THE CONTACT AND COMPACTING PRESSURES INFLUENCES ON THE QUALITY OF THE FRICTION WELDED JOINT

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Resume

The theoretical and experimental analyses of the friction welding pressure influence on the plastic deformation level and the quality of the friction welded joint are presented in this paper. The joint of the tempering and the High-Speed steel was realized by the friction welding. The objective was to relate the two basic process parameters - the friction and compacting pressures - to plastic deformation parameters during the friction welding of two the steels. The fact that materials are dissimilar additionally complicates the welding procedure and its analysis. The friction welding is a specific and complex process, since in the joint zone material is heated and plasticized with necessary action of the multi-step pressure to realize the joint. The total deformations in the axial and radial directions are directly dependent on the applied welding pressure. Considering that geometry and shape of the friction welded joint directly depend on the friction pressure, some welded joints' basic shapes obtained with various pressures are presented. The experimental investigation was conducted on cylindrical samples made of the two steels and the analysis of results served for establishing the influences of the friction and compacting pressures on changes of the steel samples dimensions and shapes.

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1. Introduction

The friction welding procedure was selected for joining of the two dissimilar steels. The experimental pair of materials consisted of two steels – the high speed steel (HSS) and the carbon steel for tempering. This selection is not arbitrary, but the decisive role had their application in industry, especially in the cutting tools manufacturing (such as drills, mills, etc.). The thermal and mechanical properties of those two steels are significantly different. This is why the friction pressure has the strong influence on the contact layers of those materials. The proper pressure selection ensures the balance between the quantity of the generated heat and plastic deformation in the phase of stable friction, since those steels possess different abilities for plastic deformation [1]. In addition, they also differ with respect to the strength level in the hot conditions, due to what an uneven line of joining would appear. The possibility of lack of penetration appears in the zones of sharp and deep jamming of the high speed steel into the tempering steel. This is why it is necessary to ensure the optimal thermal-deformation conditions, which will enable necessary plastic flow of material during the compacting and filling in the points where the penetration was missing. The mentioned conditions can be achieved properly by selecting the optimal values of the friction pressure and the compacting pressure. The friction welding process is being conducted due to the compressive stress action, set by the machine. That is the reason why in the friction welding of these two steels the risk of hot cracks appearance does not exist. It is the well-known fact that in welding by melting the HSS has strong proneness towards formation both of hot and cold cracks. That makes the justifiability of application of the friction welding even greater. The friction welding of the dissimilar steels was considered in papers [2 - 5]. In earlier research by authors of this paper it was shown that the joining of the two dissimilar steels can be realized, but that it is necessary to select the optimal welding parameters [1, 2]. Otherwise, the flaws in the joint may appear, like the lack of penetration or poor joint's geometry. In addition, in paper [3] are presented results, which are related to structural and chemical changes in the joint, as well as to the influence of the welding parameters on the joint deformation – shortening and joint diameter. Those results have shown that one of the most important parameters is the welding time and that by its extension the deformation of joints is increasing. The pressure increase causes increased shortening of the samples, where the tempering steel one is more shorten than the HSS sample. Similar investigations were conducted by Savić et al. [4], who were measuring the temperature cycles and monitoring the micro structure of the joint's zones in welding of the high speed steel HS 6-5-2C and the carbon steel C60 and made an attempt to make a model of the friction welding. In further research, Handa and Chawla [5] have presented a study of continuous drive friction welding of austenitic stainless steel and ferritic steel combinations. The major contribution of their study consisted of the friction welding process parameters optimization, mechanical characterization, micro structure and fracture behavior analyses. Their experimental results indicated that the axial pressure has a significant effect on the mechanical properties of the joint and that it is possible to increase the quality of the welded joint by selecting the optimal axial pressure. The same authors in paper [6] have determined the strength of the joint by means of mechanical properties such as torsional strength, impact strength and micro hardness. The experimental results indicate that the rotational speed and the axial pressure have a significant effect on mechanical properties of the joint and that it is possible to improve the quality of the joint by selecting the optimal parameters.

Studies of numerous advantages of the friction welding procedure with respect to other welding processes and obtaining of the high quality joints of excellent physical, mechanical, technological and other properties were conducted in papers [7 - 10]. Veljić et al. [7] have shown that the friction welding procedure has advantages related to health and environmental protection and work safety. This refers, primarily, to lowering the emission of gasses and harmful radiation, which are present in the arc welding procedures. The quality of the friction stir welding joints was analyzed in works by Dascau et al. [8] and Eramah et al. [9], where the joints' impact toughness was tested on the Charpy pendulum with separated energies of the crack initiation and separation. It was shown that the highest influence on the crack initiation energy exhibit the rotation velocity (42 %) and the tool angle (39 %), while the rotation velocity imposes the strongest influence on the crack propagation energy (63 %). All these also point to necessity of selecting the optimal welding parameters. Influences of the immersion phase and the tool penetration angle were studied by Veljić et al. in [10], where it was shown that the increase of the tool rotation causes decrease of the maximal temperature zones, what can later lead to improvement of the joint's mechanical properties. Mechanical tests of the aluminum-copper joint were the subject of research in [11], where it was shown that the tensile strength of the joint depends to the largest extent on the welding time and that it has to be longer than 10 s in order to obtain the maximal tensile strength. In addition, besides the mechanical properties, some very important research on the wear resistance of the friction welded joints was done in paper by Kumar et al. [13].

2. General remarks on friction welding

The friction welding (FW) belongs into a group of welding procedures under pressure, i.e. it is the type of welding where the deformation cycle is dominant. The friction welding is, by its nature, the compound of thermal and mechanical phenomena, mutually conditioned and dependent on the base materials' properties. The joint is being realized due to action of the heat released due to friction on the contact surfaces between the base materials. The heat generation is strictly localized and it occurs in the narrow layers in the friction zone. The joint is created at the temperature, which is lower than the base materials' melting temperatures, when the materials are in the plasticized state and when, due to action of the compressive force, the welding occurs.

In continuous friction welding one welded element is rotating with certain speed, while the other element is moving translatory along the straight line towards the first one, Fig. 1. The initial phase of friction begins when the first contact is established between the welded elements. During that confronting of the cylindrical elements the very complex changes of materials are happening in the contact zone within the short time interval.

The process of friction welding actually consists of the two phases: the first is the friction phase, which is characterized initially by the mutual interactions of the very small particles of the two materials, which is then followed by the intensive wear all the way up to transition into the stable friction. The mixing of the highly plasticized particles occurs in the contact zone. The friction pressure corresponds to this phase, Fig. 1. The second phase consists of compacting, when the pressure is increasing until the compacting pressure p_c is reached. The rotation of the welded element is then stopped by abrupt braking. The maximum plastic deformation is then reached. The contact layers of the welded parts are coming to a distance as close as the crystal lattice parameters and the joining occurs.

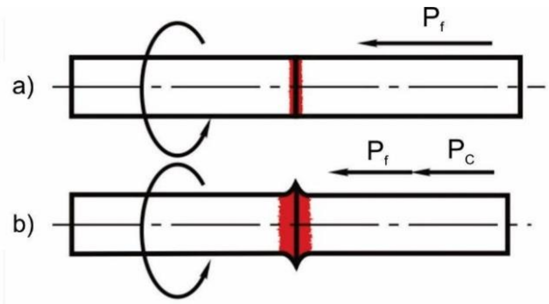

Fig. 1. Schematics of the friction welding:
(a) the friction phase; (b) the compacting phase.
(full colour version available online)

The specific phenomenon during the FW of these two dissimilar steels is hard facing of the high speed steel onto the tempering steel's surface, even during the friction phase. The hard faced layer of the HS steel is about 10 to 200 μm thick, thus the friction pair actually becomes the HS steel-HS steel joining.

3. The friction pressure and the compacting pressure

The pressure in the friction phase has a significant influence on the thermal-deformation phenomena. The pressure action causes intensive deformation of the materials' surface layers, heat release and increase of temperature. In the final phase of the FW cycle, the pressure ensures closing of the contact surfaces to each other at the submicroscopic distances. It also ensures the extrusion of the surplus material and the remaining impurities from the joining spot at the flange, where the so-called "mushroom" is formed. The two-step pressure variation was applied during the experimental part of this research, Fig. 2.

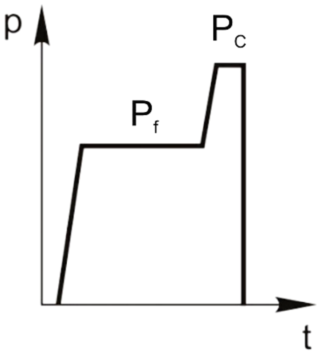

Fig. 2. The pressure variation with time: p_f – the friction pressure, p_c – the compacting pressure.

Besides the various forms of the two-step cycles, some recommendations exist for the three-step pressure variations. It was shown that in the friction welding of the two similar materials of the same cross-section, the same efficiency is achieved by application of the continuous or any other type of the step-wise pressure cycle, while for welding of the dissimilar materials it is necessary to apply the multi-step pressure variation cycle.

The proper selection of the friction pressure (p_f) ensures the balance between the quantity of the released heat and the plastic deformation, in the stable friction phase, [6]. If the applied pressure is too small, the necessary heating of the frontal surfaces cannot be realized, since the quantity of the released heat is small with respect to heat, which is being taken by conduction into the base material, namely into the extruded material of the wreath. In addition, the undesired phases would not be squeezed out from the joining zone, what would create the unfavorable conditions for the final compacting. At the lower pressures, than the optimal values, the axial deformation is reduced. That is manifested by appearance of the zones where the elementary joints were created only spot-wise. Such zones have the shape of the broken concentrically positioned ring-like surfaces where the lack of penetration occurs. It is recommended that the friction welding should be executed with pressures which are proportional to the strength of the base materials at the forging temperature [1]. If the pressure level is higher than the optimal value, the completely different configuration of the joint would appear and the unwanted larger quantity of the material would be extruded into the joint's wreath, Fig. 3.

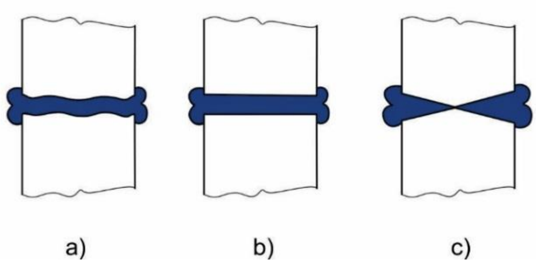

Fig. 3. Influence of the friction pressure pf on the joint shape: (a) too small value, (b) optimal value; (c) too large value.
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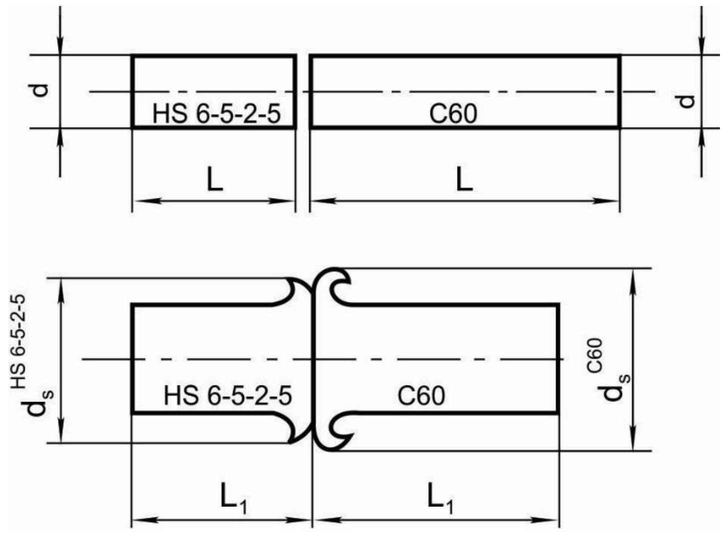
4. Experimental investigation

The experimental part of this research consisted of the friction welding of elements made of the high speed steel HS 6-5-2-5 and steel for tempering C60, Fig. 4a, executed on the friction welding machine with continuous drive, Fig. 4b. The objective of the experiment was to establish the influence of the friction and compacting pressures on the plastic deformation parameters and the quality of the welded joint.

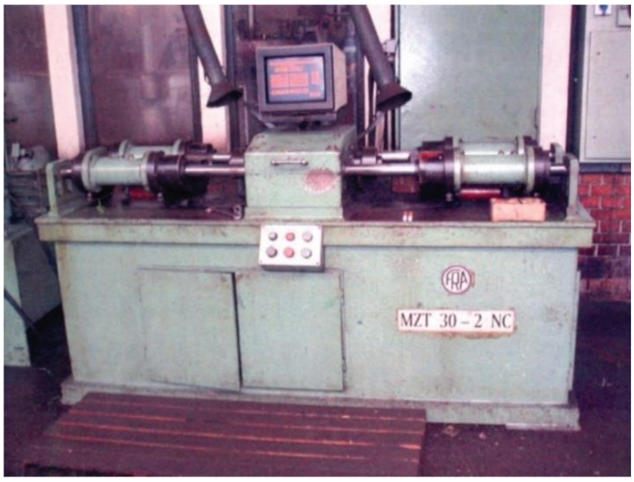
The recommended values of the friction pressure are 10 to 110 MPa and of the compacting pressure 20 to 320 MPa. In the conducted tests the friction pressure values were p_f = 70, 80 and 90 MPa, while the ratio of the compacting and the friction pressures was p_c/p_f = (2.2 – 2.8). Measurements were done for different welding times.

5. Results and discussion

Monitoring of the axial force was done by measuring the change of length of both welded steels' elements. Results are presented by graphs in Fig. 5, for three values of the friction pressure of 70, 80 and 90 MPa.



a) elements of the steel pair (HS 6-5-2-5/C60): prior to welding (above) and after the welding (below)



b) the friction welding machine MZT 30-2 NC
Fig. 4. Friction welding of elements.
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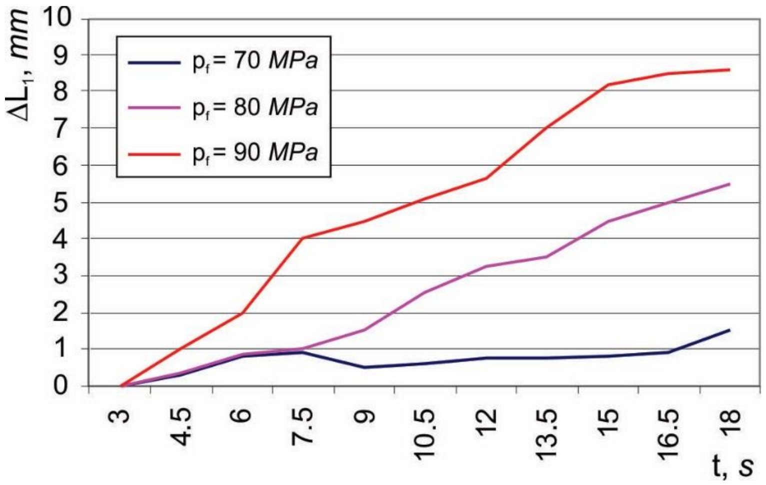
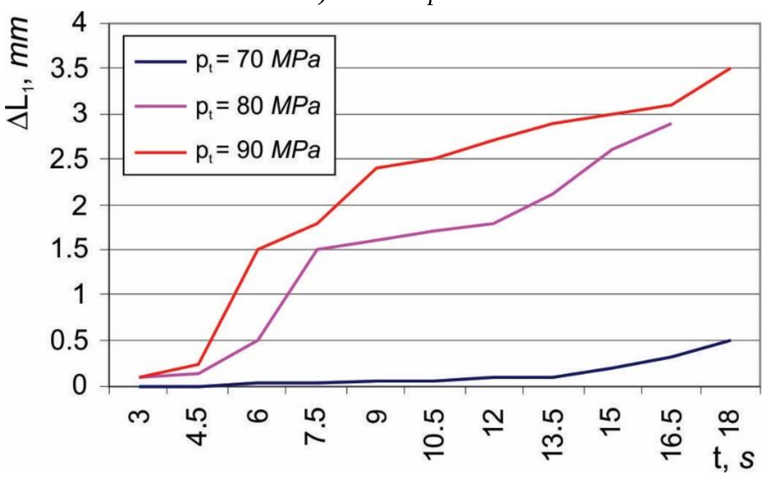
According to results, presented in Fig. 5, one can notice that shortening of the element made of the C60 steel for tempering was significantly bigger than shortening of the element made of the high speed steel HS 6-5-2-5. It can also be observed that during the first 10 s of friction, when the pressure is increasing, the shortening increase per time unit is somewhat smaller. For instance, the element of the tempering steel C60 shortened for 6.8% for 10 s, while in the next 8 s the shortening reached 10.8%; the element made of the steel HS 6-5-2-5 was shortened for 5.2 % during the first 10 s and then in 8 s for 7.4%. This is the consequence of the narrow zone, which is heated up to the elevated temperatures, namely the narrow heat affected zone, for both materials. At the constant friction pressure, the extrusion of the heated metal out of the joining zone is smaller, since the deformation resistance is higher.

Variation of the samples' wreath diameters in the joint zone, for both materials, expressed in % is shown in Fig. 6. Results given in this figure are obtained for the friction pressure of 90 MPa and the compacting pressure of 200 MPa. Analyses have shown that the variation of the extruded materials diameter depends more on the duration of friction than on the friction pressure.



a) C60 sample



b) HS 6-5-2-5 sample

Fig. 5. Graphical presentation of the samples shortening in terms of time.

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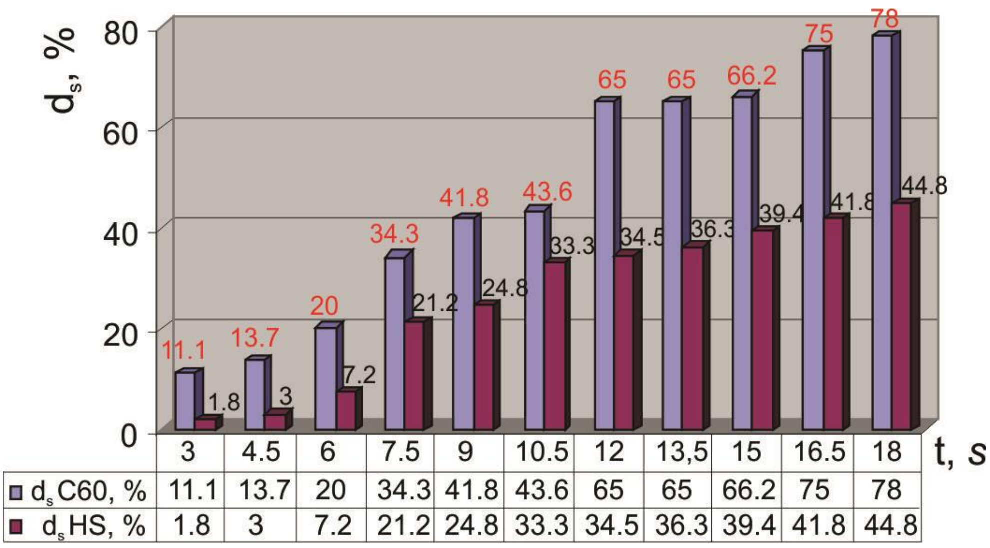

Fig. 6. Variation of the wreath diameter (ds) at the joint spot in terms of the friction time, for both elements at pf = 90 MPa and pc = 280 MPa.

(full colour version available online)

6. Conclusion

The quality of the joint, realized by the friction welding, cannot be defined based on a single parameter, only. However, it could be established how each particular parameter, within range of its values, contributes to that quality. Due to the complexity of the friction welding process, one should investigate all the relevant parameters, like the friction and the welding times, which, in the proper correlation with the pressure, enable obtaining of the best results. One should also study influence of the welding speed, i.e. the number of rpms, then temperature and other parameters, as well as the metallurgical indicators. All these are even more prominent when the friction welding is used for joining the two dissimilar materials.

Considering the pressure, as one of the most important process parameters in the friction welding, it was shown in this paper that its influence on unfolding and results of the plastic deformation, and by that on the quality of the realized joint, is very important. By measuring and analysis of the investigated parameters, related to plastic deformation (samples' shortening, wreath diameter changes), one can come up with the feedback information, which helps in determining the interval of the optimal values of the considered process parameters (friction and compacting pressures in this case).

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Note

The shorter version of this research was presented at the SEMDOK 2016 International Seminar, 27. – 29. January, 2016, Terchová, Slovak Republic, reference [14].

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