Cavitation in Friction Stir Processing of Al-Zn-Mg-Cu Alloy

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***Abstract*—Friction Stir Processing (FSP) is a solid state process to modify the microstructure of the metals. FSP was carried out on the high strength aluminum alloy to investigate the defects such as cavitation. Temperature profiles were recorded to evaluate the maximum temperature during FSP. Macro and Microstructure examination was performed after FSP using optical microscopy. Cavitation was observed in all FSP samples at different locations and amount within the processing zone. High heat input samples reported more cavitation volume compared to low heat input sample. Pin geometry was found the governing factor for material flow and consequently the level of the cavitation during FSP.**

***Index Terms*—aluminum, cavitation, friction, parameters, process, stir**

I. Introduction

Friction stir processing has gained popularity in material processing industries due to its solid state nature. FSP consists of the non-consumable rotating tool, which is inserted in workpiece to modify the microstructure for specific property enhancement [1]. Fig. 1 shows the schematic of the FSP. FSP tool possesses geometry in form of shoulder and pin as shown in Fig. 1. During FSP the heat is generated due to plastic and frictional deformation of workpiece by tool. The temperature of the process is always remain below the melting point of the workpiece material. Tool pin and shoulder geometry are responsible for plastic and friction deformation respectively. This intense plastic and friction deformation of the workpiece results in a stirred zone (SZ) with a fully recrystallized, equiaxed and fine grain microstructure [2]-[6]. The pin is responsible for the generation of the SZ and the shoulder generates the thermo mechanically affected zone (TMAZ) near to the SZ [7].

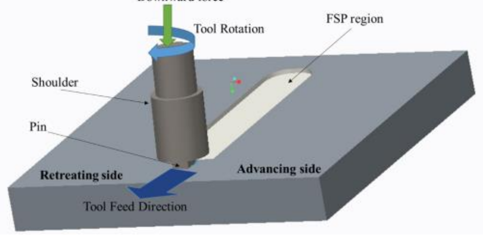

Figure 1. Schematic illustration of friction stir processing [8]

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Fine grain microstructure is a preliminary requirement to obtain the superplasticity behavior. Superplasticity is an ability of metallic material to achieve more than 200 % uniform elongation before fracture takes place. Superplastic material offers designer to design complex geometry which can be formed without need of any joint. 7075 (Al-Zn-Mg-Cu) alloy possesses the highest strength among all aluminum alloys. It is widely used in the aerospace industries due to its good mechanical properties such as strength, hardness and fracture toughness. Welding of 7075Al alloy is difficult because of its poor joint strength [9]. Hence, by achieving superplasticity in 7075Al using FSP eliminates need of the joint to manufacture unitized structure [10]. Researchers have reported superplastic behavior in different aluminum alloys through fine grain microstructure using FSP [8], [11]-[16]. The SZ of friction stir processed material consists of the fine grain structure. The characteristics of SZ depend on the pin geometry and the process parameters such as tool rotation and traverse speed during FSP. Cavitation in the SZ is considered as prominent defect which hinders the superplastic behavior of friction stir processed material even though having fine grain microstructure. The aim of the present investigation is to find the effects of process parameters on cavitation during FSP of 7075Al.

II. Materials and Methods

Aluminium 7075 plate of 100 mm long, 100 mm wide and 6.5 mm thick was processed by using heat treated tool of tool steel material. Chemical composition of AA 7075 is mentioned in Table I. Tool geometry comprise shoulder diameter of 20 mm, pin length of 6 mm having tapered threaded cylindrical pin of top diameter 6 mm and bottom diameter 3 mm as shown in Fig. 2(a). Contact type thermocouple was used by drilling 1 mm hole at center and distance of 3 mm from the processed region to measure the temperature on advancing side (AS) as well as Retreating Side (RS) as shown in Fig. 2(b). The fixture of stainless steel was used to prevent deflection of the workpiece during FSP. Three samples were prepared at different process parameters as shown in Table II. Tool tilt angle was maintained at 2^0 for all the samples. Transverse cross section of processed samples were cut to prepare specimens for microstructure study. FSP samples were cut, ground and polished for optical microscopy.

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Keller's etchant was used to reveal the grain structure of the FSP samples for optical microscopy.

TABLE I. CHEMICAL COMPOSITION OF AA 7075

Elements	Percentage (wt%)
Al	87.1 -91..4
Zn	5.1 - 6.1
Mg	2.1 -2.9
Cu	1.2 - 2
Cr	0.18 -0.28
Mn	Max 0.3
Si	Max 0.4
Fe	Max 0.5

(a) (b)

Figure 2. (a) FSP tool M2 Tool steel (b) Friction stir processed sample showing thermocouple embedded in plate at centre.

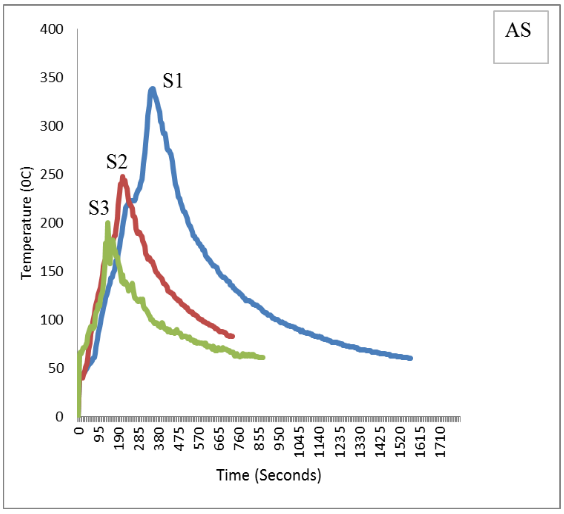
TABLE II. FSP PROCESS PARAMETERES

Sample ID	Tool rotation speed, rpm	Traverse speed, mm/min	T_p
S1	1070	31.5	367
S2	1070	50	308
S3	1070	78	222

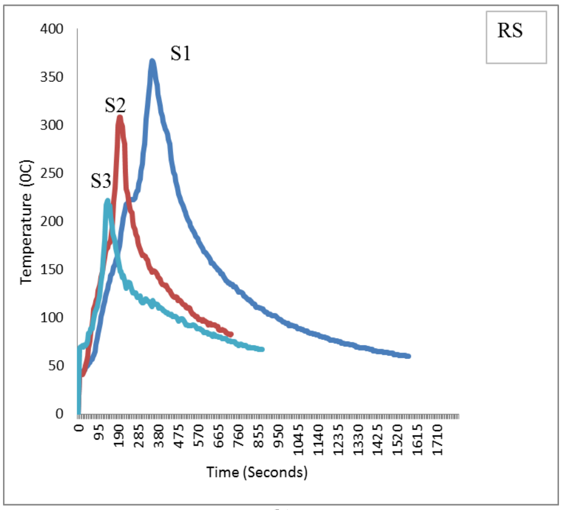
Tp = Peak temperature, ℃

III. RESULTS AND DISCUSSION

A. *Temperature History*



(a)



(b)

Figure 3. temperature distribution of FSP samples on: (a) advancing side, (b) reteatind side

Fig. 3 shows temperature distribution on AS and RS, which was recorded close to the SZ of all samples. The temperature profiles for as and RS observed almost similar. But slightly higher temperature was observed at RS for all samples due to asymmetric temperature gradient around the pin [17]. Sample S1 hiving the lower traverse speed obtained the highest temperature and the sample S3 with lower traverse speed attained the minimum temperature. The main reason behind this trend is that low traverse speed allows the more interaction of tool and work during the process, which results into more heat generation.

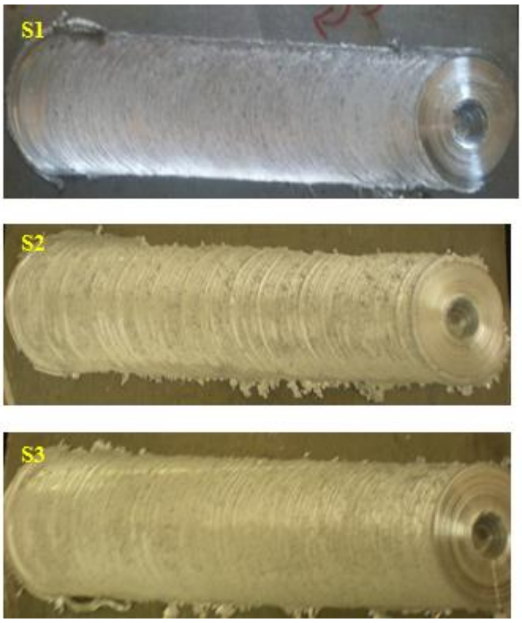


Figure 4. Surface appearance of the FSP samples

B. *Microstructure Observations*

Fig. 4 represents the surface appearance of all three FSP samples. No surface defects such as surface tunnel was observed on the FSP samples. Surface defects occur due to lack of heat input during the process. That means the process parameters opted for the sample S1, S2, and S3 have generated sufficient heat during the FSP as shown in Table II. The peak temperature found of 367, 308 and 222℃ for sample S1, S2 and S3 respectively. The traverse speed selected of 31.5, 50 and 78 mm/min for sample S1, S2 and S3 respectively. Traverse speed affects the thermal cycle of the process. High traverse speed offers the less heat input and vice versa. Hence, maximum temperature recorded for sample S1 having low traverse speed among all three FSP samples.

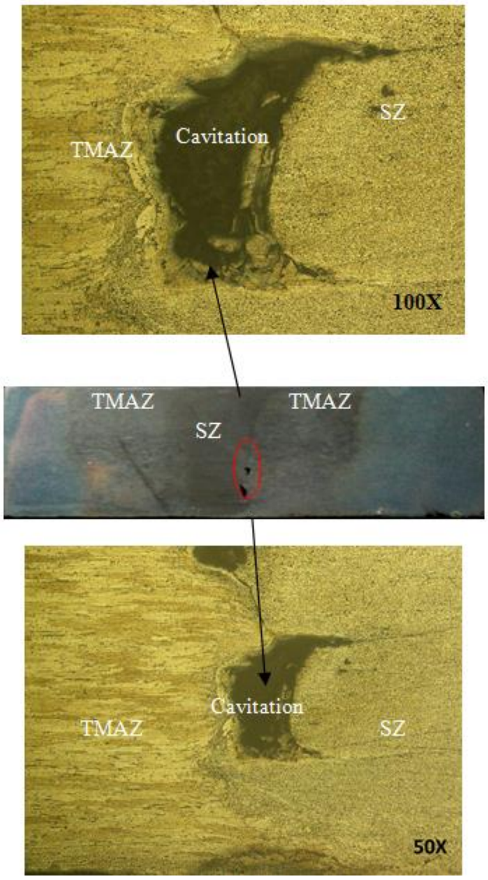


Figure 5. Optical Microstructure of FSP sample S1

Fig. 5, Fig. 6 and Fig. 7 show the fine recrystallized grains in the SZ of all samples after FSP. These fine grain microstructures are mainly due to the dynamic recrystallization [18]. The dynamic recrystallization is generated because of intense plastic deformation and friction heat during the process, which results into low dislocation density fine grain microstructure [19]. The SZ reflects the stirring and mixing of the material by the tool pin. The macro and microstructure observations of sample S1 are shown in Fig. 5. The cavitation was found at the root side of TMAZ/SZ interface. Optical micrographs confirmed the presence of the cavitation. The heat generation for sample S1 found the highest among the all samples. The SZ was observed free from the defects like cavitation except interface. The cavitation at the interface on root side may have occurred because of the improper material flow around the pin. The root side cavitation may also have generated because of the pin geometry. As tool pin is conical means the material swept by the pin near the shoulder is larger and at the tip is smaller. Hence, volume of the material flow around the tool pin is not constant throughout the pin length, which can be easily seen in the macro structure of Sample S1.

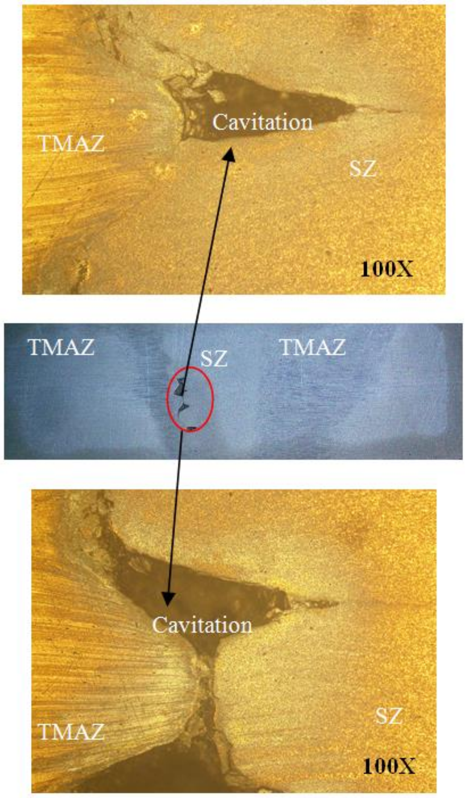


Figure 6. Optical Microstructure of FSP sample S2

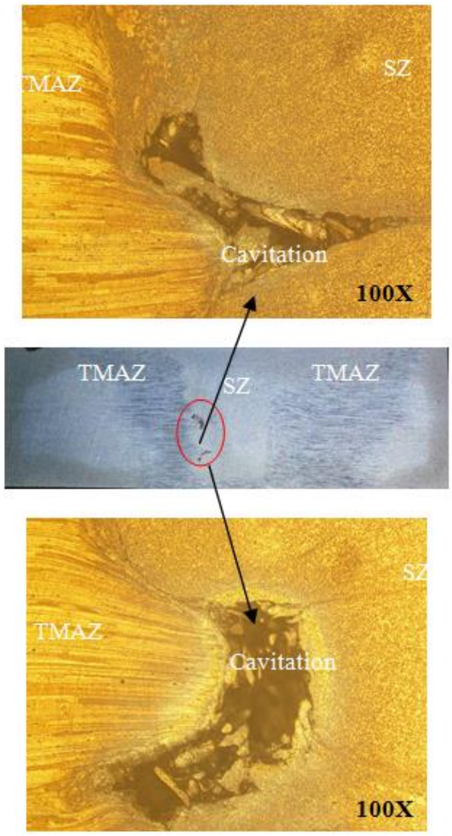


Figure 7. Optical Microstructure of FSP sample S3

Fig. 6 represents the macro and microstructure of the sample S2. The cavitation has observed at the middle of the SZ/TMAZ interface. The SZ possessed the same microstructure behavior like sample S1. The cavitation has occurred probably due to the difference in the material flow around the pin. The little cavitation observed in the sample S3 as shown in the Fig. 7. For sample S3 the SZ has characterized by the fine grain microstructure and no other defects were found within this zone. Sample S3 was produced at the higher traverse speed and hence the peak temperature of the process found the lowest one among all samples. The lowest temperature of the process would have inhibited the grain growth after the heat generation. During the grain growth the grains becomes coarsen and the cavity formation becomes prominent. Hence, inhibited grain growth has resulted into the little cavitation for sample S3.

IV. Conclusions

From the present investigation following points can be concluded:

(1) Cavitation is a prominent defect in the FSP due to inappropriate selection of the process parameters such as tool rotation speed, traverse speed and tool tilt.

(2) Location of the cavitation was found at the interfaces of the TMAZ and SZ. That indicates the inadequate flow of the material during the FSP.

(3) The level of the cavitation is dependent on the process parameters during FSP. Low heat input samples generated little cavitation because of the low thermal cycle as well as lesser grain growth.

(4) Tool pin geometry also plays a major role in the generation of cavitation during FSP.

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