N. RATKOVIĆ, R. NIKOLIĆ, I. SAMARDŽIĆ

ISSN 0543-5846
METABK 53(4) 513-516 (2014)
UDC – UDK 612.791.057:669.182:669.14.018=111

STRUCTURAL, CHEMICAL AND DEFORMATION CHANGES IN FRICTION WELDED JOINT OF DISSIMILAR STEELS

Received – Prispjelo: 2013-12-28
Accepted – Prihvaćeno: 2014-05-30
Original Scientific Paper – Prethodno priopćenje

Fundamental principles of friction welding of dissimilar steels (high speed and tempering steel) from the aspect of metallurgical and chemical processes occurring in the joint zone are presented in this paper. Considering that phenomena accompanying the friction welding are interdependent, it was necessary to experimentally determine the process variable parameters, to establish the optimal welding regime. The experiments were set and realized so that all the variables were analyzed as a function of the friction time. The metallographic investigations included analysis of the joint zone microstructure through structural phases and hardness changes, due to influence of the heat treatment - annealing. The experimental work included analysis of the geometry changes, the joint zone structure and the basic mechanical characteristics of the joint realized by the friction welding.

Key words: friction welding, base metal, carbon steel, high speed steel, friction time

INTRODUCTION

The process of friction welding belongs into procedures of metals joining in the solid state. The basis of the friction welding process is the plastic deformation due to friction induced heating of the contact layers of the base metal [1, 2]. The joining is realized through action of the compression force on the contact zone, which was brought into the plasticity state. The hot plastic deformation, as well as influence of the annealing process of the welded joint between the high speed and construction steel, is leading to changes both of structural and chemical composition of the joint zone. Those changes are consequences of the carbon diffusion from the carbon steel into the alloyed steel. In the carbon steel the decarbonized ferrite layer is being formed. Tendency to this layer forming is being explained by the better solubility of carbon in austenite than in ferrite [3, 4].

The diffusion of carbon from the construction steel into the high speed one is a consequence of solution of the less stable carbides in the construction steel and forming of the stable carbides in the high speed steel. Resistance characteristics of those steels are different at elevated temperatures; during the hot frontal contact they cause an encroachment of the high speed steel into the tempering one. The thermo-physical properties of those steels are also different [5, 6]. This is reason why it is necessary to determine the welding parameters in order to overcome large differences in thermal stability of those two types of steels.

BASICS OF FRICTION WELDING

The appearance of friction in machine structures is generally a damage causing phenomenon and the tendency always is to reduce it to the minimum extent. However, in friction welding process, the friction has completely opposite significance, where it is useful and necessary phenomenon.

Physical essence of the friction welding process is based on transformation of the mechanical energy of friction into the thermal energy on the contact surfaces of the welded elements, which are moving relative to each other and are axially loaded by the compressive force, which should realize the plastic deformation in the heated zones.

One of the elements that are being joined, fixed in the machine jaws, is rotating, while the other one is moving translationally along a straight line, Figure 1. In the initial phase of friction, during the mutual confronting of the two cylindrical parts, complex changes are starting to occur in the material of the contact zone and during very short time interval.

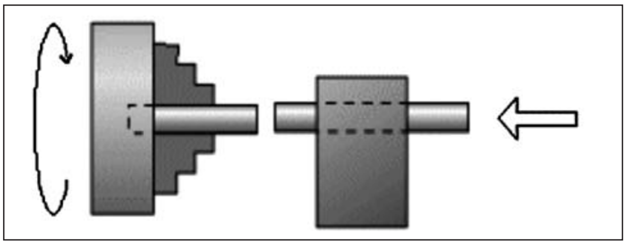

Figure 1 Schematic presentation of the friction welding process model

N. Ratković, Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia.
R. Nikolić, Faculty of Civil Engineering, University of Žilina, Žilina, Slovakia.
I. Samardžić, University of Osijek, Mechanical Engineering Faculty in Slavonski Brod, Croatia.

Mixing of particles of the two materials occurs during the intensive friction. In the very narrow zone (only a few millimeters wide), the diffusional redistribution of certain chemical elements occurs in the zone of the elevated temperatures. At the moment when the stable friction occurs, the plastic deformation causes to progress in depth, but it continues to expand laterally in certain layers. The maximal temperatures are reached in the friction plane, what in this phase leads to decrease of the friction coefficient. Material layers are moving according to the turbulent flow mechanism. Then follows the braking period, when the change of character and size of the plastic deformation appears. The rotation of welded element is stopped by braking, while in the axial direction the compacting is introduced, when the welded parts are becoming even closer, to the distance, which is of the order of the crystal lattice parameter size. The common crystal lattice of the two base metals is thus formed.

STRUCTURAL AND CHEMICAL CHANGES IN THE MIXING ZONE OF THE BASE METALS

During friction, over the joining zone, occurs creation of the hard faced layer of the high speed steel over the tempering steel, about 10 – 200 μm thick, due to “tearing” of micro welded joints of dissimilar base metals that are mixing occurs [1, 2]. Along the joining line appears a transient layer; due to laminar-turbulent flow particles of both base metals are mixing, with higher or smaller degree of homogenization. The transition zone mainly occurs in the middle part of the bar, since in the final phase of friction, the thickness of the hard faced layer decreases due to “forging out” and extrusion of material out of the joint into the “reef” of the extruded material. This zone is characterized by chemical and physical inhomogeneity with respect to the base metal and it represents the zone of poorer mechanical properties than those of the base metal [3].

Content of the basic alloying elements in the transient layer can be several times lower that in the high speed steel – the consequence of diffusion and migration of the most mobile chemical elements, primarily carbon and other carbide-forming elements (Cr, Mo, V). At the same time, the share and dispersion of the carbide phases increase. The structure of the carbide fields consists of martensite (40 %), residual austenite of dispersed carbides, mainly the interstitial vanadium carbide [5].

The chemical composition of the mixing zone is mainly homogeneous, and it consists of the same chemical elements, which are contained, in the base metal of the alloyed steel. The transient layer consists of austenite and carbides. The grain size of austenite mainly depends on the process parameters and it has large influence on the welded joint properties.

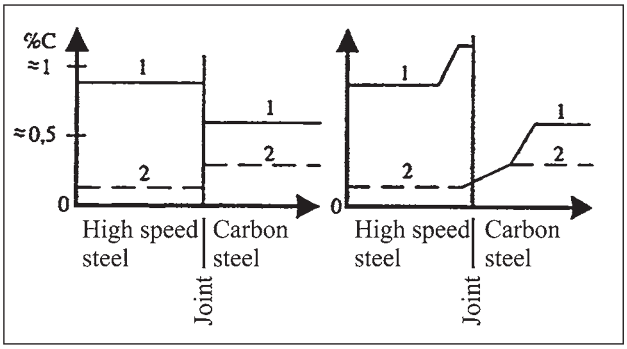

Figure 2 Graphic presentation of the carbon distribution in the joint zone: a) prior to annealing; b) after annealing at 500 – 800 °C [6]; 1 – total carbon content, 2 – carbon dissolved in austenite

THE DIFFUSION PROCESS DURING THE FRICTION WELDING

On the contact surfaces of the welded steels, at pints of effective contact, appear very high specific pressures. Though those pressures are brief, they cause deformation of material at the macro and the micro level. This changes geometrical characteristics of contact, both by shape and size. Action of the high specific pressures also causes thermo-deformation processes, which are causing motion of the point and line defects. Due to increase of the potential energy of atoms the new vacancies are being formed. Dislocations also grow in number and density. All that leads to one of the most important phenomenon during the friction welding, i.e., to diffusion.

An active process of migrations – transport of atoms of elements through the crystal lattice – diffusion, in the final outcome influences quality of the welded joints of dissimilar steels, and thus influences their reliability.

Diffusion causes physical and chemical changes in material in the vicinity of the contact surface. In the zones of dislocations, metal discontinuities or changed crystal structures, the diffusion processes are prone to changes. Due to diffusion of carbon from steel for tempering into the high speed steel, in the tempering steel is formed a decarburized ferrite layer. This phenomenon is also noticed in annealing at temperatures between 500 and 840 °C (Figure 2).

EXPERIMENTAL INVESTIGATIONS

Experimental investigations were done on cylindrical samples made of the high speed steel HS6-5-2-5 (Č9780) and tempering steel C60 (Č1730), which were welded by friction, Figure 3.

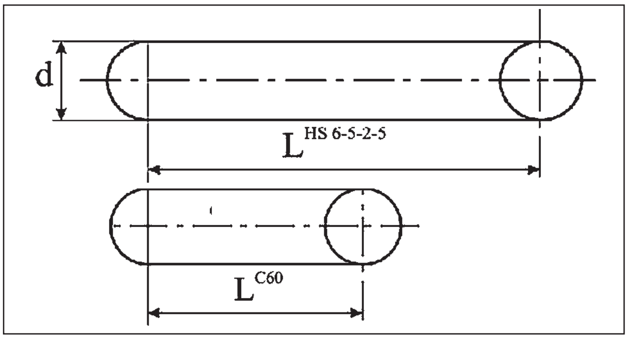

Figure 3 Sample pair for friction welding

The high speed steel HS6-5-2-5 is a special type molybdenum steel. It is applied for high strained tools for cutting machining, aimed for high cutting speed, larger cross sections of chips, namely for milling tool, spiral drills, taps, threader, etc. The carbon steel C 60 has the guaranteed chemical composition and it is aimed for tempering. Of all the non-alloyed steels it is the best one for hardening. It possesses high wear resistance, low corrosion resistance, but it is considered as unweldable by the melting welding procedures (REL, CO_2, TIG). It is used for manufacturing parts in the automobile industry, machine–building industry (for axles, shafts, tools' parts). The declared chemical composition of both steels is given in Table 1.

Table 1 **Content of elements in steels / mass %**

	C	Si	Mn	Cr	Mo	V	W	Co	P, S
HS	0,82	0,45	0,4	4,0	5,0	1,9	6,5	5,5	0,035
C60	0,63	0,19	0,82	-	-	-	-	-	0,045

During the experiment the welding parameters were: number of rotations 2 400 rev./min, welding time 3 – 18 s, friction pressure 90 MPa, compression pressure 200 MPa.

The friction time is the priority parameter, which influences the quality of the joint. It was varied within limits of 3 to 18 s. This variation affects the form of the joint line and macro and micro structure of the joint zone. The most favorable joint line forms and the best mixing of the base metals occur during the friction time of 10,5 to 15 s (narrow tolerance).

The friction and compression pressures influence both the friction process itself and the outcome of the welding. At lower friction pressure 70 MPa, with extended time 15 s, the better extrusion of the softened metal and carbides out of the joint is realized, what cannot happen at pressure of 110 MPa; at that pressure the form of the joint line is quite uneven due to larger extrusion of heated layers and due to uneven plastic deformation of roughness at the contact surfaces.

Micro structure of the base metal – the high speed steel – is perlite; while for the carbon steel it is perlite–ferrite one, Figure 4.

Analysis of the joint zone's micro structure and micro hardness (Figures 5 and 6), before and after the additional heat treatment, has shown that the most favorable values of hardness (especially on the high speed steel side) are obtained after annealing. It is done according to regime 820 °C/4 h.

One of the objectives of investigations presented here was to establish the influence of the friction time and compression on sizes changes of the friction welded samples.

Measurement results show that length reduction of C 60 element is significantly bigger than that of the HS 6-5-2-5 element. It was also noticed that the shortening is uneven during the whole process of friction welding. This is why one can conclude that after approximately

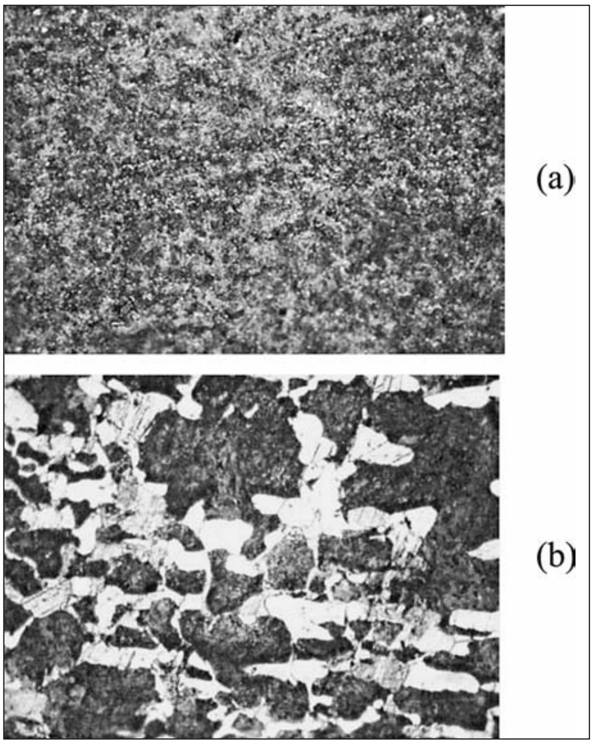

Figure 4 Micro structures of the base metals: a) HS 6-5-2-5; b) C 60 (200 x)

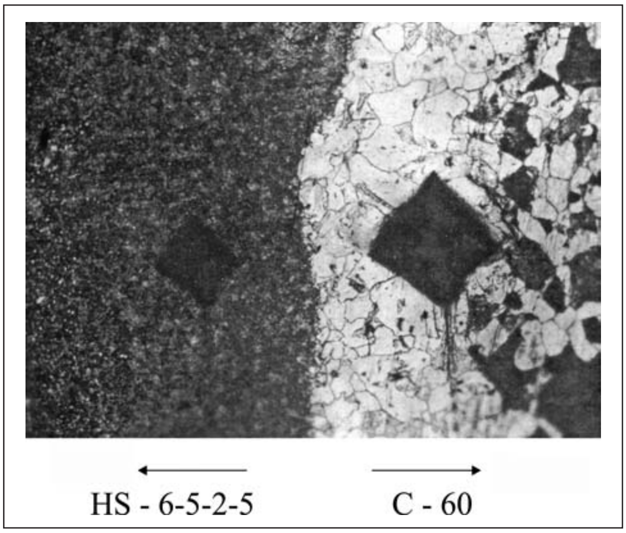

Figure 5 Microstructure in the joint zone(magnification 200 x)

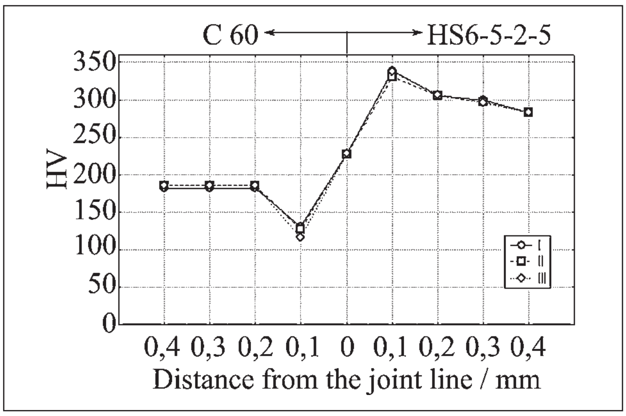

Figure 6 Micro hardness distribution in the joint zone of HS 6-5-2-5 and C 60 (hardness measurements directions: I – the joint axis, II – 2 mm from the axis, III – 6 mm from the axis)

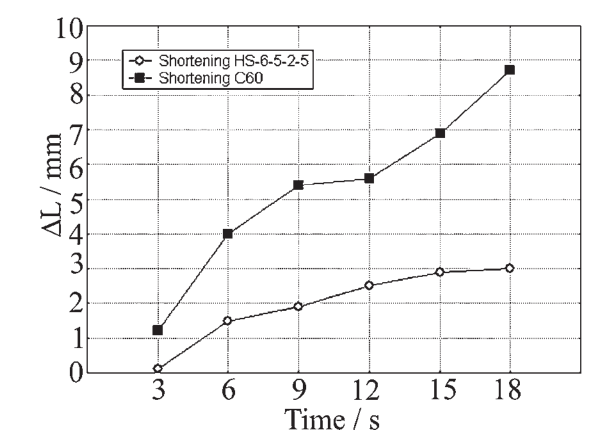

Figure 7 Influence of the friction time on shortening of the samples' lengths

10 s the deformation conditions for transition of welding into the final phase of friction were established. Figure 7 presents the graphical presentation of the samples lengths shortening as a function of the friction time.

Measurement results are presented in Table 2, related to friction pressure of 90 MPa and the compression pressure of 200 MPa.

Table 2 **Measurements results of the initial and final dimensions of the friction welded samples**

Variable / mm *	Steel	Time, t / s					
		3	6	9	12	15	18
L_1	C60	79,4	76,6	75,2	75	73,7	71,9
L_2	HS	44,4	43	42,6	42	41,6	41
ΔL_1	C60	1,2	4	5,4	5,6	6,9	8,7
ΔL_2	HS	0,1	1,5	1,9	2,5	2,9	3,5
ΔL		1,3	5,5	7,3	8,1	9,8	12,2
d_s	C60	20,9	22,3	24	26	28,4	29,6
d_s	HS	18	18,4	19,8	21,1	22,2	23,1
Δd_s	C60	4,9	6,3	8	10	12,4	13,6
Δd_s	HS	1,5	1,9	3,3	4,6	5,7	6,6

***** $L_1 = L_{C60}$; $L_2 = L_{HS}$ - samples lengths, $L = L_1 + L_2$ total length; ΔL_1; ΔL_2 lengths reductions, $\Delta L = \Delta L_1 + \Delta L_2$ total length reduction; d_s samples' diameters; Δd_s diameters reductions.

RESULTS AND CONCLUSION

Through detailed analysis of the welded joint characteristic zones, it was established that they have different content, structure and properties, what directly affects the quality of the welded joint. The microstructure state in the joining zone is a result of the active diffusion process.

Decarburized ferrite zone in the carbon steel C60, with simultaneous increase of the carbon content in the high speed steel HS 6-5-2-5, immediately next to the joint line, is the consequence of diffusion during the annealing process. That caused change of hardness in the mentioned zones.

The plastic deformation character changes with the friction time. Mechanism of plastic deforming is the three-dimensional movement of material which has the non-homogeneous content, i.e., the softened steel, what is the multi-phase system with carbide particles extracted from the solid solution of the high speed steel HS 6-5-2-5.

Intensive plastic deformation occurs during the last phase of the friction welding process, when the compressive pressure of 200 MPa is introduced.

The measurement results of dimensions changes, in the axial and the lateral direction, point to their intensifying with friction time increase. For example, if the friction time was increased from 3 s to 18 s, the reference length of the carbon steel sample would be shortened for 11 % and for the high speed steel sample for 7,6 %, for the same time interval.

Considering that the friction welding process of dissimilar steels is itself extremely complex and that it is quite complicated to obtain relations between individual parameters, this paper offers essential data related to plastic deformation as a function of the friction time.

Technological-metallurgical problems in friction welding of carbon and high speed steels are lesser than if some other welding process was applied, while the economic factor is not negligible as well, what justifies the application of this particular welding procedure, especially in manufacturing of the cutting tools.

Acknowledgement

Parts of this research were supported by the Ministry of Education and Science of Republic of Serbia through Grants ON174001 and TR 32036.

REFERENCES

[1] F. N. Kazakov, Difuzionaja svarka materialov - spravočnik, Mašinostroenie Moskow, 1981.
[2] V. Vilj, Mašinostroenie, 45 (1982), 175-185
[3] R. Ćirić, Prilog analizi osobina trenjem zavarenih spojeva Č7680 sa Č1730, Magistarska teza, Tehnološko metalurški fakultet, Beograd, 1986.
[4] K. Fukakusa, T. Satoh, Traveling Phenomena of Rotational Plane during Friction Welding, IIW Doc. III-806, 1985.
[5] R. Ćirić, Zavarivanje i zavarene konstrukcije, 46 (2001) 1-2, 31-36.
[6] R. Ćirić, Zavarivanje i zavarene konstrukcije, 55 (2010) 4, 137-142.
[7] M. Sahin, Journal of Materials Processing Technology, 168 (2005) 2, 202-210.
[8] R.Ćirić, N. Radović, Metalurgija, Association of Metallurgical Engineers of Serbia, 11 (2006), 315-320.
[9] M. Djurdjanović, Istraživanje procesa oblikovanja krajeva cevnih profila trenjem, Doktorska disertacija, Mašinski fakultet, Niš, 1990.
[10] N. Ratkovic, Modeliranje procesa zavarivanja trenjem mašinskih delova različitih oblika i materijala, Doktorska disertacija, Mašinski fakultet, Kragujevac, 2009.

Note: For English language translation and editing responsible is prof. Martina Šuto, University of Osijek, Croatia