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Micro-structure in the joint friction plane in friction welding of dissimilar steels

Nada Ratković[a], Dušan Arsić[a,*], Vukić Lazić[a], Ružica R. Nikolić[a,b], Branislav Hadzima[b]

[a] Faculty of Engineering University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia
[b] Research Center, University of Žilina, Univerzitna 8215/1, Žilina 010 26, Slovakia.

Abstract

In the friction welding of dissimilar base metals occurs an uneven heating in the outside and inside zones of materials what causes appearance of various structures in the joint zone. Considering that the objective is achieving of the homogeneous welded joint, an imperative is to analyze the microstructure of the realized welded joint. By the microstructure analysis, one can establish the relationship between the friction welding parameters and the structure that appears in each of the joint's characteristic zones. In addition, it is possible to analyze the potential appearance of flaws during the welding process and to discover the causes for their appearance in order to prevent those in the future. This paper presents a review and analysis of microstructures of the characteristic joint zones in the friction plane of the two different steels, the high-speed steel and carbon steel for tempering. The experiment consisted of varying the friction welding parameters (friction pressure and friction time) and monitoring of micro structure in the joint zone and its immediate vicinity, both from the side of the tempering steel and the HS steel, as well as defining the present phases and compounds. The emphasis was set on analysis of the melting and the mixing zones and carbides created during the welding.

Keywords: Friction welding, microstructure, friction plane, mixing zone, melting zone.

1. Introduction

The friction welding occupies an important place, whether it concerns the classical friction welding or the friction welding with mixing. The reason for that are the numerous advantages of the friction welding procedure, with respect to other welding procedures, primarily in regards with environmental protection and human health [1], while simultaneously one obtains the welded joints of the exceptional mechanical properties [2-5]. Analysis of mechanical properties, performed by Handa and Chawla in [2], has assumed studying of joining the austenitic and ferritic steels. That study consisted of the friction welding process parameter optimization, microstructure, mechanical characterization and fracture behavior. 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 optimum axial pressures. The same authors in paper [3] have shown the experimental results that indicate that the rotational speed and the axial pressure have a significant effect on the mechanical properties especially the torsional strength, impact strength and micro hardness. An analysis was conducted by Savić et al. in [4] of joining the high-speed steel HS 6-5-2C and the carbon steel C60, where an attempt was done to form a model of friction welding of the dissimilar materials, by monitoring the temperature cycles and variation of the microstructure during the welding process. Similar investigations were performed by authors in [5-7] where the results which are related to structural and chemical changes in the joint were presented, 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

* Corresponding author. Tel.:+381 64 276 39 81.
E-mail address dusan.arsic@fink.rs

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Nomenclature

BM	– Base metal;
HAZ	– Heat affected zone;
WM	– Weld metal;
L	– Specimens' lengths;
d	– Specimens' diameters;
n	– Number of rpms;
p_c	– Compacting pressure;
p_f	– Friction pressure;
t	– Thickness of the hard-faced layer;
t_f	– Friction time;

extension the deformation of joints is increasing. The main conclusion is also that the joining of the two dissimilar steels can be realized, but that it is necessary to select the optimal welding parameters. That is also shown by some of the state-of-the-art researches [9-14], which were dealing with this problematics. Ma et al. [9] were investigating the friction welding of the two different steels – 1045 carbon steel and 304 stainless steel and performed a detailed analysis of microstructure and mechanical characteristics of the joint. Obtained results have shown that the weld interface can be clearly identified in the central zone, while the two metals interlock with each other by the mechanical mixing in the peripheral zone. On the carbon steel side, a thin pro-eutectoid ferrite layer was formed along the weld interface while on the stainless steel side the austenite grains were refined to a submicron scale. In addition, the existing δ-ferrite content in the stainless steel decreased from base metal towards the weld interface. It was also established that the severe plastic deformation plays a predominant role in rapid dissolution of the δ-ferrite, compared to the high temperature role. The carbide layer, consisting of CrC and Cr23C6 was formed at the weld interface because of elements' diffusion. Finally, it was also established that the carbide layer thickness significantly influences the tensile properties of the joint. On the other hand, Nathan et al. [10] were trying to investigate possibilities of application of the titanium alloys for manufacturing the tools for the friction stir welding (FSW), as well as the microstructural characteristics of the three tungsten based alloys FSW tools, viz. 90%W, 95%W and 99%W. The welded part was made of the high strength low alloy (HSLA) steel and plate thickness was 5 *mm*. The joint zones' micro structure was monitored by the SEM and the chemical compositions of the compounds by the EDS. In this investigation was found that the tool made of the 99% W doped with 1% La_2O_3 exhibited microstructural stability at elevated temperatures during the FSW process. Li et al. in [11] were investigating the joining of titanium and steel, where they were observing the influence of the rotational speed of parts on creation the non-metallic inclusions in the joint zone, as well as on the tensile strength and micro hardness of the welded samples. Results have shown that the morphology of the intermetallic compounds, mainly $TiFe_2$ and TiFe, created at the steel part, transformed from dispersive to laminar pattern, as the rotation speed increased from 400 to 1800 rpm, with a transition point of around 600 rpm. The highest tensile strength of 468 MPa, corresponding to the joint efficiency of 90%, was achieved at 600 rpm, where the valley value of equilibrium interfacial temperature was obtained. The similar problems, as considered in this paper, were investigated by Reilly et al. in [12], where the material flow during the FSW of aluminum and steel was monitored, as well as by Sarkara et al. in [13] and Kurt in [14] who were considering the material flow during the FSW of the two steels. They all monitored the influence of the material flow on the tool geometry, welding conditions (rotation speed, plunge depth, dwell time), and the surface state of the steel sheet (un-coated or galvanized). Based on the conducted research, it was possible to establish the consistent interpretation of the stick-slip conditions at the tool-work piece interface, addressing an elusive and long-standing issue in the modeling the heat generation in the friction stir processing. It was also determined in [13] that the flow zone size and ligament width increase with increasing tool penetration and that material flow during the FSW can be subdivided in two components, namely the rotational flow and the through thickness flow. A combination of the two components results in the spiraling motion of the plasticized material within the flow zone.

In this paper is presented an analysis of microstructure in different zones of the friction welded joint. Analysis involved the plane (zone) of friction in which the largest changes occur, due to introduced heat and the welding pressure. All the processes occurring in the friction plane were analyzed, especially the microstructure and appearance of carbides and carbide planes and their position in the joint during the process. The specific characteristics is also the fact that the joining by friction welding of the two steels is done, the high-speed steel (HS) and the carbon steel, which are very different with respect to their mechanical properties, chemical composition and structure.

2. General data on applied materials

The decisive role in materials selection had their applicability in industry. Bearing in mind the wide application of the high-speed steels in metal machining and their high price, it is economically more rational to manufacture the working part of the tool of the HS steel, while its holder is made of the carbon steel.