Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 97 (2014) 732 – 740
Procedia Engineering
www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Friction Stir Processing of SSM356 Aluminium Alloy

S. Chainarong [a]*, P. Muangjunburee [b], S. Suthummanon [c]

[a] *Department of Engineering, Faculty of Industrial Technology, Songkhla Rajabhat University, Songkhla, Thailand*
[b] *Department of Mining and Materials Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla, Thailand*
[c] *Department of Industrial Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla, Thailand*

Abstract

The aim of this experiment was to improve the mechanical properties of SSM 356 aluminum alloys by friction stir processing, a solid-state technique for microstructural modification using the heat from a friction and stirring. The parameters of friction stir processing for SSM 356 aluminum alloys were studied at three different travelling speeds: 80, 120 and 160 mm/min under three different rotation speeds 1320, 1480 and 1750 rpm. The hardness and tensile strength properties were increased by friction stir processing. The hardness of friction stir processing was 64.55 HV which was higher than the base metal (40.58 HV). The tensile strengths of friction stir processing were increased about 11.8% compared to the base metal. The optimal processing parameter was rotation speed at 1750 rpm with the travelling speed at 160 mm/min. Consequently, the application of the friction stir processing is a very effective method for the mechanical improvement of semi-solid metal aluminum alloys.

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

Keywords: Friction stir processing; SSM356 Aluminium Alloys; Mechanical popertiry

1. Introduction

Friction stir processing (FSP) was developed based on the principles of friction stir welding (FSW) which was developed and patented by TWI Ltd, Cambridge, UK in 1991. FSP is a solid-state welding, microstructural modification technique using a frictional heat and stirring action, has recently attracted attention for making aluminum alloys with an excellent specific strength, and its studies have been actively performed [1-9]. Friction stir

* Corresponding author. Tel.: +66-89-659-5906; fax: +66-74-324-221.
E-mail address: Suppachai.ch@skru.ac.th

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014
doi:10.1016/j.proeng.2014.12.303

processing is a special technique to improve the microstructure in the solid state by using the heat from friction for the aluminum-casting alloy, which has a higher specification [10-13]. The mechanical properties of friction stir processing are improved due to the grain refinement of the microstructure [14-18]. The Semi-Solid Metal (SSM) is the one of potential technology for die casting, but there is not much developed in the past decade. In recent years, SSM has become popular for various applications, and semi-solid casting technology, which was applied in local industry, is Gas Induced Semi-Solid (GISS). The GISS process uses argon or nitrogen gas flowing through porous graphite [19]. The SSM 356 aluminium alloy is one type of SSM. The SSM 356 aluminium alloy is an aluminium alloy processed by a hardening precipitation process, containing magnesium and silicon as major alloy additions. Magnesium and silicon forms Mg_2Si which in turn forms a simple eutectic system with aluminium. However, aluminum casting is limited by mechanism such as hardness, tensile, elongation and fatigueness, which cause from porosity. Friction stir processing is effective for improving the mechanical properties and microstructure of aluminum alloy castings. For this research, we use the technique to improve the mechanical properties and the microstructure of a friction stir process of aluminum alloy castings, investigate the variable in the stirring which affects the structure of the microstructure and mechanical properties of the area to stir zone, and improve the processes used to improve the mechanical properties as well as terms of research and to extend the results to the industry.

2. Experimental procedures

Material used in the experiment is a semi-solid aluminum casting SSM 356, cut into bite size 70×140×4 mm. The chemical compositions are listed in Table 1. A non-consumable tool made from JIS-SKH 57 was used as the tool material, which was used to fabricate the joints. The cylindrical pin used as the stirring tool is shown in Fig. 1. The tool has a shoulder dia., pin dia. and pin length of 20 mm, 5 mm and 3.2 mm, respectively. In this study, tool parameters were fixed at 4.5 kN with downward tool plunge force and 3^o tool tilt angle. The parameters of friction stir processing, for SSM 356 aluminum alloys under casting temperature at 620°C and argon gas flowing through porous graphite for 5 second by the time at quenching, were studied at three different travel speeds: 80, 120 and 160 mm/min, and different rotation speeds: 1320, 1480 and 1750 rpm. Mild steel was used for the backing plate. FSP was continuously performed 3 times by moving in 8 mm increments toward the advancing side.

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

Materials	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Al
SSM 356	7.74	0.57	0.05	0.06	0.32	0.01	0.05	0.02	0.01	Bal.

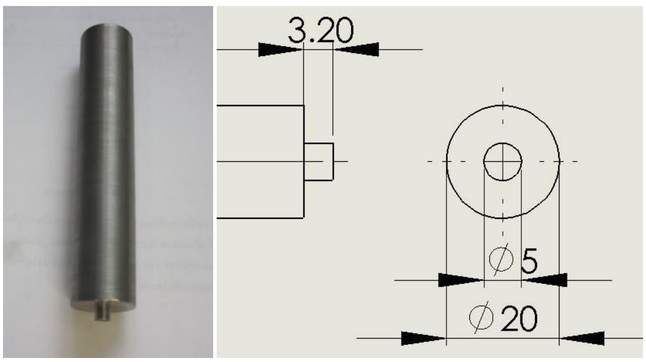


Fig. 1. Illustration of the tool used in the present study

After the friction stir processing, the specimen is cut perpendicularly to the vertical stirring shown in Fig. 2. These sections were polished and etched using Keller's reagent: 190 ml H_2O, 5 ml HNO_3, 3 ml HCl, and 2 ml HF. The boundary stirring was checked by an optical microscopy (OM, Olympus: BH2-UMA). The shape and size of a grain boundary stirring were examined by the vicker's microhardness tester (Highwood, model: HWDM-3) type A at a load of 50 gf on the diamond indenter for 10 seconds. The sub-size tensile test specimens with gage length 25 mm, width 6 mm, total length 100 mm and fillet radius of 6 mm were machined and tested according to American Society for Testing and Materials (ASTM E8M-04) standard on an initial strain rate of 1.67×10^{-2} mm/s at room temperature. The tensile properties of the joint were evaluated using three tensile specimens in each condition prepared from the same joint.

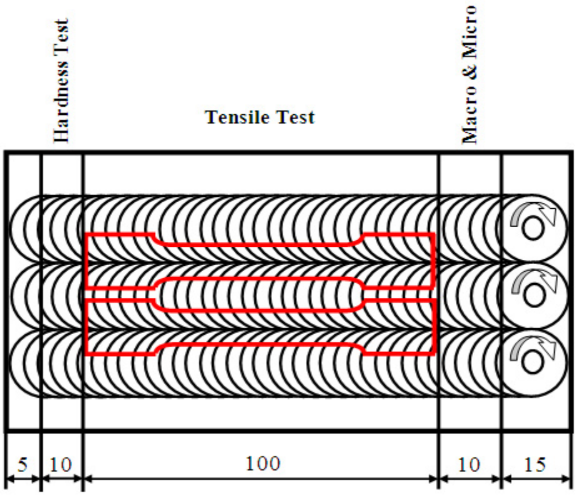


Fig. 2. Schematic diagram illustrating FS processing

3. Results and discussion

3.1 surface of friction stir processing

Fig. 3. illustrates the surface of the stirring SSM 356 aluminum alloy at the rotation speed at 1750 rpm, and travel speeds at 80, 120 and 160 mm/min. It showed that the surface of the skin is smooth and uniform mixing. The analyses of the stirred surface, after using friction stir processing, showed that the stirred surface area achieve great synchronized pattern in stirred zone at all condition of rotation speed and travelling speed. The bottom of it stirred a penetration well, no cracks in stirring zone. However, the end of the stirring has a hole due to the profile of the pin. Stirred roughness boundaries surface as a result of heat generated during stirring caused by rotation speed and travel speed. In the reduction of travelling speed from 160 to 80 mm/min, heat generated during the stirred increased the plasticity to material in a high state. The less internal resistance of material can be observed because the weakening areas of material was stirred resulting in less surface roughness on the stirred area [20] which corresponds to with rotation speed. By increasing the rotation speed from 1320 up to 1750 rpm, the heat generated during the stirred will increased deformations, which also turn material to plastic deformation, less internal resistance of material, and less surface roughness on stirred area. However, heat generated from the friction stir processing is caused by both the rotation speed and travel speed. In the condition of rotation speed at 1750 rpm and travel speed 80 mm/min, the minimum roughness was about 8.85 μm, and found the flake of the retreating side due to heat accumulation in the boundaries stirred which is large enough to cause material in a state of plastic that the motion of the material easy to overflow out of the shoulder of the stirred as a the flake on the retreating side. This causes by the direction of the rotation speed opposite to the direction of the travelling speed [21].

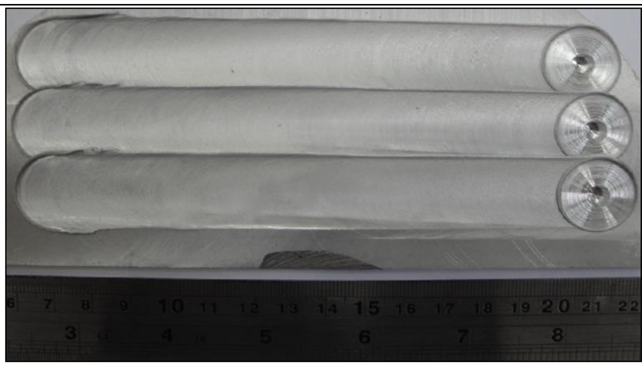
Travel speed	Surface of friction stir processing
80 mm/min.	
120 mm/min.	
160 mm/min.	

Fig. 3. Surface of rotation speed at 1,750 rpm

3.2 Macrostructure

The analysis of macrostructure of the speed of Fig. 4. showed three levels, three different travel speeds: 80, 120 and 160 mm/min without any defects. Heat will accumulate in the stir zone in a state of the plastic flow around the tool that occurs due to heat, pressure, rotation speed, and travelling speed. This causes the flow of material is resolution than the base metal and the direction of flow in the certain of around tool. Furthermore, if the material is not heated enough, it will cause the void [22]. Moreover, the same depth of the stir zone can be seen in all the conditions because the same pressure was applied. The width of the area will get wider which has been stirred up as the heat of stirring.

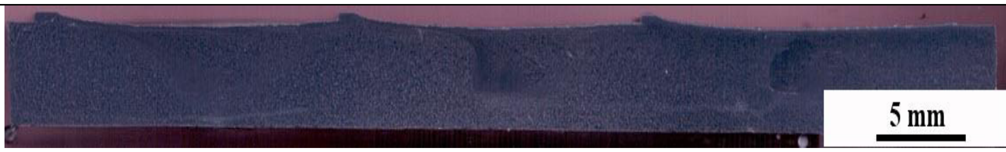
Travel speed	Macrostructure of friction stir processing
80 mm/min	
120 mm/min	
160 mm/min	

Fig. 4. Macrostructure of rotation speed at 1750 rpm

3.3 Microstructure

The base metal is globular grains that have equal average size. Stir zone (SZ) area is occurred friction stir processing to fine grain structure more than base metal. The heat generated from stirred to silicon into the mixture in aluminum-metric (α) with eutectic (Mg_2Si), homogenized and refine grain, and found that grain size decreases when the travel speed increase [20, 23] due to the high travel speed will be the distribution of silicon particles constantly more than low travel speed. The rotation speed is too high to result in grain larger [24] because increased rotation speed was stirred to the high temperature. As a result, grains is larger which cause the reduction of mechanical properties of the materials. So, the rotation speed threshold is appropriate, because it will produce enough heat and not too much plastic deformation which result in reduction of porosity and fine grain size in the stir zone [23, 25] . However, if specimen gets too little hot, it will appeared that void [22]. Boundary have been influenced by thermal on the advancing side resulting from the friction in the pull from rotation of tool, which is the same direction as the movement of the workpiece. Structural characteristics of grain is similar to pulled. The shape of grain was distorted in the direction of the tool movement. And found that, the high rotation speed has longer grain size than the grain size from low rotation speed because increased rotation speed to higher temperatures will result in more heat. At the retreating side, this results from the friction in the compression from rotation of the tool, which is in the opposite direction to the movement of the workpiece. Structural characteristics of grain are similar to compressed. The shape of grain was fine and narrow more than the advancing side [26]. Found that, the high rotation speed has smaller grain size than the low rotation speed because increased rotation speed to higher temperatures will result in more heat, shown in Fig. 5.

3.4 Hardness

Microhardness distribution data on the transverse cross-section of friction stir processing all stirring conditions are summarized in Fig. 6. Found in rotation speed at 1320, 1480 and 1750 rpm, travel speed at 120 and 160 mm/min were hardness of stir zone more than base metal due to stirred characterizes structure of grain boundary consisting of refined small particles of silicon, and distribution is better than the other zone. The particles of silicon which are smaller due to fracture of structural silicon and the distribution of good around the stirred results from the stirring tool [27-28]. The travelling speed of 80 mm/min, of all rotation speed were hardness is lower than base metal because of excessive thermal from stirred, resulting in the hardness of the stir zone lower than the base metal [22]. Experiments show that heat generated during stirred depends on the rotation speed and travel speed of the stir tool [23]. When travel speed increases, it tends to cause an average increase of hardness. But, if rotation speed increases, it tends to cause an average decrease of hardness after stirred; therefore, the hardness has resulted from heat generated while stirred. With the rotation speed and travel speed, it can cause a thermal on the material.

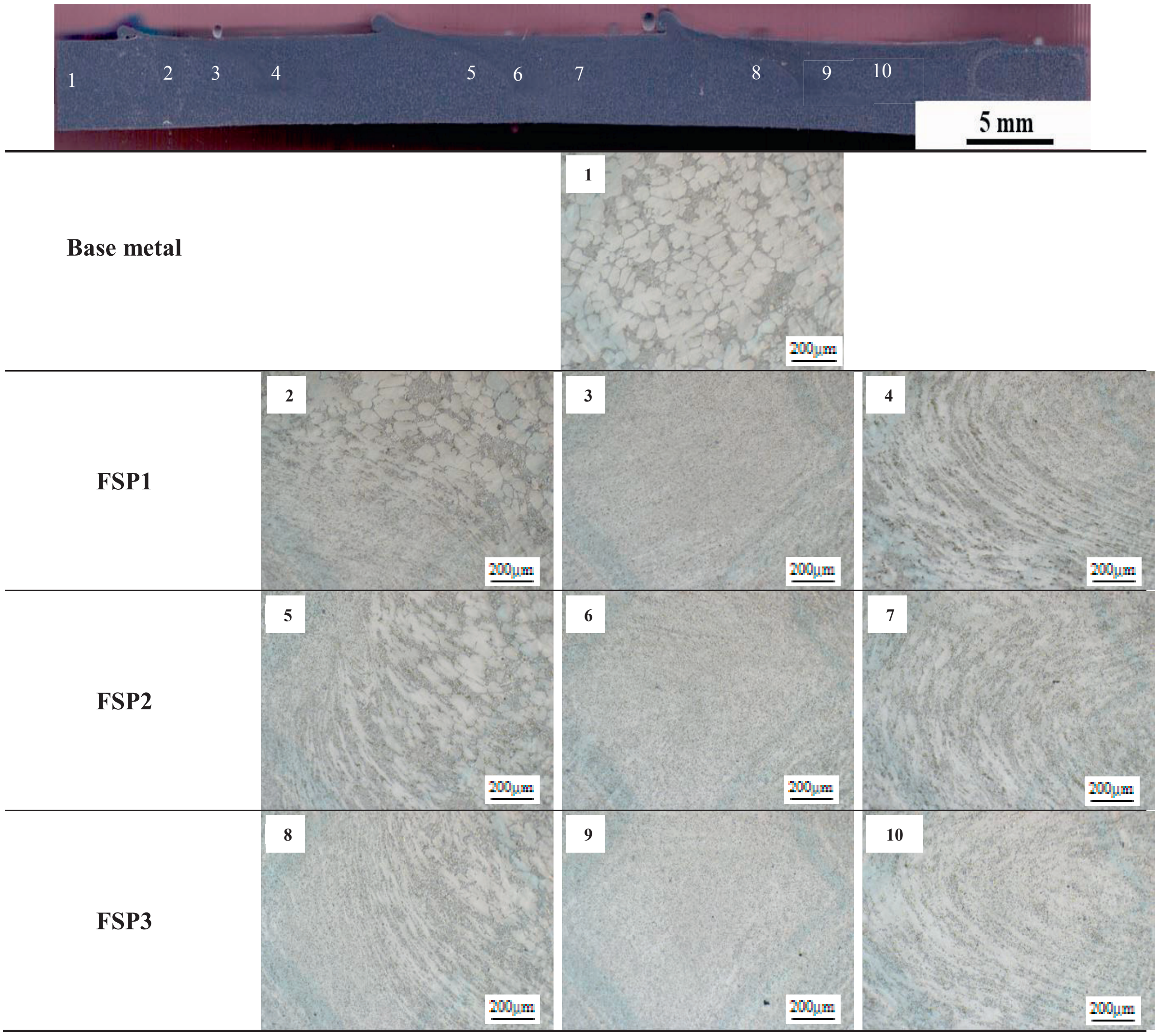


Fig. 5. Microstructures of friction stir processing at rotation speed; 1,750 rpm and travel speed; 160 mm/min.

We also found that the rotation speed at 1750 rpm and travel speed at 160 mm/min, the hardness is the best 64.55 HV. The area has been influenced by thermal for all conditions, which consists of the retreating side and advancing side. This area has been affected by the thermal caused the small grain compared to base metal. As a result, the hardness of this area is more than base metal, and the hardness of the areas which have been influences from thermal all conditions were similar.

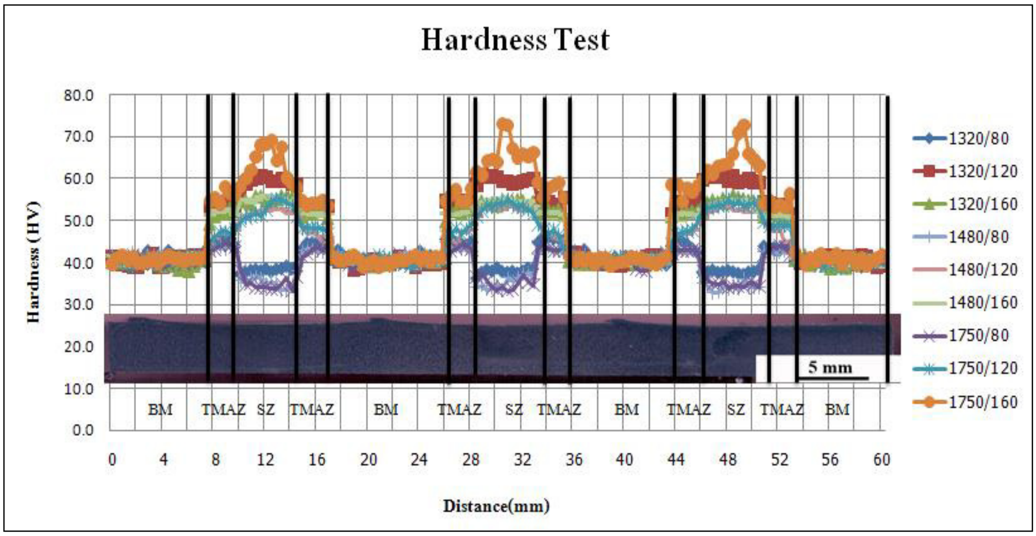


Fig. 6. Microhardness profiles of specimen in friction stir processing.

3.5 Tensile strength

Tensile properties of friction stir processing at different conditions are summarized in Table 2. From the investigation, tensile strength is increased from rotation speed at 1480 up to 1750 rpm because heat generated during stirred was less. Appropriately, the rotation speed at 1750 rpm and travel speed at 160 mm/min provides the optimal tensile strength. A maximum average tensile strength value is 188.57 MPa. when putting to specimen by cutting transverse to boundaries stirred. The specimen was cut across to boundaries stirred that have tensile strength less than a cutting transverse to boundaries stirred because the area has been influenced by thermal and an array of specific characteristics of particulate Si (not distributed uniformly). Thus, this causes the tensile strength of a cutting across to boundaries stirred is less than a cutting transverse to boundaries stirred [16].

The rotational speed at 1320 rpm was found that the tensile strength of the travelling speed at 120 mm/min is higher compared to travelling speed at 160 mm/min due to heat that have close to the heat property of the experimental. Thus, the tensile strength is higher at travelling speed of 160 mm/min. And found that the cause of tensile strength is less than base metal when heat generated during stirred is too much [22].

Table 2. Mechanical properties at stir zone and base metal.

Material	**rotation speed** (rpm)	**Travel speed** (mm/min)	**Tensile properties at room temperature**	
			Tensile strength (MPa)	Elongation (%)
SSM 356	-	-	168.68	5.14
FSP1	1,320	80	163.24	4.88
		120	183.25	4.84
		160	174.49	4.72
FSP2	1,480	80	157.69	4.38
		120	172.22	4.43
		160	174.62	4.42
FSP3	1,750	80	153.99	4.78
		120	171.25	4.81
		160	188.57	5.03

Conclusions

The results of the specimen during casting of the alloy aluminum-silicon, semi-solid, 356 grades used in this study can be concluded that:

(1) The surface of specimen is improved by the friction stir process.

(2) Macrostructure through a friction stir processing showed a homogeneous appearance as well. No defective part was found. The surface of stirred is smooth.

(3) The microstructure after the friction stir processing at all conditions have a very refined structure, which consists of a silicon particles in aluminum alloy matrix uniformly distributed throughout the area to be stirred. However, investigation did not find any defects with the stirred.

(4) The hardness of the area was influenced by the thermal both retreating and advancing with increased hardness for all experimental conditions compared to that of base metal. But for the stir zone, the hardness can be either increased or decreased. The condition that increased the hardness is travelling speed at 120 and 160 mm/min with any rotation speed. The condition that reduced the hardness is travel speed at 80 mm/min with any rotation speed. The highest hardness, obtained at 1750 rpm with travel speed at 160 mm/min, is equal to 64.55 HV, an increase of 59.07% compared to the base metal.

(5) The average maximum tensile strength after using friction stir processing is equal to 188.57 MPa, an increase of 11.8% compared to the base metal. It was found that the conditions providing strength to pull up the average is at the speed around the 1750 rpm and at the travel speed at 160 mm/min.

Acknowledgment

This work was supported by a research fund from the Graduate School, Prince of Songkla University. Researchers thank the Department of Engineering, Faculty of Industrial Technology, Songkhla Rajabhat University.

References

[1] R.S Mishra, M.W Mahoney, S.X Mcfadden, N.A Mara, A.K Mukherjee, High strain rate superplasticity in a friction stir processed 7075 Al alloy, Scripta Mater. 42 (2000) 163-168.
[2] P.B Berbon, W.H Bingel, R.S Mishra, C.C Bampton, M.W Mahoney, Friction stir processing: a tool to homogenize nanocomposite aluminum alloys. Scripta Mater. 44 (2001) 61-66.
[3] Z.Y Ma, R.S Mishra, M.W Mahoney, Superplastic deformation behaviour of friction stir processed 7075Al alloy. Acta Mater. 50 (2002) 4419-4430.
[4] R.S Mishra, Z.Y Ma, I Charit, Friction stir processing: a novel technique for fabrication of surface composite. Mat. Sci. Eng. A. 341 (2003) 307-310.
[5] Z.Y Ma, R.S Mishra, M.W Mahoney, Superplasticity in cast A356 induced via friction stir processing. Scripta Mater. 50 (2004) 931-935.
[6] S.R Sharma, Z.Y Ma, R.S Mishra, Effect of friction stir processing on fatigue behavior of A356 alloy. Scripta Mater. 51 (2004) 237-241.
[7] M.L Santella, T Engstrom, D Storjohann, T.Y Pan, Effects of friction stir processing on mechanical properties of the cast aluminum alloys A319 and A356. Scripta Mater. 53 (2005) 201-206.
[8] I Charit, R.S Mishra, Low temperature superplasticity in a friction-stir-processed ultrafine grained Al–Zn–Mg–Sc alloy Acta Mater. 53 (2005) 4211-4223.
[9] R.S Mishra, Z.Y Ma, Friction stir welding and processing. Mat. Sci. Eng. A. 50, (2005) 1-78.
[10] L Karthikeyan, V.S Senthilkumar, V Balasubramanian, S Natarajan, Mechanical property and microstructural changes during friction stir processing of cast aluminum 2285 alloy. Mater Design 30 (2005) 2237-2242.
[11] L Karthikeyan, V.S Senthilkumar, K.A Padmanabhan, On the role variables in the friction stir processing of cast aluminum A319 alloy. Mater Design 31 (2009) 761-771.
[12] M.L Santella, T Engstrom, D Storjohann, T.Y Pan, Effects of friction stir processing on mechanical properties of the cast aluminum alloys A319 and A356. Scripta Mater. 53 (2005) 201-206.
[13] P. S Sklad, Friction Stir Processing of Advanced Materials. Lightweight Materials Program Metals and Ceramics Division Oak Ridge National Laboratory 2003.
[14] W.M Thomas, E.D Nicholas, Friction Stir Welding for the Transportation Industries. Mater Design 18 (1997) 269-273.
[15] A.K Lakshminarayanan, V Balasubramanian, Process parameters optimization for friction stir welding of RDE-40aluminium alloy using Taguchi technique. Trans. Nonferrous Met. Soc. China 18 (2007) 548-554.
[16] K Nakata, Y.G Kim, H Fujii, T Tsumura, T Komazaki, Improvement of Mechanical Properties of Aluminum Die Casting Alloy by Multi-pass Friction Stir Processing. Mat. Sci. Eng. A. 437 (2006) 274-280.
[17] Y Morisada, H Fujii, T Nagaoka, M Fukusumi, Effect of friction stir processing with SiC particles on microstructure and hardness of AZ31. Mat. Sci. Eng. A. 433 (2006) 50-54.
[18] J Wannasin, S Thanabumrungkul, Development of a semi-solid metal processing technique for aluminium casting application. Songklanakarin J. Sci. Tech 30(2) (2008) 215-220.
[19] Y.H Zhao, S.B Lin, L Wu L, F.X Qu, The influence of pin geometry on bonding and mechanical properties in friction stir weld 2014 Al alloy. Mater Lett 59 (2005) 2948-2952.
[20] Y.G Kim, H Fujii, T Tsumura, T Komazaki, K Nakata, Effect of Welding parameter on Microstructure in stir zone of FSW joints of Aluminum die casting alloy. Mater Lett 60 (2006) 3830-3837.

[21] Y.G Kim, H Fujii, T Tsumura, T Komazaki, K Nakata, Three defect types in friction stir welding of aluminum die casting alloy. Mat. Sci. Eng. A. 415 (2006) 250-254.
[22] H.S Park, T Kimura, T Murakami, Y Nagano, K Nakata, M Ushio, Microstructure and mechanical properties of friction stir welds of 60%Cu-40%Zn copper alloy. Mat. Sci. Eng. A. 371 (2003) 160-169.
[23] M Azizieh, A.H Kokabi, P Abachi, Effect of rotation speed and profile on microstructure and hardness of $AZ31/Al_2O_3$ nanocomposites fabricated by friction stir processing. Mater Design 32 (2011) 2034-2081.
[24] A.A Hassan, A.F Norman, D.A Price, P.B Prangnell, Stability of nugget zone grain structures in high strength Al-alloy friction stir welds during solution treatment. Acta Mater 51 (2003) 1923-1936.
[25] G Padmanaban, V Balasubramanian, Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy-an experimental approach. Mater Design 30 (2008) 2647-2656.
[26] M Amirizad, A.H Kokabi, M.A Gharacheh, R Sarrafi, B Shalchi, M Azizieh, Evaluation of microstructure and mechanical properties in friction stir welded A356+15%SiCp cast composite. Mater Design 60 (2006) 565-568.
[27] K Elangovan, V Balasubramanian, Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy. J Mater process tech 200 (2008) 163-175.
[28] W.B Lee, Y.M Yeon, S.B Jung, The improvement of mechanical properties of friction-stir-welded A356 Al alloy. Mat. Sci. Eng. A. 356 (2003) 154-159.