = \frac{d}{\lambda} \quad (9)$$

in which: D_{limit} permeates the grain boundaries; D_{volume} - scattering volume; d-the average grain size; λ - the thickness of the grain boundary.

If the couple filler-material, analyzed in this paper were determined values: d = 5.10-5 m and λ = 5.10-10 m, at 500 ^{0}C, resulting weld cladding without ultrasonic activation ratio :

$$\frac{D_{\lim it}}{D_{volume}} = \frac{5.10^{-5}}{5.10^{-10}} = 10^5 \quad (10)$$

In the case of ultrasonic activation during solidification taking place by fragmentation of the grains and the determined values of d = 5.10^{-6} and λ = 5.10^{-11}, resulting in an expression of the form:

$$\frac{D_{\lim it}}{D_{volume}} = 10^6 \quad (11)$$

namely 10 fold higher than in the case of coating with ultrasonic activation.

4. CONCLUSIONS

1. When the plating process in the field loaded ultrasonic welding , thermal conductivity from the total conductivity is made due to thermal agitation of the electrons of the ion conductivity due to thermal agitation and the agitation of the thermal conductivity and the sub-limits of the grain boundaries due to the ultrasonic wave propagation , the liquid metal bath ;

2. Order to determine the thermal field in the case of coating in the field loaded in the ultrasonic welding using the method sources with good results , taking into account the amount of heat due to propagation of ultrasonic wave soldering bath;

3. Cladding by welding in the case of the ultrasonic field is necessary to determine a function which describes the heat transfer of the boundary steady state, but also non-steady state

4. Mechanical characteristics and behavior of the welding carbon steels are primarily determined by the carbon content;

5. Cladding by welding to 5 carbon steels with a high content can occur in the ZIT a hardening material, so to avoid brittle material required a number of technological steps; preheating, welding linear energy high torque suitable choice of materials, ultrasonic welding field and so on;

6. The case of coating by ultrasonic welding has been found that the field is carried in a deep diffusion process volume at the boundary between the grains and the outer surface of the grain;

7. Diffusion of atoms of Ni and Cr and other elements of the additive material in the core material is carried out by substitution or interstitial the change in the circle by the addition power and holidays;

8. Experimentally it was found that the predominant mechanism of diffusion is given by diffusion through the holidays, it is very much enhanced by ultrasonic wave propagation;

9. When the two materials of the torque, are the predominant liquid in the volume diffusion and solid-state diffusion prevails at the grain boundaries;

10. Experimentally found that the solid state to the cladding by welding in the ultrasonic field, the diffusion is about 10 times higher than in the case of plating without activation by ultrasonic welding.

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