Effect of tool geometry and heat treatment on friction stir processing of AA6061

Karan Chauhan*, M.V.N.V. Satyanarayana, Adepu Kumar

Department of Mechanical Engineering, National Institute of Technology, Warangal 506004, Telangana. India

karanchauhan884@gmail.com, veeru.setti@gmail.com, adepu_kumar7@yahoo.co.in

Abstract. In this study, AA6061 plates of 6 mm thickness were subjected to friction stir processing with 50% pin overlapping to produce bulk area fine grain structure using three different tool geometries. Post-processing heat treatment was carried for all samples to investigate effect of different tool geometries on microstructure and micro-hardness of AA6061. 3D optical microscope and Vickers micro-hardness tester were employed to examine the microstructure and micro-hardness and results have been reported. From analysis, it was observed that, post-processing heat treatment improved the properties and among three different tool geometries, the samples processed with hexagonal pin profile yield the best results.

Keywords: Friction stir processing, Fine-grained structure, AA6061

1. Introduction

Huang et al. addressed new developments in processing of fine-grained (FG) structured materials. FG structure materials possess wide range of properties such as super-plasticity, high toughness, high strength etc. [1]. Wide variety processes are available for producing fine-grained structured materials such as Equal channel angular processing (ECAP) [2], High-pressure torsion (HPT) [3], Accumulative roll bonding (ARB) [4], and Friction stir processing (FSP) [5-6]. Grain refinement occurs in above processes due to recovery and recrystallization. But in first three processes bulk area FG cannot be produced and in addition to that they induce large strains and require large temperature. To avoid these difficulties FSP was studied and the results were very good compared to other processes. FSP is derived from Friction Stir Welding (FSW) [6] but instead of joining the materials, it focuses on enhancement of properties of the desired material. This process is widely used when enhancement of properties is required without other disadvantages and so FSP is an effective method for producing fine grain structure [8]. AA6061 alloy is extensively used in aircraft industry for wing tension members, shear webs and ribs. It requires FG structure for improving mechanical properties and formability.

Yong-Jai Kwon et al. [7] produced UFG of AA 1050 alloy with variation of process parameters and found that temperature is an important parameter and less heat input is required to obtain UFG. Jian-Qing Su et al. [8] produced bulk UFG with overlapping passes, concluded that fine grains were obtained with rapid cooling and found low dislocations in bottom region. Liu et al. [10] fabricated UFG of 6061 Al alloys with different rotation rates and by employing water-cooling to reduce the grain size. Xue et al. [11] used pure Cu with 5-passes of FSP and obtained bulk area UFG structure by varying process parameters and cooling medium.

2. Experimental Procedure

AA6061-T6 aluminium alloy with 6 mm thickness plates were used as a base metal for this study. **Table 1.** shows the chemical composition of AA6061. All experiments were performed on a 3-Ton capacity CNC based Friction Stir Welding machine. AISI H13 tool steel was selected as the tool material as it has excellent combination of abrasion and shock resistance along with better hardenability. The composition of tool material is shown in **Table 2.** Three different tools with different geometries were taken for experimentation and their description is shown in **Table 3.** The plates were processed with a tool rotational speed of 800 rpm and traverse speed of 40 mm/min. FSP with 50% pin overlapping was conducted to produce the bulk-area FG structure in AA6061. Total five overlapping passes were done. After FSP, the samples were kept in heat treatment furnace at 160^{0}C for 16 hours to improve the properties. For analysis, samples were cut transverse to processing zone by using a power hacksaw. The samples were polished with different grades of emery papers followed by disc polishing and polished surface was cleaned with acetone to remove the dirt and contaminants on the polished surface. Keller's reagent was used to etch the polished surface and the etching time was 150s. Microstructures were examined with 3D optical microscope. Vickers micro hardness tester was used for measurement of hardness with a load of 100 g for 10s dwell time using diamond indenter. The hardness was measured along the processed zone with interval of 0.5 mm.

Table 1. Composition of AA6061

Element	Al	Cu	Mg	Si	Fe	Mn	Cr
Composition (Wt. %)	Remainder	0.15-0.4	0.8-1.2	0.4-0.8	Max 0.7	Max 0.15	0.04-0.35

Table 2. Composition of AISI H13

Element	Cr	Mn	C	Mo	P	S	Si	V
Composition (Wt. %)	4.75-5.5	0.2 -0.5	0.32-0.45	1.1-1.75	Max 0.03	Max 0.03	0.8-1.2	0.8-1.2

Table 3. Tool geometry

Tool No.	Tool geometry	Notation
Tool-1	Square pin with ridges	T-1
Tool-2	Hexagonal pin with concentric circles	T-2
Tool-3	Triangle pin with scrolls	T-3

3. Results and Discussion

3.1 Microstructure

The microstructures of heat-treated (HT) samples with single-pass FSP without overlapping in stir zone (SZ) are shown in **Fig. 1(a-c).** From the microstructures of the HT samples, it was observed that, fine equi-axed grains along with uniform precipitates were obtained in SZ. This is due to dynamic recrystallization and plastic deformation that occurred because of high temperature and stirring action. Microstructure results witnessed the grain refinement is more in the sample processed with T-2. These results indicate that shearing is more in stir zone in sample processed with T-2 due to the six sharp edges of hexagonal pin profile. Coarse grains were observed in stir-zone of T-3 due to the less shearing action caused by the less number of edges. The grain refinement in stir zone of T-1 is in between the grain refinement of T-2 and T-3. **Fig.**

2(a-c) shows the microstructures of HT samples in overlapped SZ. From the microstructures, it was seen that the grains were further refined as they were subjected to two pass FSP. **Fig. 3 (a-c)** represents the microstructures of thermo-mechanically affected zone (TMAZ). The microstructures of all samples consisted of large elongated grains of Al-matrix with some amount of precipitates. This is due to fact that, TMAZ experiences temperature changes with small effect of stirring action. **Fig. 4 (a-c)** displays the microstructures of Heat affected zone (HAZ). Compared to all other zones, grain coarsening is more in HAZ due to the absence of pinning action and temperature changes.

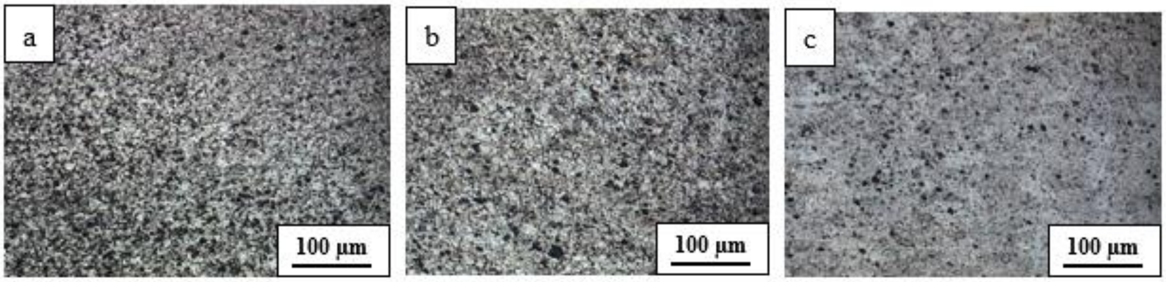

Fig. 1. Microstructures of stir zone in first pass for (a) Tool-1 (T-1) (b) Tool-2 (T-2) (c) Tool-3 (T-3)

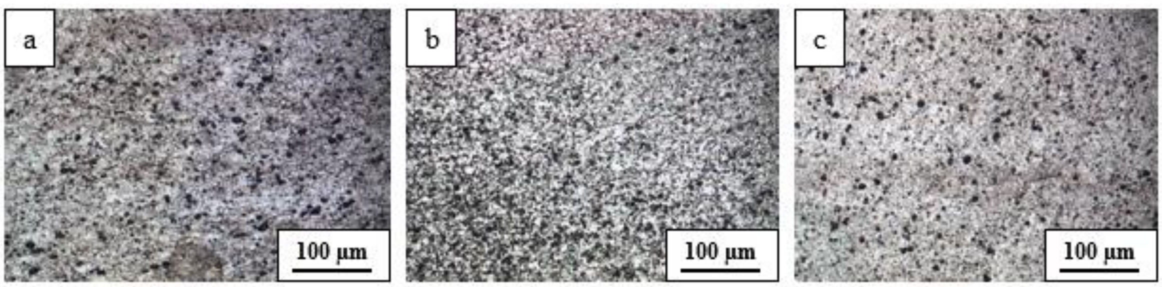

Fig. 2. Microstructures of stir zone in overlapping pass for (a) Tool-1 (T-1) (b) Tool-2 (T-2) (c) Tool-3 (T-3)

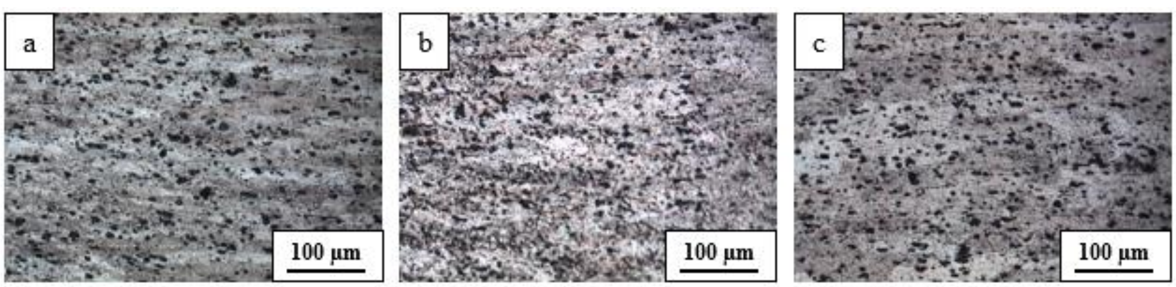

Fig. 3. Microstructures of TMAZ for (a) Tool-1 (T-1) (b) Tool-2 (T-2) (c) Tool-3 (T-3)

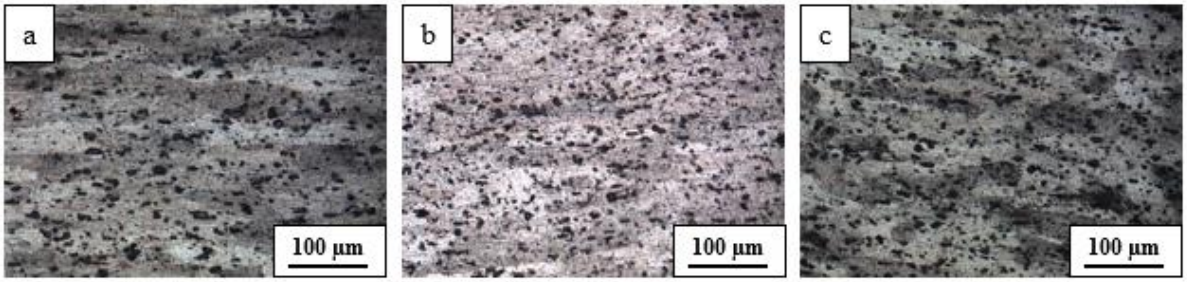

Fig. 4. Microstructures of HAZ for (a) Tool-1 (T-1) (b) Tool-2 (T-2) (c) Tool-3 (T-3)

3.2 Hardness

Fig. 5 displays the micro-hardness profiles of HT samples. Uniform hardness was achieved in stir zone of all samples. Sample processed with T-2 possessed highest hardness in SZ. The more grain refinement in T-2 sample is the reason for more hardness according to Hall-Petch equation. The lowest hardness in the SZ was obtained in sample processed with T-3. These results are attributed to grain coarsening during FSP. All these hardness values were compared with hardness values of NON-HT samples and results have been represented in the graph form shown in **Fig.6 (a-c).** The average hardness in the stir zone for HT sample processed with T-1 in stir zone was 64.61 HV, which is 19.95 % higher than NON-HT (53.86 HV) shown in **Fig 6 (a)**. From **fig. 6 (b)**, it was observed that the average hardness in the stir zone for HT sample for T-2 in stir zone (69.39 HV, which is 7.56 % higher when compared to NON-HT sample (64.51 HV). For T-3 there was an improvement of 12.76% in HT sample (54.88) compared to NON-HT sample (48.47) shown in **fig. 6 (c)**. These results witnessed the precipitation behavior in SZ.

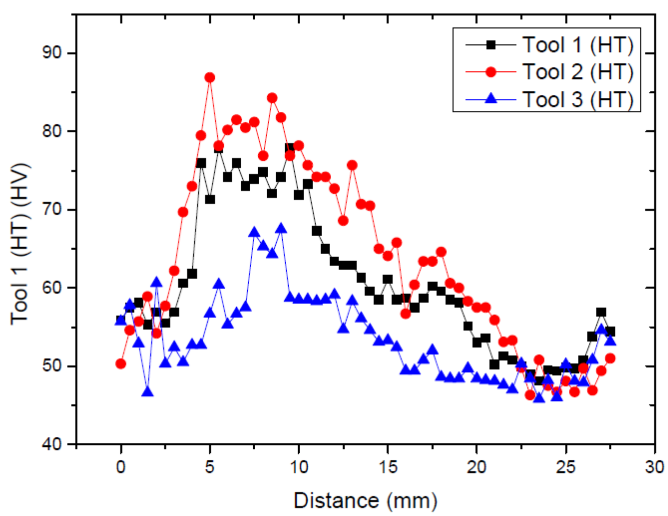

Fig. 5. Hardness profile of HT samples

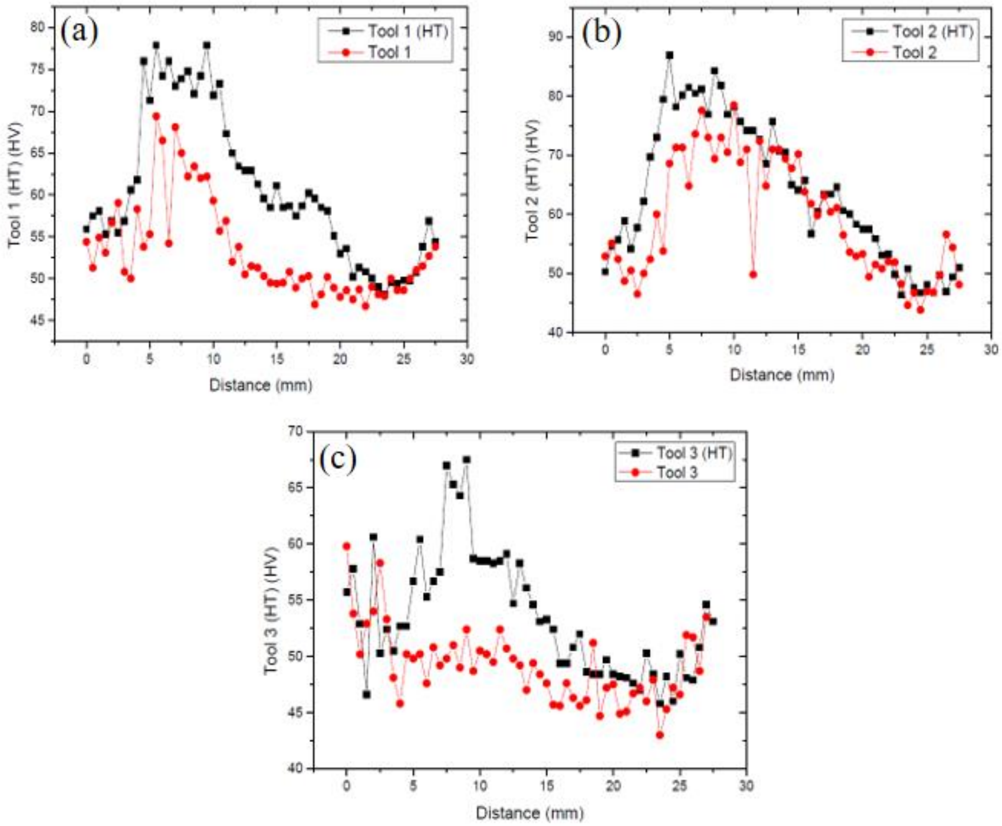

Fig. 6. Comparison of hardness profiles of HT and NON-HT samples of (a) T-1 (b) T-2 (c) T-3

4. Conclusions

In this investigation, large bulk-area FG structure was prepared with 50% pin overlapping using different tool geometries, post-processing heat treatment was carried, and the following results were extracted.

- For all tool geometries, with single-pass FSP grains were refined due to the severe plastic deformation and dynamic recrystallization and the grains size were further refined in overlapped passes.
- Sample processed with T-2 has more grain refinement than other profiles due to more number of edges of hexagonal pin profile and resulted in more plastic deformation.
- The highest average hardness was recorded in T-2 sample, lowest average hardness was recorded for T-3 sample due to the grain refining and grain coarsening.
- Better hardness was obtained in HT samples compared to NON-HT samples as a result of precipitation hardening behavior.

Acknowledgements

The authors are very much thankful to the Aeronautical Research Board and Development (ARDB), New Delhi, India for providing the financial assistance and National Institute of Technology, Warangal, India for providing the lab facilities to carry out the project smoothly.

References

[1] Yi Huang and Terence G. Langdon, Advances in Ultrafine-grained materials, Materials Today, 16 (2013) 85-93.

[2] Yoshinori Iwahashi, Jingtao Wang, Zenji Horita, Minoru Nemoto, Terence G. Langdon, Principle of equal-channel angular pressing for the processing of ultra-fine grained materials, Scripta Materialia, 35 (1996) 143–146.

[3] Mehrnoosh Naderi, Martin Peterlechner, Sergiy V. Divinski, Gerard Wilde, The effect of pre-annealing on defects, microstructure and recrystallization of ultra-fine grained Al produced by high-pressure torsion, Materials Science and Engineering A. 708 (2017) 171-180.

[4] N. Tsuji, Y. Saito, H. Utsunomiya, S. Tanigawa, Ultra-fine grained bulk steel produced by accumulative roll-bonding (ARB) process, Scripta Materialia, 40 (1999) 795–800.

[5] Z.Y. MA, Friction stir processing technology: A Review, Metallurgical and Materials Transactions A. 39A (2008) 642-658.

[6] R.S. Mishra, Z.Y. MA, Friction stir welding and processing, Materials Science and Engineering R. 50 (2005) 1-78.

[7] Yong-Jai Kwon, Ichinori Shigematsu, Naobumi Saito, Production of ultrafine-grained Al alloy using Friction Stir Process, Materials Transactions, 44 (2003) 1343-1350.

[8] Jian-Qing Su, Tracy W. Nelson, Colin J. Sterling, Friction stir processing of large-area bulk UFG aluminium alloys, Scripta Materialia. 52 (2005) 135-140

[9] N. Kumar, R.S. Mishra, C.S. Huskamp, K.K. Sankaran, Microstructure and mechanical behaviour of friction stir processed ultrafine grained Al-Mg-Sc alloy, Materials Science and Engineering A. 528 (2011) 5883-5887

[10] C.Y. Liu, B. Qu, P. Xue, Z.Y. Ma, K. Luo, M.Z. Ma, R.P. Liu, Fabrication of large-bulk ultrafine grained 6061 aluminum alloy by rolling and low-heat-input friction stir welding, Journal of Materials Science & Technology, 34 (2018) 112-118.

[11] P. Xue, B.L. Xiao, Z. Y. Ma, Achieving Large-area Bulk Ultrafine Grained Cu via Submerged Multiple-pass Friction Stir Processing, J. Mater. Sci. Technol. 29(2013) 1111-1115.