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DYNAMIC RECRYSTALLIZATION IN M2 TOOL STEEL DURING FRICTION WELDING

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ABSTRACT

Friction welding of M2 tool steel and 1730 quenched and tempered steel was performed with the aim to reveal the origin of extremly fine martensitic grain in M2 steel after welding. Taking into account thermomechanical parameters and final grain size it was assumed that austenitic grain refinement prior to martensitic transformation have been produced solely by dynamic recrystallization in M2 steel. Obtained grain size is in a good agreement with previously published data and values predicted by models.

Key words: Dynamic recrystallization, friction welding, grain refinement

INTRODUCTION

Friction welding is a welding process developed with the aim to provide bonding of materials which, due to different properties and microstructures, could not be bonded using traditional fusion processes [1]. Two pieces rotate in contact and heat necessary for welding is generated on the friction plane. Heat input is governed by rotating speed, friction time and applied pressure. Increase of any of these parameters would increase heat input [1].

In spite of long tradition of industrial use of this welding process, it is not clear why deformation step in this process was not discussed in more details. Therefore, the aim of this paper was to find out an explanation for the presence of very fine martensitic grains in welded zone after friction welding.

EXPERIMENTAL

The chemical compositions of two frictionally welded steels are given in Table 1, tool steel (M2) and .quenched and tempered (Q+T) steel (1730).

Table 1. The chemical compositions of two steels frictionally welded (wt.%)

Steel	**C**	**Si**	**Mn**	**Mo**	**V**	**W**	**Cr**
M2	0.89	-	-	4.75	1.82	6.03	4.07
1730	0.63	0.194	0.82	-	-	-	-

Working peaces of both steels were machined in the form of bars with diameter of 10.2mm. During friction, no upsetting was done. Total friction times varied between 7.5 and 15s; friction pressure was 80MPa, rotation speed 2850 rev/min. After welding, weld joints were cooled in still air, cut and prepared for further optic-metallographic investigation.

RESULTS

Temperature profile. Typical temperature vs. time dependence obtained during friction welding of Q+T and M2 tool steel is shown in Figure 1. The thermocouple was positioned in M2 steel.

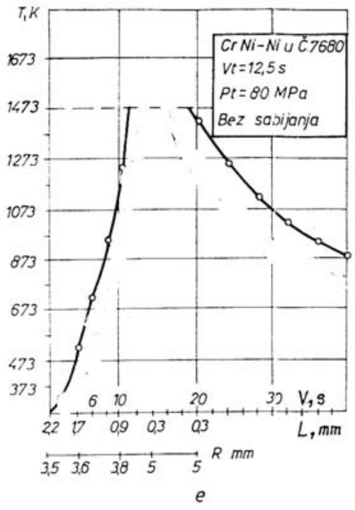

Fig. 1. Temperature vs. time dependence obtained during friction welding of Q+T and M2 tool steel (Friction time 12.5s; friction pressure 80MPa; no upsetting)

Temperature profile is similar in all tests, i.e. it takes between 7 and 11s for temperature to increase up to 1473K. Above 1473K, the holding time for specimens wad different, depending on welding parameters. Also, Ni-CrNi thermocouples have limited temperature monitoring and recording capability, since 1473K is the highest temperature at which these thermocouples have reliable accuracy. As it can be evaluated from Fig. 1, cooling rate related to air cooling in still air after welding was close to 20K/s, for the temperature region 1473-673K.

Microstructures. Macrostructure of weld joint is shown in Fig. 2. Steel 1730 is in the lower position (black area), while tool steel is in the upper part of the micrograph. Two areas can be revealed in M2 tool steel: (i) area which was not heated over Ac_1 temperature with predominantly very fine carbides where no occurrence of phase transformation could be detected — this feature will not be discussed in further details, and (ii) area with very fine martensitic microstructure related to heating temperatures much above Ac_1. These fine grains are present on both sides of friction plane, i.e. in the area of the most intensive friction. The size of these martensitic grains is between 2 and 4μm. This feature is pointed out in Fig. 3.

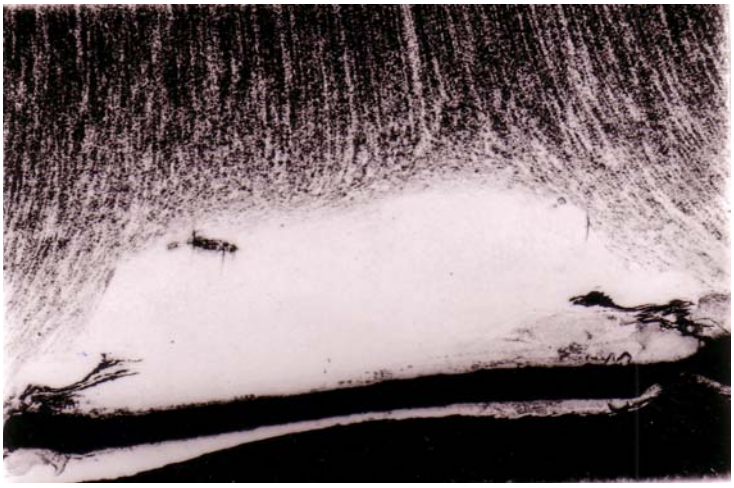

Fig. 2. Macrostructure of weld joint (X100; nital 2%)

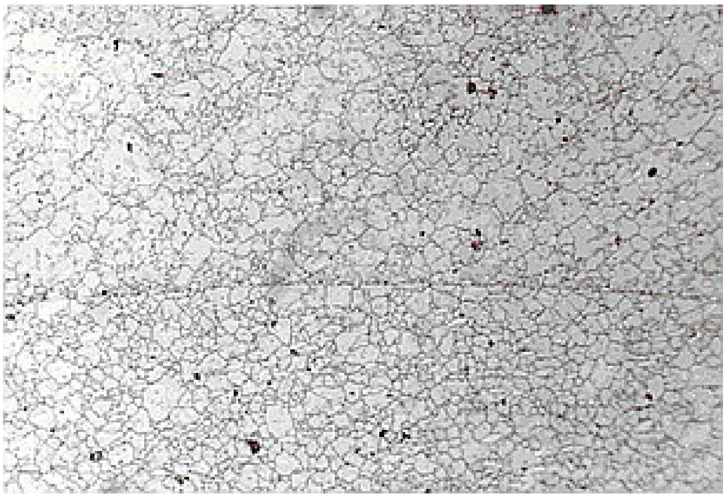

Fig. 3. Microstructure on the friction line (X1000, nital 2%?)

DISCUSSION

During welding, temperatures measured in zone 1 (see Fig. 2) are higher than 1473K. At temperatures above 1473K each specimen had spent between 4 and 9 seconds. At such high temperatures, most of the carbides in M2 steel are dissolved. Therefore, M2 steel becomes prone to intensive grain growth [2, 3]. Previously published data concerning austenitic grain size of M2 steel at high temperatures are summarized in Table 2 [2-5].

Data from Table 2 show that reported austenitic grain size is 10μm, or even greater. It may be assumed that with further temperature increase austenitic grains would grow to larger size. Therefore, an assumption was established that austenitic grain prior to air cooling (in the absence of deformation) must have been at least 12-15μm.

Table 2 Austenitic grain size in M2 steel at high temperatures

Temperature, °C	Grain size, μm	Ref.
1150	10	[2]
1150	18	[3]
1200	19	[2]
1300	30	[4]

M2 tool steel is characterized with very good hardenability, providing martensitic microstructure both deeply in cross section and during cooling in still air. Critical cooling rate for M2 steel is close to 1K/s. Martensitic transformation, as diffusionless transformation, is strongly dependant on previous austenitic microstructure, i.e. the size of martensitic grains depends strongly on the size of previous austenitic grains [5]. This implies that prior austenitic and transformed martensitic grains should have very close size. According to Fig. 3 and data in Table 2, prior austenitic grain must have been much smaller than expected as-annealed grain size at temperatures over 1474K.

Friction welding can be discussed as thermomechanical treatment, i.e. deformation process at high temperatures. Therefore, it can be assumed that large strain obtained during friction welding, together with high temperature and relatively long holding time at respective temperatures would produce conditions for commencement of dynamic recrystallization. Since the “single pass” deformation took place, it is reasonable to suppose that dynamic recrystallization and/or metadynamic recrystallization must have taken place. Fig. 4 shows a sketch of the “necklace” mechanism of dynamic recrystallization in austenite which was proposed by Sellars [6].

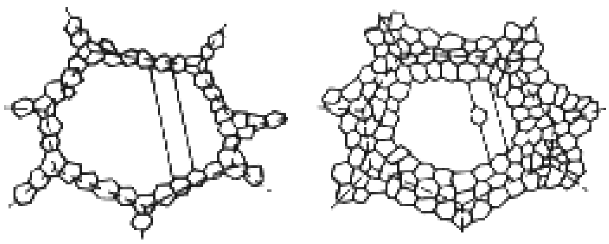

Fig. 4. Model of progress of dynamic recrystallization [6].

Nucleation of new dynamically recrystallized grains occurs at grain boundaries, subgrain boundaries, twins and deformation bands in deformed austenite. Due to a very large number of preferential places, nucleation is much faster than growth of new grains, leading to efficient grain refinement of austenite. Dynamic recrystallization will be finished at the moment when all necklaces cover the whole prior austenite grains. If after the deformation the DRX was not finished, both dynamically recrystallized and deformed grains will be present. Fig. 5 shows very fine, uniformly sized martensitic grains, close to the zone of the most intensive friction. Larger grains have originated from nonrecrystallized austenitic grains.

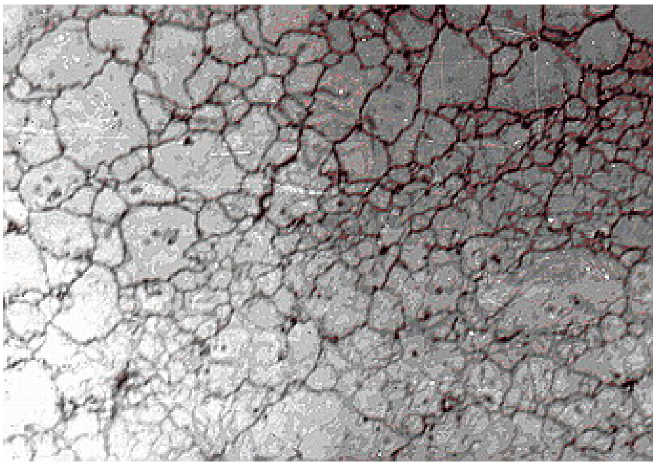

Fig. 5. Dynamically recrystallized grains in M2 tool steel close to friction plane, 1000x, nital2%.

On the other hand, proposed models for dynamically recrystallized grain size have lead to values between 3.5 and 8μm, which was taken as a confirmation of the assumption that only dynamic recrystallization could have produced such small martensitic grains.

CONCLUSION

Friction welding of M2 tool steel and 1730 quenched and tempered steel was performed with the aim to reveal the origin of extremly fine martensitic grain in M2 steel after welding. Total friction times varied between 7.5 and 15s; friction pressure was 80MPa, rotation speed 2850rev/min and without upsetting. It was assumed that austenitic grain refinement prior to martensitic transformation has been produced by dynamic recrystallization in M2 steel. Assumption was justified taking into account a good agreement between obtained grain size and values predicted by models.

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