Friction Stir Processing of AA 7039 Alloy

Sunil Sinhmar, Dheerendra K. Dwivedi, and Vivek Pancholi

***Abstract*—** Friction stir processing (FSP) is an effective solid state surface modification technique used to improve the surface properties of metals like aluminium, and titanium controlled structural refinement. In present work, friction stir processing of 5 mm thick plate of Al-Zn-Mg alloy (AA 7039) was carried out using a conical pin and overlap of 50%. Modified surfaces were characterized in respect of macrostructure, microstructure, hardness and tensile properties. It was observed that friction stir processing refined the microstructure of AA 7039 alloy and increased the ductility (%elongation). However, tensile strength and hardness were found to be adversely affected. Hardness has been found to be increased with number of passes during friction stir processing**.**

***Index Terms*—**Friction-stir-processing, Al-Zn-Mg, hardness, microstructure, ductility, strength.

I. Introduction

Friction stir processing (FSP) is a variant of friction stir welding (FSW) process. FSP selectively modifies the microstructure of processed zone to improve the properties [1]-[4]. Friction stir processing is performed by plunging a rotating non-consumable tool (having a shoulder and a small pin) into the plate to be processed. The frictional heat produced by rotating of tool softens the surface of plate. The softening of plate metal in turn facilitates tool traverse along the area of interest for friction stir processing [5]. The friction stir process can be single or multi-pass as per requirement of the surface area of the plate to be modified [6]. A combination of intense plastic deformation and friction heat generated during friction stir process causes recrystallization and refinement of grain structure of friction stir processed metal [7]-[8]. In case of friction stir processing of as cast component, dendritic structure and porosity are eliminated [9]. Friction stir processed samples have been reported to be composed of three different zones namely nugget zone (NZ) or stir zone (SZ), thermo mechanical affected zone (TMAZ) and heat affected zone (HAZ). Nugget zone comprises fine and recrystallized grain structure primarily due to severe plastic deformation and dynamic recrystallization [5], [10], [11]. Mechanical properties of friction stir processed area can be controlled by optimizing the tool geometry and process parameters [12]. A lot of work on friction stir processing of various cast Al-Si alloys and wrought aluminium alloys have been reported however the work on friction stir processing of Al-Zn-Mg system namely AA 7039 alloy is very scant. AA 7039 is an Al-Zn-Mg alloy of medium strength and is commonly used for making components of railway transport system, military vehicles, high speed trains, ships etc. [13]. Therefore, to fill up this gap, in present work, attempts were made to study the influence of single and multi pass friction stir processing on the structure and mechanical properties of AA 7039 alloy.

II. Experimental Procedure

The friction stir processing of AA 7039 alloy plate of 5 mm thickness, 50 mm width and 170 mm length was carried out on a vertical milling machine (spindle power 5 HP) and indigenously designed and fabricated fixture. The chemical composition of the alloy is given in Table I. A die steel friction stir processing tool having cylindrical shoulder of 20 mm diameter with concave base and a conical pin of 5 mm diameter and 2 mm length at the centre of shoulder was used for processing (Fig. 1). Two degree tilt angle was given to the tool. The friction stir processing was carried out using a tool rotational speed of 1025 rpm and traverse speed of 75 mm per min. The intermittent multi-pass friction stir processing was carried out at a time interval of 10 min. after each pass. The friction stir processing of the plate was performed using seven passes with an overlap of 50% during each subsequent pass in order friction stir processed area of 15 mm X 150 mm. The friction stir processed surface of AA 7039 plate was modified up to 2 mm depth below the surface (Fig. 2).

The standard metallographic procedure was used for polishing the friction stir processed samples for microstructure study with the help of optical microscope (LEICA). Modified-Poulton etching reagent was applied for 10 seconds on the polished surface to reveal the microstructure and grain boundaries. The vicker's hardness testing machine was used to measure the hardness of un-processed and friction stir processed samples. The dwell time and load for hardness testing was 15 s and 5 kgf respectively.

Fig. 1. Photograph of the tool used for friction stir processing.

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TABLE I: CHEMICAL COMPOSITION (WT. %) OF AS RECEIVED BASE MATERIAL AA7039

Al	Zn	Mg	Mn	Fe	Si	Cu
91.21	4.69	2.37	0.68	0.69	0.31	0.05

Fig. 2. Photograph of plate subjected to friction stir processing for seven passes.

Hardness testing was done on transverse cross-section of friction stir processed samples. The universal testing machine of 25 KN capacity was used for tensile testing of un-processed and friction stir processed (FSPed) samples of AA 7039 alloy plates. Tensile samples for study were obtained from both longitudinal and transverse direction of friction stir processed samples.

III. RESULTS AND DISCUSSION

A. Microstructure

Optical micrographs of friction stir processed (FSPed) AA 7039 are shown in Fig. 3-4. Microstructure study was done on transverse cross-section of friction stir processed sample. The micrograph of friction stir processed sample of AA 7039 alloy plate showed distinct zones namely stirred zone, thermo-mechanically affected zone, and heat affected zone. The base metal showed large size grains of alpha aluminium and $MgZn_2$ precipitates (Fig. 3a). The friction stir processing refined the microstructure as intense plastic deformation of metal by rotating tool in stir zone caused the breaking of all micro-constituents and dynamic recrystallization (Fig. 4). Fine grains are evenly distributed in nugget zone. The average of size of α-Al in unprocessed base metal was 44.3 µm. Image analysis of micrographs performed using Image J software revealed that friction stir processing decreased the average grain size of α-Al from 44.3 µm to 4.5 µm.

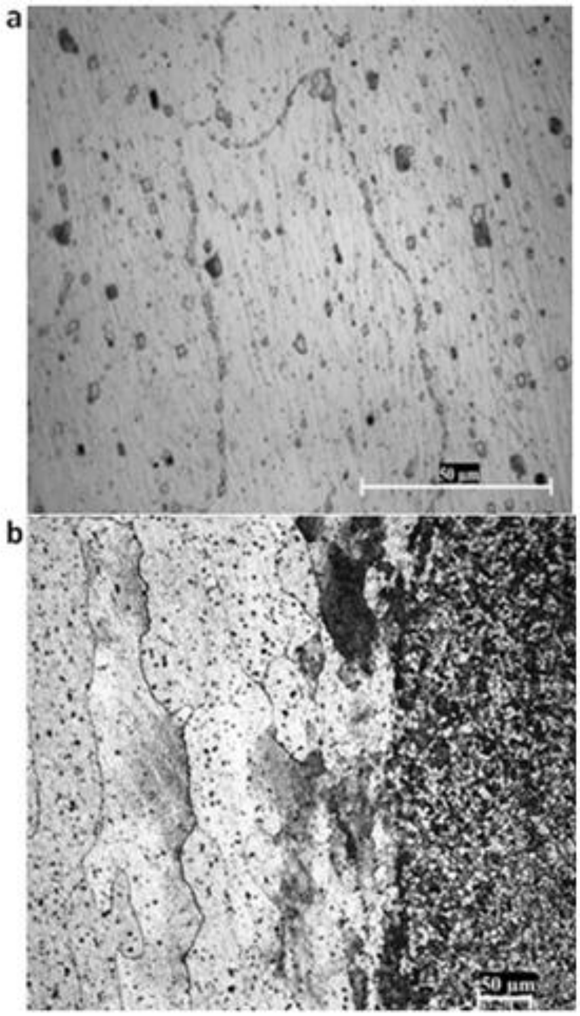

Fig. 3. Optical micrographs of (a) unprocessed AA 7039 alloy, (b) interface of unprocessed and friction stir processed AA 7039.

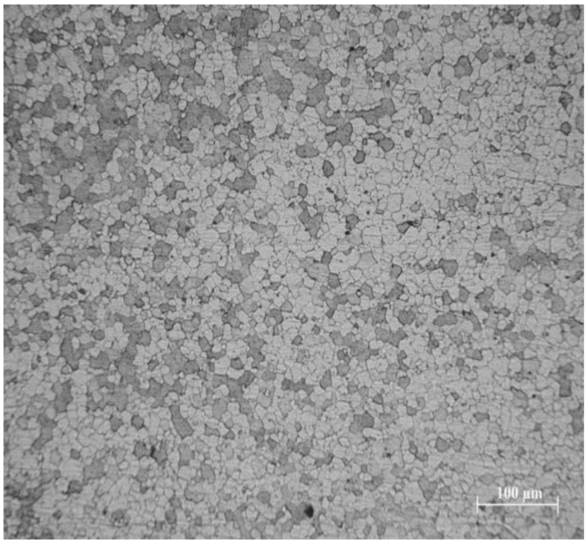

Fig. 4. Optical micrograph of stir zone of friction stir processed AA 7039.

However, the multi-pass friction stir processing led to slight coarsening of grain structure of zone processed by previous passes. Slight coarsening of grain structure of stir zone in multi-pass friction stir processing may be attributed to the two factors a) application of additional heat during subsequent passes in overlapped region of stir zone having metal in highly deformed state developed by previous pass and b) retention of high temperature for longer period in already processed zone due to frictional heating caused by friction stir processing during subsequent passes.

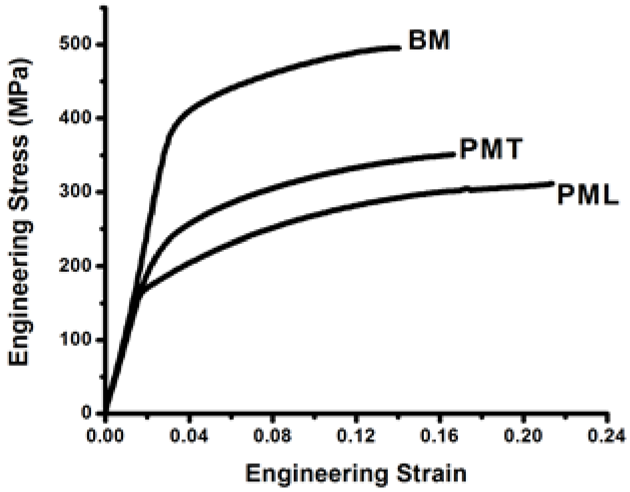

Fig. 5. Engineering stress-strain diagram obtained from tensile test of unprocessed alloy and friction stir processed alloy.

The metal in deformed state under the influence of external heat show greater structural instability than in annealed condition. This is analogous to the abnormal grain growth observed in stir zone and HAZ of friction stir weld joint of 7039 alloy during post weld heat treatment [13]. The refinement of micro-constituents in stir zone is expected to enhance the mechanical properties especially ductility and fatigue resistance.

B. Tensile Properties

The tensile testing of friction stir processed and unprocessed samples of 7039 alloy revealed that the friction stir processing decreased ultimate tensile strength and yield strength. The ductility of friction stir processed sample was found significantly greater than unprocessed base metal (Table II). Further, tensile strength of specimen taken from longitudinal direction (PML) of friction stir processed plate of 7039 alloy was slightly lower than the specimen taken from transverse direction (PMT) (Fig. 5). Ductility of sample taken from longitudinal direction showed higher elongation (23.6 %) than unprocessed alloy (13.5 %) and the sample taken from the transverse direction (16.6 %). Increases in elongation of alloy after friction stir processing can be attributed to refinement of α-Al from 44.3 μm to 4.5 μm in stir zone.

TABLE II: CHEMICAL COMPOSITION (WT. %) OF AS RECEIVED BASE MATERIAL AA7039

Material	UTS (MPa)	Yield stress (MPa)	Elongation (%)
Base Metal	495	400	13.52
PML	311	167	23.67
PMT	351	204	16.61

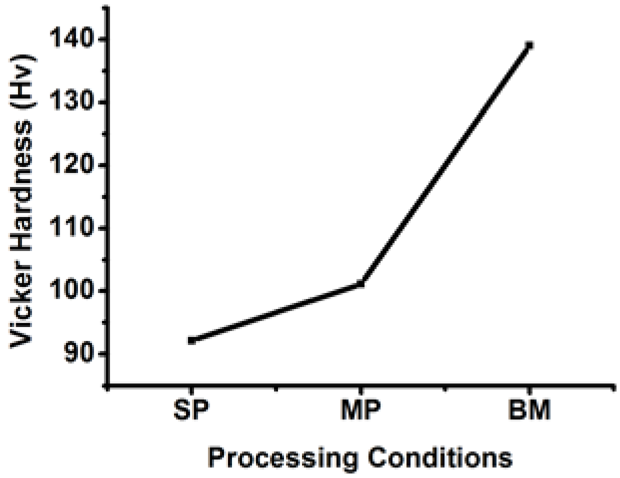

Fig. 6. Plot showing the effect of single pass and multipass friction stir prcoessing on hardenss of AA7039.

Reduction in strength of 7039 alloy after friction stir processing can be attributed to recrystallization and reversion (dissolution of strengthen $MgZn_2$ precipitates) caused by friction heat generated during friction stir processing. These findings are in agreement with published research on FSW of AA 7039 alloy [13]. Marginally higher tensile strength of sample taken from the transverse direction than that of the sample taken from longitudinal direction from friction stir processed plate is attributed to difference in thermal cycle and plastic deformation experienced by the 7039 alloy in two directions i.e. longitudinal and transverse directions during friction stir processing. Further, sample taken from transverse direction showed more heterogeneity in respect of microstructure than that in longitudinal direction due to inherent nature of multi-pass FSP process. Multi-pass friction stir processing with 50 % overlap results in two different effects in respect of a) thermal and mechanical stresses on one half of already processed metal and b) thermal stresses only on remaining half of friction stir processed zone. So the additional work hardening affect on friction stir processed alloy taken from transverse direction results in higher strength than that of sample taken from the longitudinal direction. Further, heterogeneity in the structure (banded structure) of friction stir processed sample taken from transverse direction results in fracture at lower strain than that in sample taken from longitudinal direction [14].

C. Hardness Study

The hardness of unprocessed and friction stir processed sample was measured by using Vicker's hardness tester. Hardness testing was done on base metal (BM), single pass (SP) friction stir processed and multi pass (MP) friction stir processed samples. The hardness of stir zone of friction stir processed sample was found lower than the unprocessed sample (139 Hv). Further, the hardness of multi-pass friction stir processed specimen (101.1 Hv) was lower than the single-pass friction stir processed specimen (92.1 Hv) (Fig. 6). The reduction in hardness after friction stir processing of AA 7039 can be attributed to reversion i.e. dissolution of hardening $MgZn_2$ precipitates and recrystallization. Higher hardness of multi-pass friction stir processing sample than that of single pass friction stir processed may be due to two factors a) increasing work hardening effect of already processed metal and b) re-precipitation of few strengthening precipitates ($MgZn_2$) due to thermal cycle experienced by already friction stir processed zone during subsequent passes.

IV. Conclusion

1. Friction stir processing reduces grain size by about 10 fold and improves the uniformity in grain structure.
2. Friction stir processing of AA7039 increases ductility from about 13.5% to 23.6% while the ultimate and yield strength are adversely affected.
3. Friction stir processing of the 7039 alloy results in higher ductility longitudinal direction than the traverse direction.
4. The multi-pass friction stir processing produces higher hardness than the single pass friction stir processing.
5. Hardness of friction stir processed AA 7039 was lower than the unprocessed alloy.

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