PROPERTIES AND MICROSTRUCTURE OF JOINTS CREATED BY THE METHOD OF ROTARY FRICTION WELDING

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Abstract

During the rotary friction welding process is a joint made at the interface of two materials using the parameters such as temperature, pressure, relative motion speed and the secondary parameter is time. This method offers a wide range of applications, especially when are welded rotating parts. The research is focused on homogenous and heterogenous rotary friction welds between subsequent materials: steel DIN 975, stainless steel 1.4301, aluminum alloy AlCu4PbMgMn, aluminum alloy AlMgSi, copper Cu - ETP, brass CuZn39Pb3. Heterogenous welds were formed by various combinations of the mentioned materials, where the microstructural analysis was performed and the physical nature of the joint formation during rotary friction welding was created. The influence of the geometry on the contact surfaces was monitored on homogenous welds - the results were used in the selection of the effective geometry also in heterogenous welds. Furthermore, sets of homogenous welds were subjected to a static tensile test, a hardness test and also microstructural analysis. Welded workpieces were cylindrical with 10 mm in diameter.

Keywords: Heterogeneous, microstructural analysis, rotary friction welding

1. INTRODUCTION

The need of determination the correct geometry of contact surfaces of metals welded by the method of rotary friction welding steams mainly from the need to ensure the most efficient welding process for the homogeneous welds and from the diversity of mechanical properties of the individual materials in the heterogeneous welds.

Equally important is an understanding of internal processes, that ensure the connection. However, theoretical claims must always be substantiated by an experiment that verifies the claims. The principles are mainly at the level of crystal lattice of material and physical mechanisms associated with it.

The main goal of research is findings related to the material area, not the technological area. In particular, these are the findings concerning the mechanism of joint formation and the influence of these mechanism on the mechanical properties.

2. MATERIALS AND METHODS

Rotary friction welds are realized on the SV 18 Ra lathe, which was not in any special way for friction welding purpose modified. As a locking element of non-rotating workpiece was used jig, which was fixed in tail stock of lathe and pressure of the workpieces ensures ejection of tail stock spindle [1].

The steel used in the experiments was purchased in the form of threated rods M12 and M14 and subsequently turned to a diameter 10 mm. Metric DIN 975 (0.25-0.55 wt% C) threated rods are one-meter-long rods that are threated along their entire length. Unlike a screw or bolt, the do not have a head. They are designed to be used in tension joining and/or stabilizing objects together [2].

Stainless steel 1.4301 (17.5-19.5 wt% Cr; 8.0-10.5 wt.% Ni), which was used during experiments, is austenitic stainless steel and manufacturer guarantees high corrosion resistance but after welding it is not resistant to intracrystalline corrosion [4]. Aluminum alloy AlCu4PbMgMn, is primary intended for machining, because the lead admixture creates a short chip that can be easily removed. It has medium to high strength, high resistance to corrosion and seawater and what is important for our purposes is well weldable without residual stresses [3]. Before the microstructural analysis were specimens abbreviated to length 20 - 25 mm, hot pressed into bakelite, grinded, polished and etched.

Problem occurs before microstructural analysis because of etching heterogeneous welds since they are two different materials. Every single material needs specific etchant or etching time, so we were doing experiments in this matter too. In some cases, we over etched the material or material was not completely/correctly etched unfortunately. Specimens prepared in this way was ready for microstructural analysis, which was realized on the basic on images made by optical microscope NEOPHOT 32 and evaluation software Axio vision from Zeiss company.

In the case when are welded materials with the different mechanical and physical properties, complications occur due the different strength of materials at the high temperatures and also different thermal conductivity, which lead to different degrees of plastic deformation. For this reason, three different contact surface geometries were tested, which provides three different processes of temperature, for individual welding parts, during the entire welding process. Homogeneous welds were also created with different geometries of the contact surfaces with later regard to mechanical properties and the efficiency of the joint formation. An overview of individual tested geometries is shown in **Figure 1**. Where the angle $\alpha = 45°$ and $\beta = 37.5°$.

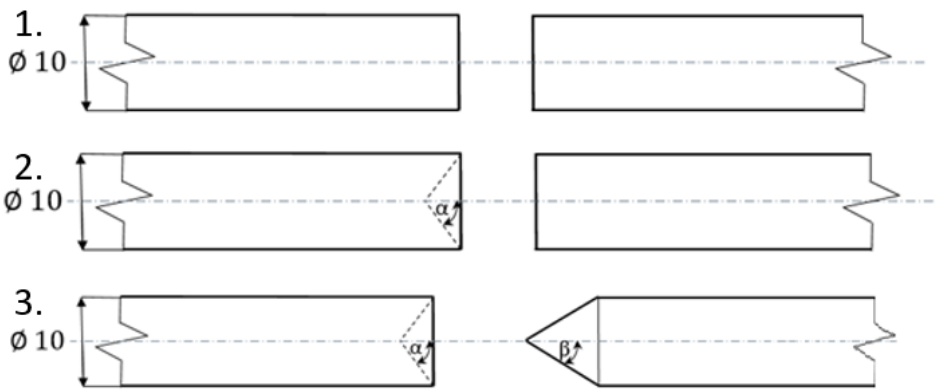

Figure 1 Overview of individual tested geometries

The investigated mechanisms of physical metallurgy associated with formation of the joint are mostly diffusion mechanisms. All diffusion mechanisms are in progress under extensive plastic deformation and local melting temperature of the material. What is important to include in rotary friction welding process is the effect of centrifugal force, which affects the said diffusion mechanism. Thus, the centrifugal force affects the diffusion direction of the atoms. This assumption was confirmed [1], where the hardness of the welded steel decreased at the weld joint and the hardness increased in the direction from the weld to the heat-affected zone and the base material. Here, the carbon in the interstitial positions diffused in the direction indicated by the centrifugal force.

It is assumed that, some heterogenous welds were formed as substitution solid solutions, which were governed by a size factor, which indicates the ratio of the effective radius of the atoms in the base metal and the impurity. This radius may differ by no more than 15% to form the substitution solid solution. The smaller difference between the atomic radiuses means better solubility in solution [5] Elements predominating in the tested alloys, meet this condition.

As for the vacancy mechanism, the interstitial atom needs less activation energy to jump to the interstitial position near the vacancy. Upon substitution, it is clear that the substitution atom fills the vacancy - unoccupied nodal point. In the initial stages of rotary friction welding, during intense friction, leveling of surfaces and increasing temperature is created a higher concentration of vacancies in these areas, which results leveling of atomic concentration described by Fick’s first law. This diffuse balancing of the concentration of atoms take place between the two contact surfaces and thus helps to form of the weld.

3. RESULTS AND DISCUSSION

In the case of homogeneous welds of steel DIN 975, we used etchant suitable for steel - Nital, which is a compound of nitric acid and ethanol (3 % HNO_3 + 97 % ethanol). In the **Figure 2**, are details of the macrostructures of the joints created by the second (inner cone - flat) and third (inner - outer cone) geometry. As you can see (left side of **Figure 2**), in the case of second geometry, the non-welded places were appeared, due the premature termination of the welding process. The friction weld created by using the third geometry (right side of **Figure 2**) was without the any visible defects. **Figure 3** represents microstructures of the friction welds created by the second and third geometries, without the visible defects. The right side of figure is little bit over-etched.

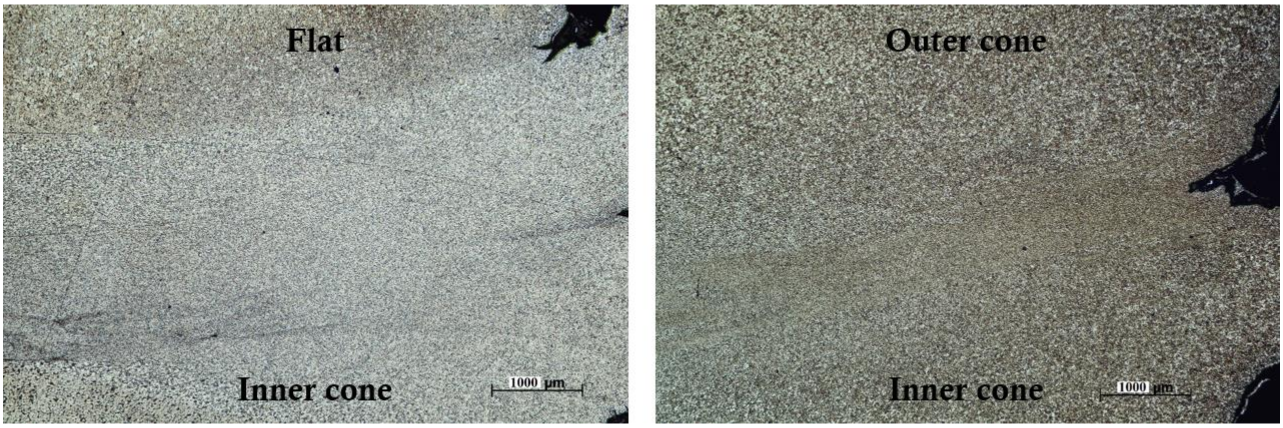

Figure 2 Detail of the macrostructures of the welded joints

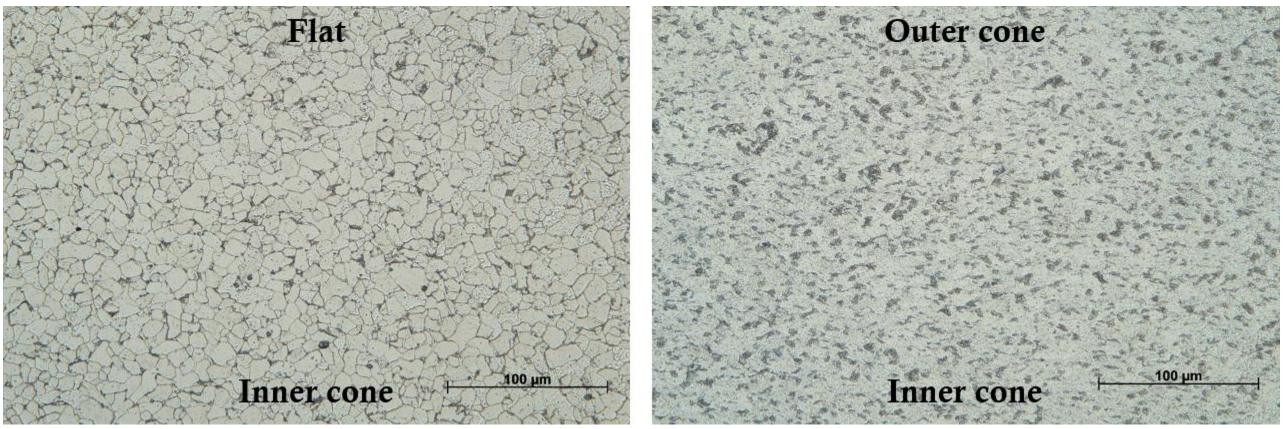

Figure 3 Microstructures of the welded joints

As for the microstructure of the rotary friction weld created by the first geometry (flat - flat), the weld showed along its entire length a fine boundary between the materials, which can be attributed to the early completion of the welding process. Due to the better visibility of the mentioned boundary, only **Figure 4** of the weld microstructure is attached.

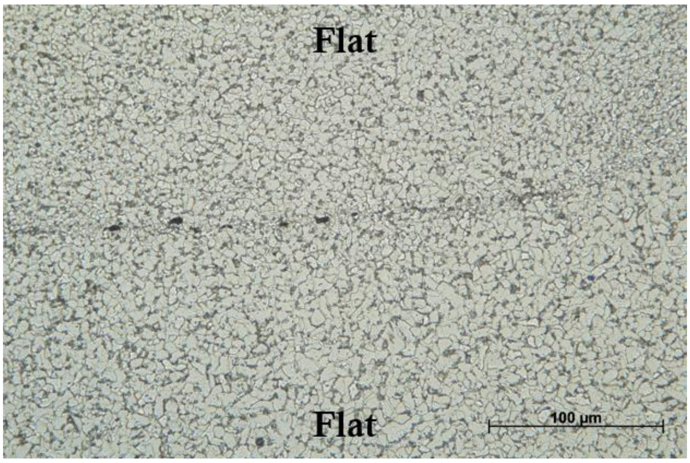

Figure 4 Microstructure of the welded joint created by first geometry

Microstructure from the weld area demonstrates, in all cases, the grain refinement in weld area and graduated transition of grain thickness, in the following direction weld → weld affected zone → basic material [1]. In the **Figure 5** are seen materials which were used in the heterogenous friction weld of steel DIN 975 and austenitic stainless steel 1.4301. In this case was used the etchant suitable for stainless steel with composition of 10 ml HNO3, 20 ml HCl, 20 ml Glycerin, 10 ml H2O2.

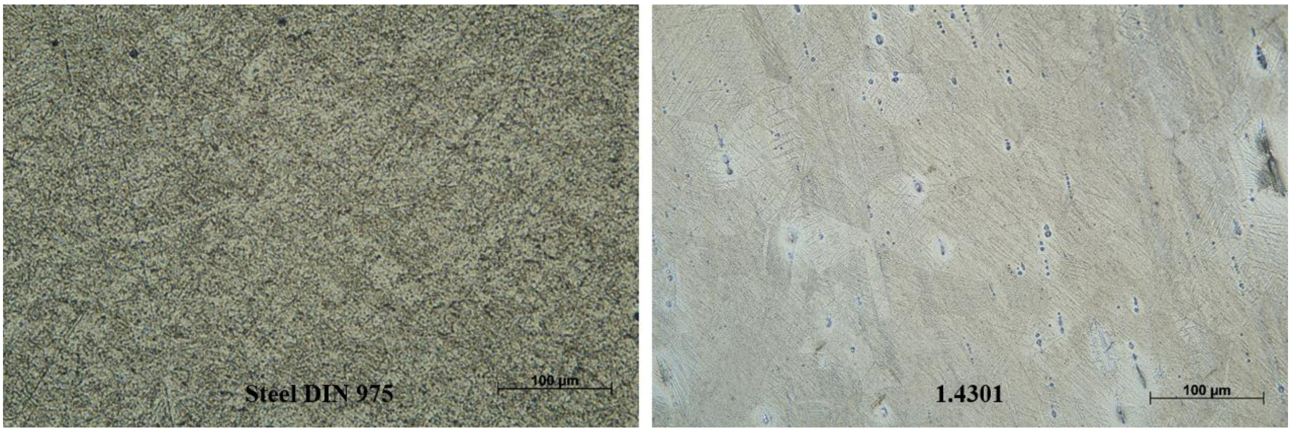

Figure 5 Microstructures of the base materials

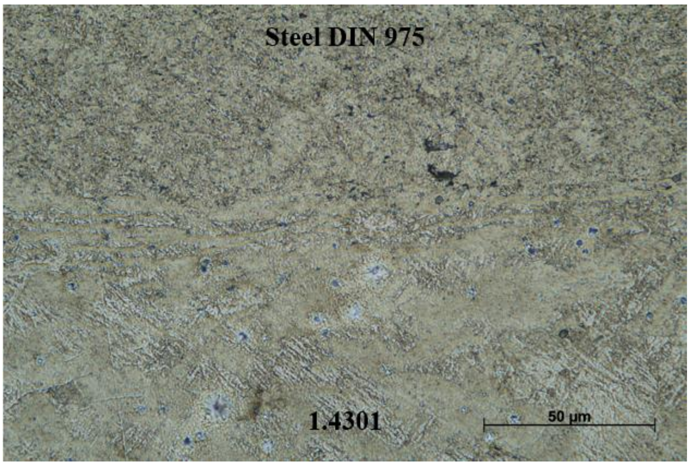

Figure 6 Microstructure of the heterogeneous weld of steel DIN 975 and stainless steel 1.4301

In the case of a heterogeneous weld of DIN 975 steel and stainless steel 1.4301, it is possible to attribute the formation of the weld to the just mentioned diffusion process, on the basis on the microstructure (**Figure 6**) of the materials in the joint area. This is provided by the difficult-to-observe boundary and the almost smooth transition of materials.

In the case of heterogeneous weld of DIN 975 steel and aluminum alloy AlCu4PbMgMn, the etchant suitable for aluminum with a composition of 0.5 % hydrofluoric acid and 99.5 % water was used. If, in the case of a heterogeneous weld of the aluminum alloy AlCu4PbMgMn and DIN 975 steel, the formation of the joint occurred on the basis of the diffusion mechanism described above, then only on minimal extend. The joining of the materials took place mechanically and probably due to the influence of Van der Waals forces (**Figure 7**). The mechanical connection was created on the basis of plastic deformation of the surfaces and the local melting temperature of the material (primarily AlCu4PbMgMn). There was no observable change in the microstructure of any of the two welded materials. The joint was macroscopically smooth and clean with a clear boundary of materials. Of course, the flash was formed only on the aluminum alloy side.

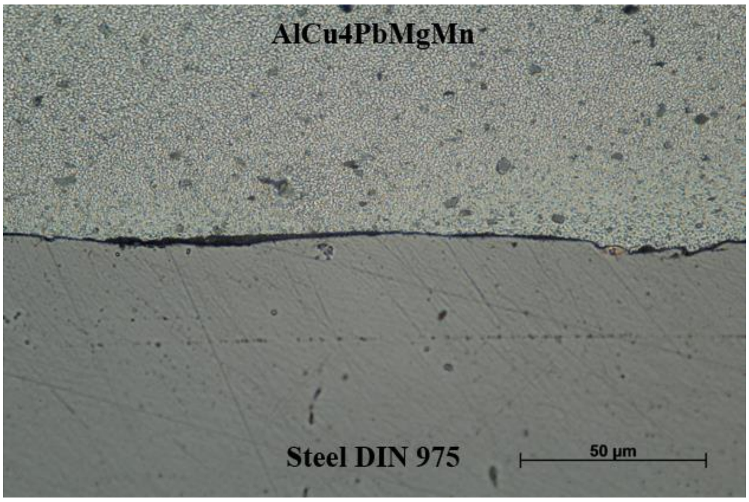

Figure 7 Microstructure of the heterogeneous weld of aluminum alloy AlCu4PbMgMn and steel DIN 975

4. CONCLUSION

In conditions of possibility of forming the joint by the method of rotary friction welding, were experiments with homogeneous welds of DIN 975 steel purposeful. From a technological point of view, a solid weld was created in all three cases without any problems within a few second. It is necessary to take account the fact, that the machine was not designed for the purpose of rotary friction welding. For this reason, I believe that it would be possible to create rotary friction welds of DIN 975 steel on a professional machine without any defects. As far as the geometry is concerned, the use of the first geometry (flat - flat) would probably bring the expected results, even within the mechanical properties of the joint and at the same time the economic characteristics. It is important to realize that, when using the remaining two geometries, it is necessary to semi-finished product adjustment before welding and also after welding modification, due to the larger flash, because during the welding process it is necessary to re-weld the entire surface of the cones to form a solid weld. As a result, more material is consumed by welding process, which is reflected in the size of the flash.

The essentially smooth transition of materials in the case of the heterogeneous weld of DIN 975 steel and austenitic stainless steel 1.430, proves the smooth mixing of said materials and also their suitable combinability during welding.

In the heterogeneous weld of AlCu4PbMgMn and DIN 975 steel, a solid joint was formed, but not predestinated for mechanical stress.

The possible determination of the weldability of individual different types of materials is useful wherever it is necessary to fundamentally influence the primary physical properties of the material, for example in electrical engineering, abrasion-stressed components or even in jewelry.

Regarding the possible application of technology to the industry, it is useful to have defined mechanisms that control the formation of the joint for a particular material.

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