Journal of Mechanical Engineering *Vol SI 5(1), 181-191, 2018*

Effect of Tool Plunge Depth and Pin Profile on Mechanical Properties of Friction Stir Spot Welded AA5052 Joints

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ABSTRACT

Friction stir spot welding (FSSW) is a new developed solid state joining technology. Automotive industry introduces FSSW to substitute resistance spot welding process to join Aluminum alloy. In this study, FSSW is applied to join 5052-H32 aluminum alloy sheets. The AA5052-H32 sheets with the thickness of 2 mm was welded using friction stir spot welding. The influence of tool plunge depth and pin profile on macrostructure, microstructure, and mechanical properties of the joints were experimentally investigated. Three different tool pin profile of cylinder, truncated cone, square pin and four different tool plunge depth of 2.2, 2.4, 2.6, 2.8 mm were used to fabricate the joint. The result shows that the increase of tool plunge depth resulted in the increase of frictional heat that affected to the wider area of stir zone and the coarser grain size. It resulted in the increase of tensile shear load of the joint. The maximum tensile shear load obtained at tool plunge depth of 2.6 mm for all variation tool pin profile. The further increase of tool plunge depth of 2.8 mm produced the lower joint strength than previous tool plunge depth. The tool pin profile affected to the physical and mechanical properties of the friction stir spot welded of AA5052 joint. Truncated conical pin resulted in the narrower of stir zone, whereas square pin resulted in the wider of stir

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ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-05-10
Accepted for publication: 2017-06-16
Published: 2018-01-15

zone. The best tensile shear load obtained in the square pin profile of 4.07 kN.

Keywords: *Friction Stir Spot Welding; Aluminium Alloy 5052; Tool Plunge Depth; Pin Profile; Mechanical Properties.*

1. Introduction

Pressing need of reducing weight of a vehicle is important to reduce fuel consumption. Aluminum and magnesium are the choices because their unique properties, especially lightweight properties [1]. Application of lightweight materials in the automotive industry has been rapidly growing in few recent years. One of lightweight material is an aluminum alloy that has been developed and low cost [2]. Even though aluminum alloys have some advantages because of good strength, formability, corrosion resistance, however, joining aluminum alloys still have some problems.

The common joining process that used in producing automotive part is resistance spot welding (RSW) that the welding takes place at fusion state. The advantages of using RSW are low capital cost, ease of maintenance, and high tolerance to poor part fit up, however joining of aluminum alloy still have some sparseness such as distortion, residual stress and fusion related defects [3]. It is well known that aluminum alloys show very poor weld ability in traditional fusion welding such as Resistance Spot Welding (RSW). It has poor weld consistency, short electrode tip life, and melt-related defect problems such as porosity [4]. Also due to local high temperature during welding, it can produce undesirable deformation of sheet metal [5].

Recently, friction stir spot welding (FSSW) has been developed. Some benefits of using FSSW on industrial application are low distortion, low energy, and avoiding melt related defects. FSSW is one of candidates that can replace the common resistance spot welding on joining a body part of automotive made from aluminum alloy. In the friction stir spot welding, the heat generation is produced by two action. The first is friction between rotating tool and workpiece, and the second is severe plastic deformation of the workpiece. Material around the tool is softened by friction heating and stirred by the tool to unify between both surface. The tool shoulder restrict the metal flow to the shoulder position. The main functions of welding tool are to generate the welding heat and to stir softened metal [6].

Several FSSW process may play an important parameters in determining the joint quality such as tool rotational speed, shoulder plunge depth, and dwell time [7]. Friction stir tool geometry influences the material flow and hence affects the static strength of joints [8]. In the case of friction stir welding, the increase of tool plunge depth and tool tilt angle resulted in the growth of welding temperature and hence the increase of the joint strength [2]. However effect of tool plunge depth and pin profile on mechanical properties of friction stir spot welded AA 5052 has not been explored well.

The aim of this research is to investigate the effect of tool plunge depth and pin profile on mechanical properties of friction stir spot welded AA 5052 joint with all the phenomenon during the joining process.

2. Methodology

The base material of AA 5052-H32 sheets with dimension 125 x 40 x 2 mm and overlap area 40 x 40 mm was used in this friction stir spot welding process. Table 1 shows the chemical composition of AA 5052-H32. The FSSW tool material that was utilized in this study was made from K100 tool steel that the dimension was shown in Figure 1. Three different tool pin profile of cylinder, truncated cone, and square were used to fabricate the joint. The variations of tool plunge depth were 2.2, 2.4, 2.6, and 2.8 mm. The shoulder plunge depth and dwell time were 0.2 mm and 5 s, respectively.

Table 1. Chemical composition of 5052 Al alloy (mass fraction, %)

Cu	Mg	Si	Fe	Mn	Zn	Cr	Al
0.001	2.5	0.072	0.254	0.051	0.005	0.188	Bal

The geometry and dimension of tensile shear test specimen can be seen at Figure 2. The tensile shear load was measured using SANS Universal Testing Machine with displacement rate 5 mm/s. Micro Vickers Hardness-

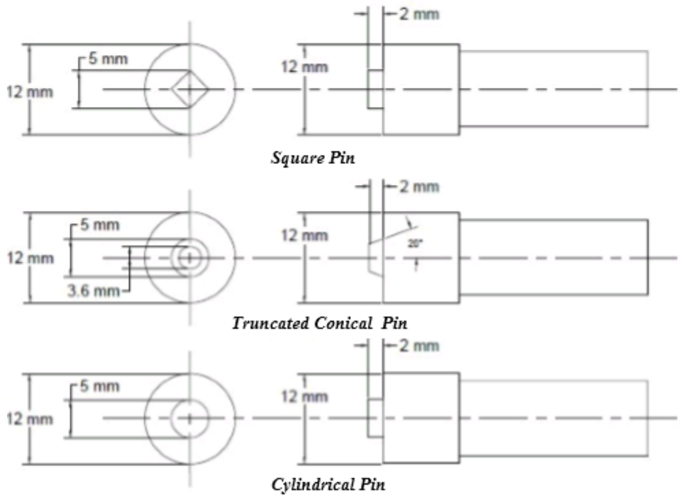

Fig. 1. Friction stir welding tool dimension (mm).

number was observed using Highwood HWMMT X7 with a load of 0.3 kgf and dwell time of 10 s according to ASTM E384. The specimens of cross section morphology of the joints were polished using multi-grade emery papers and etched using modified Poulton's reagent (30 mL HCl, 40 mL HNO3, 2.5 mL HF, 12 g CrO3 and 42.5 mL H2O). The macrostructure was observed using a light optical stereo-zoom. The microstructure was observed using optical Euromex Holland Microscope.

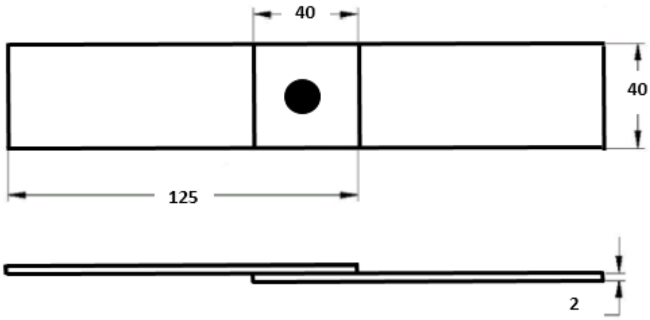

Fig. 2. Dimension of tensile shear test specimen (mm)

3. Result and Discussion

3.1. Macrostructure

Figure 3 shows macrographs of the cross sections of the friction stir spot welded AA5052-H32 sheet. It can be observed that the increase of tool plunge depth cause the wider and deeper of stir zone. The reason is that the higher tool

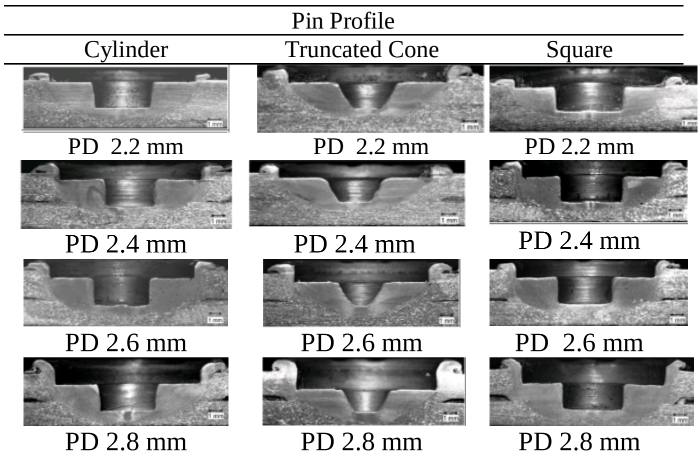

Fig. 3. Macrographs of friction stir spot welded joints under variation of tool plunge depth (PD) and pin profile

Plunge depth increases the welding heat generation and soften the material around the tool so that the material beneath the tool can be more stirred. The best material consolidation can be produced if the material has been plasticized enough [10]. The tool plunge depth parameter gives the highest effect on the friction stir welding processes [2].

The increase of tool plunge depth causes higher welding axial force especially material below the shoulder and the pin as well. It produces higher friction heat and the more material can be flowed in this processes so that the wider stir zone can be generated. In line with [2] that the higher welding temperature can soften the material around the tool, so the size of stir zone become wider. The increase of friction heat that cause the increase of peak temperature result in the lower material viscosity[12]. It enhances the material flow during welding.

The tool pin profile also influences the weld nugget area. Square tool pin profile produces wider weld nugget area then those of cylindrical pin profile and conical pin profile. The narrowest weld nugget area is obtained at conical pin profile. The square pin profile produces higher heat generation [9] that can soften the more volumes of workpiece material around the pin. The more volumes of softened material can be stirred to make the weld nugget wider. Figure 4 shows the partially metallurgical bonded zone (PMBZ) that produced under the parameter of tool plunge depth. The increase of tool plunge depth causes the decrease of PMBZ at the junction of nugget zone and -

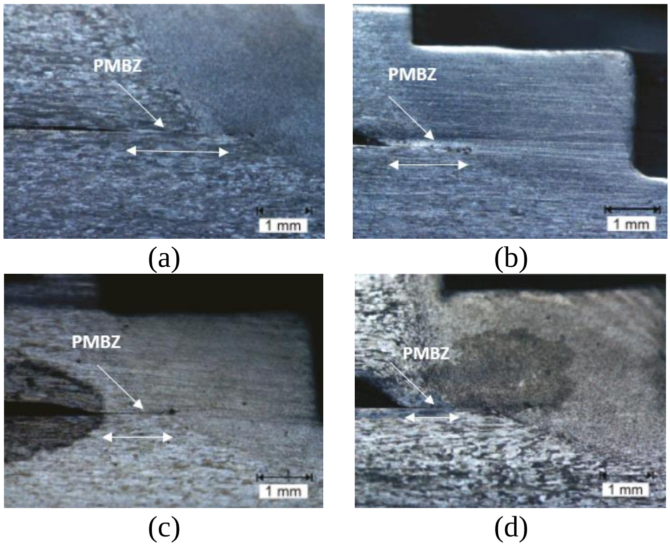

Fig. 4. Partially metallurgical bonded zone (PMBZ) under square pin profile parameter with variations of tool plunge depth of (a) 2.2 mm, (b) 2.4 mm (c) 2.6 mm, and (d) 2.8 mm

thermo mechanically affected zone (TMAZ). The formation of PMBZ result from material flow during welding due to the degree of stirring action of shoulder and tool pin. The weaker material flow can produce higher PMBZ. One of the welding parameter that affected the formation of PMBZ is tool plunge depth [11]. The higher partially metallurgical bonded zone, the weaker tensile shear load. The change of tool pin profile also affected PMBZ. Square pin profile resulted in the smallest PMBZ. The highest PBMZ can be obtained at truncated conical pin profile.

3.2. Microstructure

Figure 5 (a), (b) and (c) show a typical of microstructure of base metal (BM), heat affected zone (HAZ), thermo mechanically affected zone (TMAZ), and stir zone (SZ) that are taken from the specimen. The characteristics of the

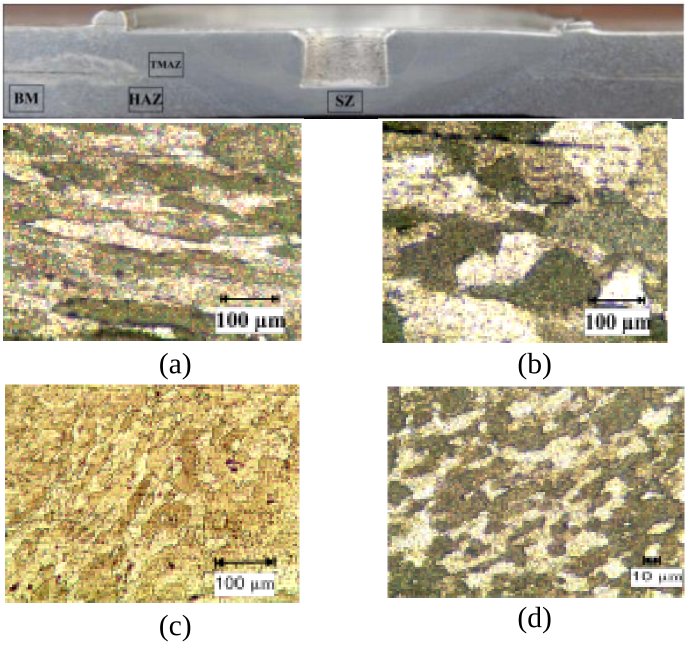

Fig. 5. Typical Microstructure of (a) Base metal (BM), (b) Heat affected zone (HAZ), (c) Thermo-Mechanical Affected Zone (TMAZ), and (d) Stir Zone (SZ)

Microstructure of base material are elongated grain that is the result of cold work processing as seen in Fig. 5 (a). It can be observed from Figure 5 (b) that the grain size of Heat Affected Zone (HAZ) is coarser than that in the parent material. The material in this zone has undergone thermal cycles of welding without plastic deformation that has modified its structure to be coarser grain size. Figure 5 (c) shows microstructure of thermo-mechanical affected zone (TMAZ). The material of thermo-mechanically affected zone has experienced plastic deformation and friction heat cycles that significantly influence microstructure to be elongated grain. Stir Zone (SZ) as seen in Figure 5 (d) is the area that the grains is an equiaxed grain which is produced by combination of high friction heat and high severe plastics deformation.

The heat affected zone under tool plunge depth and pin profile variations are shown in Figure 6. The increase of tool plunge depth lead to the grain growth. The grain size increases continuously with increasing temperature, which is caused by an increase of tool plunge depth. A high heat input results in coarse grain size [10].

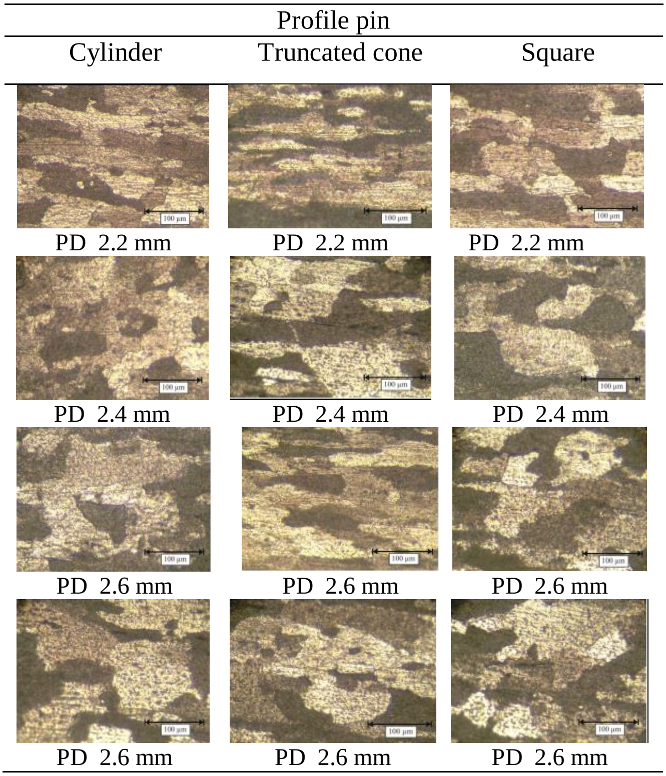

Fig. 6. Microstructure of heat affected zone under variation of tool plunge depth (PD) and pin profile

3.3. Mechanical Properties

The tensile shear load of all welded specimens under variation of tool plunge depth of 2.2, 2.4, 2.6, and 2.8 mm and three variation of pin profile of cylinder, truncated cone and square pin can be seen in Figure 7. It can be observed from

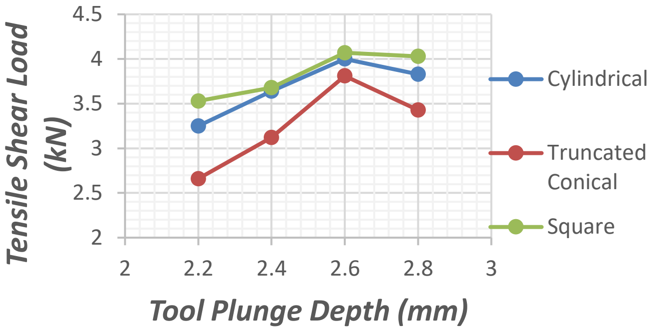

Fig. 7. Tensile shear load of FSSWed joint under variation of tool plunge depth and pin profile.

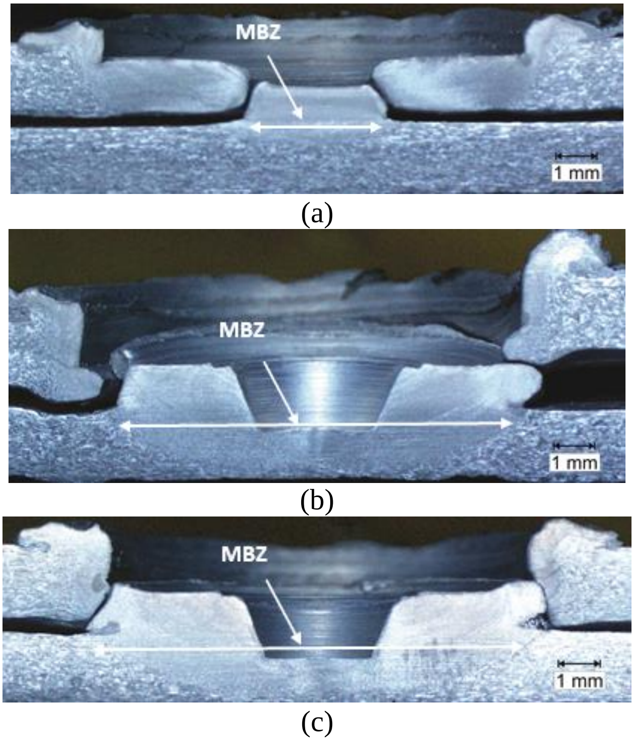

Fig 8. Cross section area of fractured specimen of Friction stir spot welded joint under the pin profile of truncated conical pin and variation tool plunge depth of (a) 2.2, (b) 2.4 and (c) 2.8 mm

Figure 7, that the increase of tool plunge depth strengthen the tensile shear load of joint. The maximum value is obtained at tool plunge depth of 2.6 mm for all variation of pin profile. The 5052-H32 is the non heat treatable aluminum alloy that can not be strengthened by precipitation so the increase of tensile shear load can be attributed to the decrease of partially metallurgical bonded zone. It means that the increase of tool plunge depth produces the narrower partially metallurgical bonded zone as seen in Figure 3. It can be proved from Figure 8 that the cross section area of fractured tensile shear specimen that increase of tool plunge depth results in a wider metallurgical bonded zone (MBZ).

The effect of pin profile can also be seen from Figure 7. The highest tensile shear load can be obtained at the square pin profile for all variation of tool plunge depth. It is attributed to the improvement of thermo mechanical effect onto the interface [6].

4. Conclusions

The effect of tool plunge depth and pin profile on mechanical properties and microstructure of friction stir spot welded aluminum alloy 5052 has been investigated, the conclusion as follows:

1. The increase of tool plunge depth and variation of pin profile influence the tensile shear load of friction stir spot welded AA 5052 joint.
2. The increase of tool plunge depth lead to the increase of tensile shear load and obtained maximum value of 4.07 kN at tool plunge depth of 2,6 mm and then the further increase tool plunge depth of 2.8 mm, the tensile shear load slightly decrease of 4.03 kN.
3. The Square pin profile produced the highest tensile shear load of friction stir spot welded AA5052, whereas the lowest one is obtained at the truncated conical pin profile

Acknowledgements.

The author would like to acknowledge for financial supporting from Indonesian Ministry of Research Technology and Higher Education by Penelitian Unggulan Perguruan Tinggi (PUPT) tahun anggaran 2017 Grant, Contract No. 873/UN27.21/PP/2017

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