INVESTIGATION OF DYNAMIC RECRYSTALLIZATION ON THE ROOT SIDE OF FSW JOINTS

Ákos Meilinger[1], Dr. Imre Török[2]
[1]assistant lecturer, [2]honorary professor
University of Miskolc, Institute of Materials Science and Technology

1. INTRODUCTION

The grain size is basically influences the mechanical properties of welded joints. During friction stir welding (FSW) different grain sizes occur on the welded joint as a function of wall thickness and joint zones [1] [2]. The main goal is to reach the fine grained structure in whole joint. According to the literature [3] [4] [5] the dynamic recrystallization (DRX) can occur during friction stir welding and it can cause extra fine grains. This can be determining for the aspects of tool design and technological parameter optimization. The weakest part of a friction stir welded joint is the root because the circumstances are not always good for dynamic recrystallization, so coarser grains are appeared there. Therefore the investigation of dynamic recrystallization on the root side is important for technological parameter optimization.

2. MATERIALS

During the experiments examinations of the material structure were in focus. Two aluminium alloys were examined for comparison: a heat treatable AlMgSi alloy (6082-T6) and a non-heat treatable AlMg alloy (5754-H22). The heat treatable alloy was an extruded profile often used in the industry; the non-heat treatable alloy was a rolled sheet. Table 1 shows the chemical compositions and table 2 shows the mechanical properties of base materials.

Table 1.
Chemical compositions of base materials (weight %)

Base material	Al, %	Mg, %	Si, %	Fe, %	Mn, %	Condition
6082	97,3	0,56	1,11	0,23	0,51	T6
5754	95,8	2,78	0,29	0,36	0,37	H22

Table 2.
Mechanical properties of base materials

Base material	$R_{p0,2}$, MPa	R_m, MPa	A_{50}, %	Condition
6082	266	305	22	T6
5754	180	234	17	H22

3. DYNAMIC RECRYSTALLIZATION

For different materials the occurring of dynamic recrystallization requires different temperature, strain rate and strain. It highly depends on alloying and manufacturing process of base material. So same technological parameters and FSW tool normally are not good for every aluminium alloy. Therefore different base materials require different technological parameter combinations to reach the dynamic recrystallization.

During FSW the DRX can occur especially in the weld nugget (fine-grained zone), but on the root side coarser grains occur. The reason of this can be the unsufficient values of temperature, strain rate and strain. The FSW joints have very good mechanical properties because the fine-grained structure on the weld nugget. These mechanical properties can be improved by fine-grained root side, but important to know critical temperatures, strain rates and strains here.

The DRX can be investigated by hot compression tests which results a true stress – true strain curve. The DRX can be occurring when on the true stress – true strain curve after the elastic deformation the stress reaches the maximum value during hot compression. The recrystallization must be started before the maximum stress value [6], so a critical stress and strain value can be determinate. The other basic method of the DRX determination is the measure of the grain sizes after hot compression tests. If the dynamic recrystallization occurs the grain size will smaller than original.

4. TESTING CONDITIONS

The hot compression tests were made with Gleeble 3500 physical simulation equipment. The 6082-T6 test pieces made from the extruded profile, the direction was perpendicular to the extruding direction. The 5754-H22 test pieces made from the rolled sheet, the direction was perpendicular to the rolling direction. The diameter of test pieces was 10 mm, the length was 15 mm.

Tests were made with previously measured [7] welding slow and fast heat cycle on the root. On the fast heat cycle we used additional cooling on the root side which can decrease the grain size and it can influence the DRX. The fast heat cycle required additional air flow cooling. The testing peak temperature was 250 °C. The strains were 0,1 [mm/mm]; 0,5 [mm/mm]; 1 [mm/mm]. The strain rates were 0,1 s^{-1}, 0,5 s^{-1} and 1 s^{-1}. After hot compression tests we got true stress – true strain curves where we can find the critical stress and strain values for DRX. We use the Poliak – Jonas method [8] [9] to determine these critical values. After this the grain sizes were measured by optical microscope.

5. RESULTS

After hot compression tests we determine the critical stress and strain values and the grain sizes were measured. Table 3 summarizes these results:

Table 3.
Results of hot compression tests

Nr.	Base material	Strain [mm/mm]	Strain rate [1/s]	Heat cycle	Critical stress [MPa]	Critical strain [mm/mm]	Grain size [μm^2]
1.1	5754-H22	0,1	1,0	slow	-	-	25,7
1.2	5754-H22	0,5	1,0	slow	-	-	29,3
1.3	5754-H22	1,0	1,0	slow	-	-	34,3
1.4	5754-H22	0,1	0,5	slow	-	-	27,4
1.5	5754-H22	0,5	0,5	slow	-	-	29,2
1.6	5754-H22	1,0	0,5	slow	-	-	31,3
1.7	5754-H22	0,1	0,1	slow	-	-	36,2
1.8	5754-H22	0,5	0,1	slow	-	-	38,9
1.9	5754-H22	1,0	0,1	slow	-	-	42,2
2.1	5754-H22	0,1	1,0	fast	-	-	33,7
2.2	5754-H22	0,5	1,0	fast	-	-	36,1
2.3	5754-H22	1,0	1,0	fast	-	-	38,9
2.4	5754-H22	0,1	0,5	fast	-	-	33,6
2.5	5754-H22	0,5	0,5	fast	-	-	33,7
2.6	5754-H22	1,0	0,5	fast	-	-	36,2
2.7	5754-H22	0,1	0,1	fast	-	-	29,2
2.8	5754-H22	0,5	0,1	fast	-	-	31,3
2.9	5754-H22	1,0	0,1	fast	-	-	36,1
3.1	6082-T6	0,1	1,0	slow	not definable		258
3.2	6082-T6	0,5	1,0	slow	no DRX		257
3.3	6082-T6	1,0	1,0	slow	no DRX		460
3.4	6082-T6	0,1	0,5	slow	not definable		124,6
3.5	6082-T6	0,5	0,5	slow	208	0,062	137
3.6	6082-T6	1,0	0,5	slow	166,8	0,049	192,4
3.7	6082-T6	0,1	0,1	slow	not definable		144,3
3.8	6082-T6	0,5	0,1	slow	153,0	0,024	130,5
3.9	6082-T6	1,0	0,1	slow	156,9	0,069	119,2
4.1	6082-T6	0,1	1,0	fast	not definable		274,2
4.2	6082-T6	0,5	1,0	fast	no DRX		274,1
4.3	6082-T6	1,0	1,0	fast	no DRX		391,7
4.4	6082-T6	0,1	0,5	fast	not definable		62,6
4.5	6082-T6	0,5	0,5	fast	207,4	0,034	105,4
4.6	6082-T6	1,0	0,5	fast	206,5	0,038	125,3
4.7	6082-T6	0,1	0,1	fast	not definable		124,6
4.8	6082-T6	0,5	0,1	fast	193	0,070	119,2
4.9	6082-T6	1,0	0,1	fast	187,4	0,062	144,4

As we can see the table 3 does not contain critical stresses and strains for 5754-H22 base material because with these testing parameters the DRX cannot occurs. In case of 6082-T6 the DRX occurs but not in every case.

Figure 1 shows the grain sizes as a function of strains with different strain rates and heat cycle on 5754-H22 alloy.
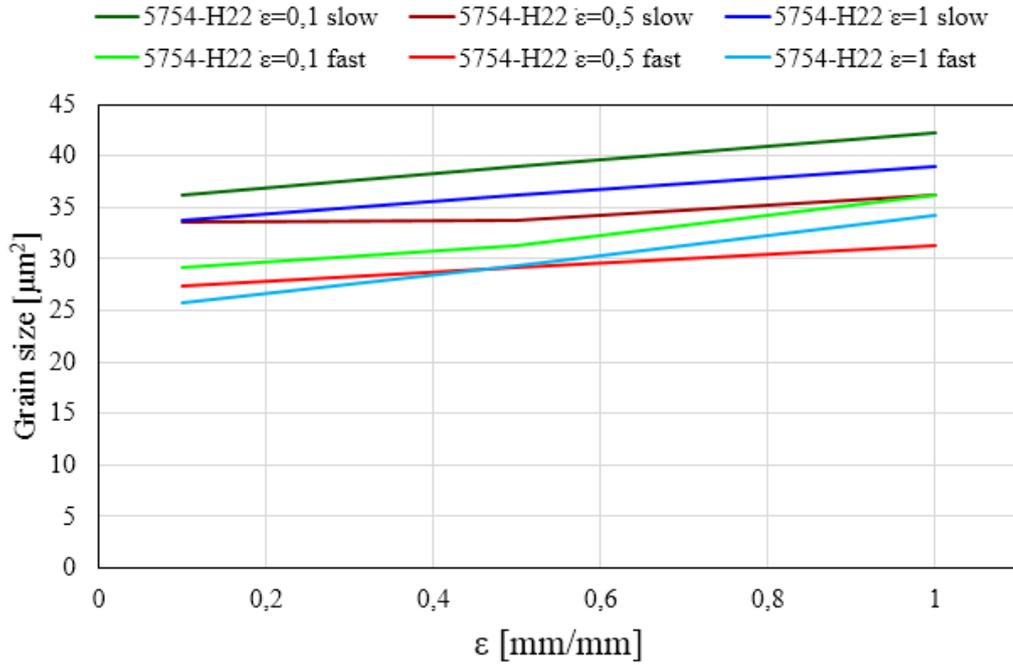

Figure 1.
Measured grain sizes after hot compression tests on 5754-H22 alloy

The figure clearly shows the increasing of strains results slightly grain coarsening. The initial average grain size of this base material is ~28 μm^2, and larger sizes were measured, so this is evidences the lack of recrystallization. The faster heat cycle results smaller grain sizes during tests.
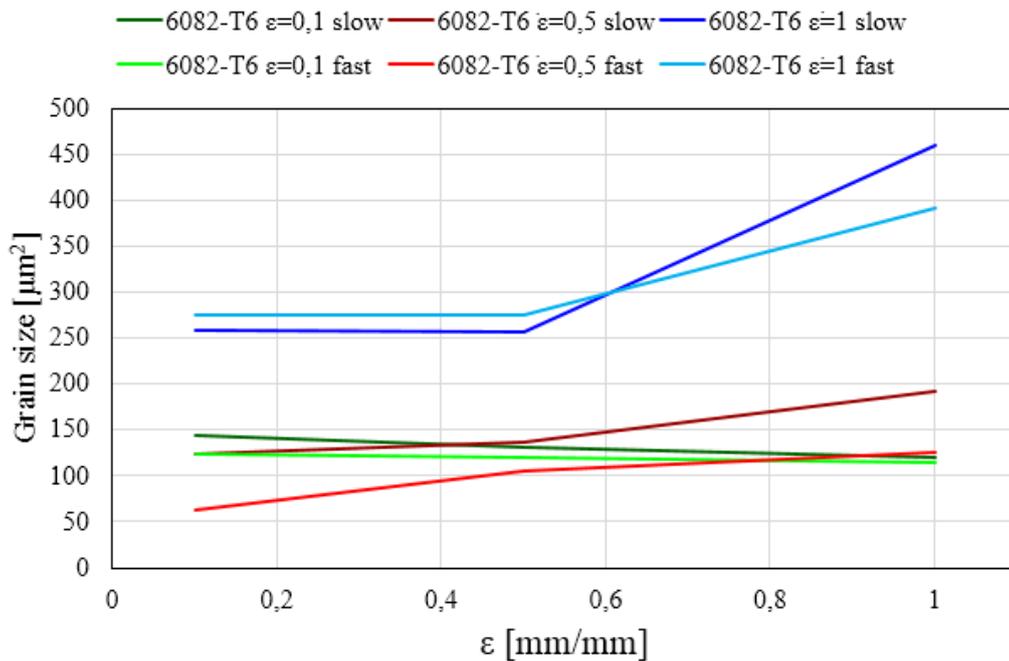

Figure 2.
Measured grain sizes after hot compression tests on 6082-T6 alloy

The initial average grain size of this base material is ~260 μm^2. In case of 6082-T6 alloy typically larger grain sizes occur with large strain rates both slow and fast heat cycle. It can be concluded that during FSW the lower strain rates preferable on the root side (e.g. application of lower rotational speed). In case highest strain rates the occurring of DRX cannot be definable. The possible explanation of this there is a critical value of strain to reach DRX [10]. This is an increasing value when the strain rate and/or temperature increase [10]. Hence, it can be assumed that the strains were insufficient in case of high strain rates. So these results show that preferable the lower strains and strain rates on the root side of the FSW joints (e.g. smaller tool pin diameter). Lower strain rates result fine-grained structure so the dynamic recrystallization probably occur. In case of 0,5 s^{-1} strain rate there is significant grain size difference between slow and fast heat cycle, but when the strain rate was 0,1 s^{-1} this difference is not significant.

6. CONCLUSION

The investigation clearly shows that in case of 5754-H22 the dynamic recrystallization cannot occur whit the application of slow or fast FSW root heat cycle and typical strains and strain rates. The grain size was smaller in case of fast root heat cycle. The 6082-T6 alloy has different reaction to hot compression tests, because lower strain rates results dynamic recrystallization both slow and fast root heat cycle. In case of 1 s^{-1} strain rate grain coarsening observed because probable it requires a critical strain which was not reached.

ACKNOWLEDGEMENT

REFERENCES

[1] MISHRA, R. S., MAHONEY, M. W.: **Friction stir welding and processing**, 2007, pp. 1 - 17.

[2] MEILINGER, Á., TÖRÖK, I.: **Effect of temperature field and pressure force on the inhomogeneity of 5754-H22 and 6082-T6 FSW joints**, Materials Science Forum, vols. 794 - 796, 2014, pp. 377 - 382 ISSN: 1662-9752

[3] SAUVAGE, X., DÉDÉ, A., CABELLO M., A., HUNEAU, B.: **Precipitate stability and recrystallisation in the weld nuggets of friction stir welded Al-Mg-Si and Al-Mg-Sc alloys**, Material Science Engineering A491, 2008. pp. 364-371.

[4]   WANG, H., COLEGROVE, P., MAYER, H.M., CAMPBELL, L., ROBSON, R.D.: **Material Constitutive Behaviour and Microstructure Study on Aluminium Alloys for Friction Stir Welding**, Advanced Material Research Vol. 89-91, 2010. pp. 615-620.

[5]   MCNELLEY, T.R., SWAMINATHAN, S., SU, J.Q.: **Recrystallization mechanisms during friction stir welding/processing of aluminum alloys**, Scripta Materialia 58, 2008. pp. 349-354.

[6]   CHEN, Z., F., CUI, S.: **Recrystallization of 30Cr2Ni4MoV ultra-super-critical rotor steel during hot deformation**. Materials Science and Engineering, 528, 2011, pp.5073-5080.

[7]   MEILINGER, Á., TÖRÖK, I.: **The effect of welding heat cycle to the properties of friction stir welded joints**, Production processes and systems, vol 7., 2014, ISSN 1786-7983, pp. 19-30.

[8]   POLIAK, E. I., JONAS, J. J.: **Critical Strain for Dynamic Recrystallization in Variable Strain Rate Hot Deformation**, ISIJ International Vol. 43, 2003. pp. 692-700.

[9]   STEWART, G. R., JONAS, J. J., MONTHEILLET, F.: **Kinetics and Critical Conditions for the Initiation of Dynamic Recrystallization in 304 Stainless Steel**, ISIJ International Vol. 44, 2004. pp. 1581-1589.

[10] SAKAI, T., BELYAKOV, A., KAIBYSHEV, R., MIURA, H., JONAS, J.J.: **Dynamic and post-dynamic recrystallization under hot, cold and severe plastic deformation conditions**, Progress in Materials Science 60, 2014. pp. 1-207.