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Evaluation of Mechanical Properties with Tool Rotational Speed in Dissimilar Cast Aluminum and High-Strength Steel of Lap Jointed Friction Stir Welding

Jeong-Hun Park[*,**], Seong-Hwan Park[**], Soo-Hyeong Park[**], Young-Hwan Joo[**], Myungchang Kang[**,#]
[*]Chasys Corporation, Ltd.
[**]The Graduate school of Convergence Science, Pusan National University

이종 주조알루미늄-고장력강의 겹치기 마찰교반접합에서 툴회전속도에 따른 기계적 특성평가

박정훈[*,**], 박성환[**], 박수형[**], 주영환[**], 강명창[**,#]
[*](주)체시스, [**]부산대학교 융합학부

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ABSTRACT

Recently, friction stir welding of dissimilar materials are one of the biggest issues in terms of light-weight and eco-friendly technology of the automotive, aircraft and ship industry. In this study, friction stir welding of dissimilar materials is introduced with different tool rotational speed. Materials used in experimentation consist of A357 gravity cast aluminum alloy and FB590 high-strength steel plates. Dissimilar materials of plate type are fabricated with width of 150mm, length of 300mm and thickness of 3mm and welding is carried out by the lap joint method. The correlation between probe length and mechanical properties were investigated according to rotational speed and welding speed at tool tilt angle 0 degree. Consequently, feasibility of FSWed dissimilar materials were successfully presented in case of cast aluminum and high-strength steel at lap joint method.

Key Words : Friction Stir Welding(마찰교반접합), Dissimilar Materials(이종소재), Cast Aluminum(주조 알루미늄), High-strength Steel(고장력강), Mechanical Properties(기계적 특성)

1. Introduction

Recently, the automotive industry, environmental protection and energy saving through utilizing lightweight and compact products are key issues[1-3].

In the automotive industry, improvement of automobile fuel efficiency is urgently required as fuel efficiency regulations are being enforced worldwide. Measures to improve fuel efficiency include highly efficient powertrain components such as superchargers and hybrid engines, improving component structures, weight reduction through process improvement, and

Corresponding Author : kangmc@pusan.ac.kr
Tel: +82-51-510-2361, Fax: +82-51-510-7396

reducing air resistance. Among them, fuel efficiency improvement through weight reduction is being actively applied because it can also decrease the carbon dioxide generated during driving[2]. One example is changing steel parts to nonmetal parts. In industry, various welding method apply protective gases such as TIG, MIG, and CO_2 are being applied to weld steel and dissimilar materials[4].

However, there is the problem of low weldability for dissimilar materials due to the different characteristics between the two materials. To address this problem, welding and joining technologies with high weldability are required between steel and lightweight materials. Friction stir welding is being actively introduced in automotive part manufacturing processes because it has many advantages such as environmental friendliness and economic efficiency in welding two dissimilar metals. Furthermore, friction stir welding is a solid state welding method that has high welding efficiency between aluminum and steel due to the low temperature generation during welding[5]. For aluminum materials in vehicles, 50 series aluminum with excellent formability and 60 series alloys with excellent strength are typically used, followed by cast aluminum alloys.

Among the representative studies on welding aluminum to high strength steel, Tanaka[6] performed friction stir welding between 3mm-thick AA7075-T6 and mild steel and reported that the welded product showed 60% of the strength of the original aluminum material. Lue[7] performed friction stir welding by butt joint between AA6061-T6 and TRIP800, and reported that the welded product showed 85% strength. Coelho[8] performed friction stir welding with a lap joint between 1.5mm thick AA6181-T4 and HC430LA and confirmed that it had 73% strength compared to the original aluminum material. Cast aluminum has a problem of inner pores in the final product, and the pores expand when it is welded due to the heat generated during welding, which causes fine inner defects and separation. However, it has the advantages of high dimensional accuracy for various complex shapes and broad application in many industries.

Therefore, friction stir welding is performed in this study for the dissimilar materials of cast aluminum and high strength steel and their weldability is evaluated according to the tool rotational speed. In addition, the existence of inner pores in the weld zone of the cast aluminum is checked through microstructure observation and the applicability of friction stir welding for the dissimilar materials of cast aluminum and high strength steel for weight reduction is presented.

2. Experimental Setup and Method

2.1 Materials for friction stir welding

For this experiment, cast aluminum A357 and high strength steel FB590 were used. Table 1 outlines the chemical compositions of these materials. A357 is an Al-Si-Mg alloy characterized by the excellent toughness and corrosion resistance required of body parts. A357 was produced at 3 mm thickness for the weld zones and 6 mm thickness for non-weld zones. The high strength steel FB590 was produced at 3 mm thickness. Both materials were cut into rectangular shapes 150 mm wide and 300 mm long and friction stir welding was performed by a lap joint. Figure 1 shows the schematic diagram.

2.2 Experimental setup and method

Figure 2 shows the schematic of the tool for friction stir welding used in this experiment and detailed dimensions. The tool was produced using a W-Ni-Fe alloy, which is a heavy alloy. The tool's probe was produced in the threaded conical shape.

In this experiment, the tilting angle was fixed at 0 degree. When the tilting angle was small, the vertical force of the Z-axis was reduced. When the vertical force was reduced, it was highly likely to generate defects in the weld zone[9-10].

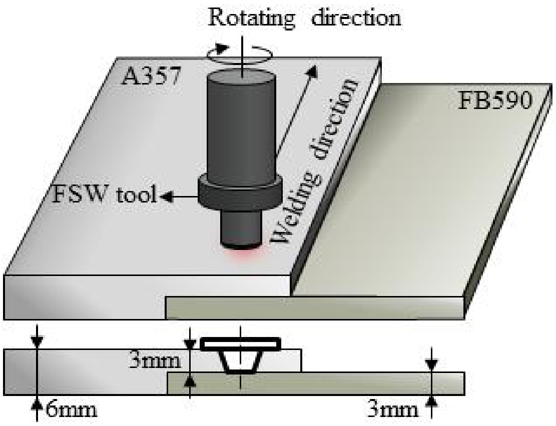

Fig. 1 Schematic illustration of FSW experimental configuration

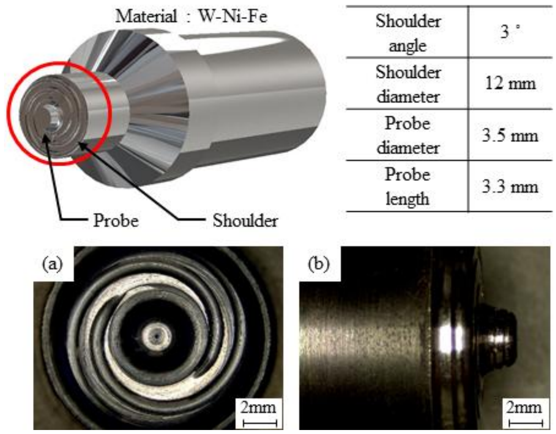

Fig. 2 Image and size of FSW tool used in experiment (a) Spiral shoulder and (b) Threaded probe

Table 1 The chemical composition of FB590(High Strength Steel) and A357(Cast Aluminum) sheets

Material	C	S	Mn	P	S	Cr	Ni
FB590	0.076	0.094	1.472	0.013	0.001	0.019	0.008

Material	Si	Mg	Cu	Zn	Fe	Mn	Ti
A357	6.937	0.507	0.034	0.017	0.181	0.007	0.116

Table 2 Friction stir welding conditions for A357-FB590 dissimilar materials

Tilting angle (degree)	Tool Rotational Speed (RPM)	Welding Speed (mm/min)
0	1700 1800 1900	60

However, because automotive parts have complex structures and many curved shapes, friction stir welding must be applicable to curve shapes when it is finally applied. Applying friction stir welding to curve shapes requires fixing the tilting angle 0 degree. Hence, the tilting angle was fixed in this experiment. To increase the Z-axis vertical force that was reduced by the tilting angle, a convex type was selected for the tool shoulder. The convex angle was machined at 3 degree and the friction heat and stirring force were improved in the welding process by machining in a spiral shape.

Table 2 lists the welding parameters in this experiment. The tilting angle was fixed at 0 degree and the welding speed at 60 mm/min. The tool rotational speed was changed in 100 RPM intervals from 1700 to 1900 RPM and the microstructure and mechanical characteristics of the weld zone were evaluated according to the tool rotational speed. To observe the microstructure and evaluate the mechanical characteristics of the weld zone, tensile test specimens and specimens for microstructure observation were fabricated through wire processing.

The microstructure of the specimens for microstructure observation were observed using an optical microscope(KH-8700, HIROX) and an electronic microscope(S-4800, HITACHI) after the polishing process and their hardness was tested using microhardness tester(MMT-X7B, MATSUZAWA). It was measured in 0.3 mm intervals with 50 gf hardness test load and a 10 s pressurizing time. The tensile test specimen was fabricated in accordance with the ASTM E8 standard and the tensile test was performed using a tensile tester(AGS-X, SHIMADZU).

3. Results and Discussion

3.1 Microstructure characteristics of the friction stir weld zone

Figure 3 shows the macrostructure photograph of the friction stir weld zone of the A357-FB590 lap joint. There is a stir zone(S.Z.) at the center of the weld zone. Outside the S.Z., there is a thermo-mechanically affected zone (TMAZ) that has an increased grain size due to the plastic flow. On the outside of the TMAZ, their is a heat affected zone (HAZ) that receives the heat effect even though it is not accompanied by plastic deformation. The TMAZ and HAZ were observed in a wider region compared to the distance from the advancing side (AS) to the retreating side (RS) of the tool. Furthermore, a TMAZ region can be observed in a partial section of the S.Z. that is considered to be and effect of the probe thread. Fig. 3(d) shows that a part of the high strength steel become physically attached. Furthermore, Fig. 3(f) shows the base metal (B.M.) that is not affect by the rotating tool and large grain size is observed. However, as it gets closer to the S.Z., the grain size becomes very small due to the effect of the rotating tool. It becomes difficult to observe with an optical microscope.

Figure 4 shows the macrostructure result of the weld zone according to the change in RPM. When the RPM is increased while the other variables are fixed, more heat is input into the material. It can be seen that the largest heat input occurs at 1900 RPM, and as observed in the macrostructure, a larger TMAZ and HAZ are observed. Pores are observed in a part of the base metal, which is a characteristic of cast aluminum, but no pores were observed in the zone affected by the tool. More finely crushed microstructure were observed in the S.Z. When thy

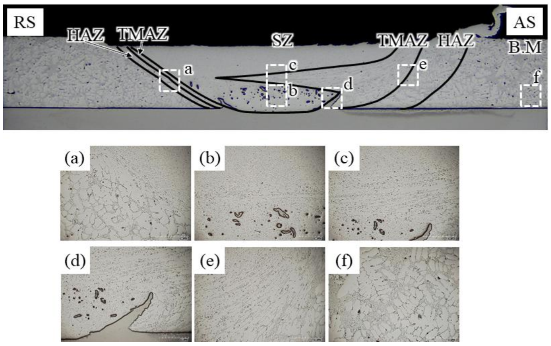

Fig. 3 O.M image of the cross-section of lap joints (a) TMAZ&HAZ, (b) S.Z, (c) S.Z&TMAZ, (d) Hooking, (e) TMA&HAZ, and (f) B.M

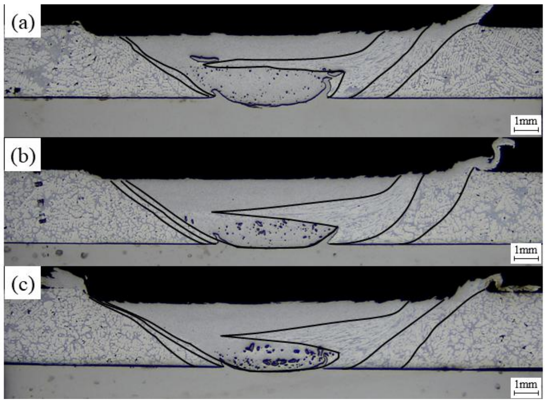

Fig. 4 The comparison of macrostructure of A357 - FB590 lap joint with different welding parameter (a) 1700 RPM, 60 mm/min, (b) 1800 RPM, 60mm/min, and (c) 1900 RPM, 60mm/min

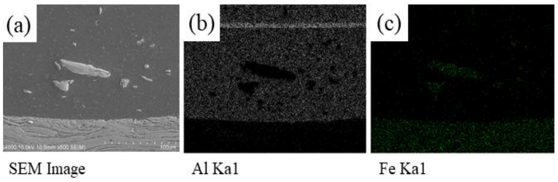

Fig. 5 SEM image and EDS analysis of particle in S.Z (a) SEM image, (b) EDS mapping image of Al element, and (C) EDS mapping image of Fe element

were analyzed by EDS mapping image, some of the high strength steels had been finely crushed by the rotating tool. The existence of S.Z. could be observed from the stirring force. Figure 5 shows the SEM images and EDS mapping results.

3.2 Micro-hardness characteristics of the fiction stir weld zone

Figure 6 shows the micro-hardness measurement results of the friction stir weld zone. Among the zones affected by the tool, the S.Z. showed the highest hardness at 66-75 Hv while the HAZ showed the lowest hardness at 52-57 Hv. The hardness of the S.Z. was 64-69 Hv at 1700 RPM, 69-75 at 1800 RPM, and 71-77 Hv at 1900 RPM. Thus, the hardness of the S.Z. increased as the RPM increased. The hardness of the HAZ was similar in all conditions. At 1700 and 1800 RPM, the hardness showed an increasing trend from the rear part of the tool toward the original material. At 1900 RPM, the hardness increased from the rear part of the tool to the HAZ, but decreased again after the HAZ this implies that the hardness of the original material in the hardness measurement region was unverifiable. These results confirmed that the influence zone of the tool was larger at 1900 RPM.

3.3 Tensile experiment result for friction stir weld zone

Figure 7 shows the tensile load graph according to displacement after friction stir welding. The original material of cast aluminum showed the maximum tensile load of 7,912N. When the maximum tensile load of the friction stir weld zone was checked under different conditions, it showed the highest maximum tensile load at 5,719 N under the conditions of 1900 RPM and 60 mm/min. This values 72.8% of that for the original aluminum material (A357). The fracture in the tensile test occurred in the HAZ of aluminum

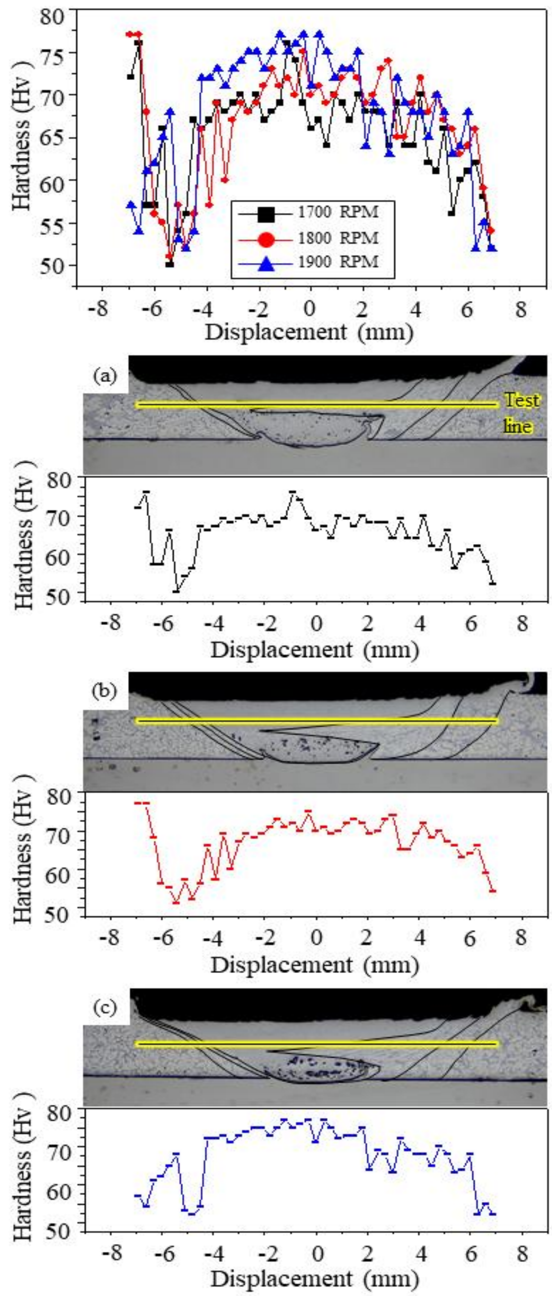

Fig. 6 Microhardness with different welding parameter (a) 1700 RPM, 60mm/min, (b) 1800 RPM, 60mm/min, and (c) 1900 RPM, 60mm/min

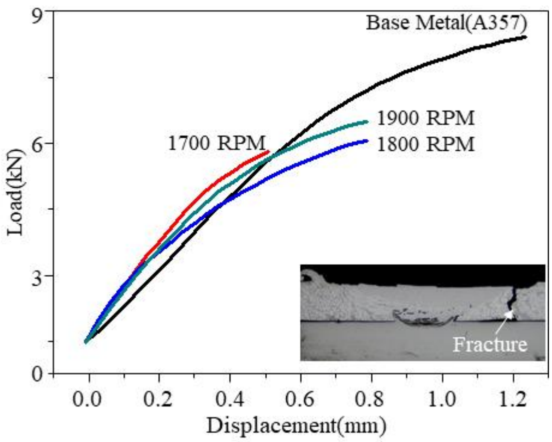

Fig. 7 Tensile test results of different welding parameter and fracture location

Table 2 Tensile test results of different welding parameter

Condition	Peak Load (N)	Ratio (%)
Base Metal (A357)	7912	-
1700 RPM	4947	62.5
1800 RPM	5235	66.2
1900 RPM	5719	72.8

under all conditions. A comparison with the micro-harness results revealed that fractures occurred at the parts with low hardness values.

4. Conclusion

In this study, lap joint friction stir welding was performed between cast aluminum A357 and high tensile steel FB590; microstructure were observed and the mechanical characteristics were analyzed according to the welding conditions to obtain the following conclusions. When the spindle rotation speed was increased from 1,700 RPM to 1,900 RPM, a larger weld zone was found in the macrostructure observation. When the front and rear parts of the tool were compared, a larger weld area was observed in the front part than in the rear part. The micro-hardness measurement results also showed that the weld zone area increased as the RPM increased. When the microstructure was observed after friction stir welding between dissimilar materials of cast aluminum A357 and high tensile steel FB590, fine fragments crushed by the tool were found at the interface of the weld zone; these were confirmed to be high tension fragments through EDS(Energy dispersive X-ray spectroscopy) analysis. The tensile test result after the friction stir welding showed a load of 5,719 N at 1,900 RPM, which corresponds to 72.8% of that of the original cast aluminum.

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REFERENCES

1. Joo, Y. H., Park, Y. C., Lee, Y. M., Kim, K. H., and Kang, M. C., “The Weldability of a Thin Friction Stir Welded Plate of Al5052-H32 using High Frequency Spindle,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 16, No. 1, pp. 90-95, 2017.
2. Noh, J. S., Kim, J. H., Go, G. H., and Kang, M. C., “New technology Trends on Friction Stir Welding Based on Milling Process in terms of Tools, Machine and Pllied Parts,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 12, No. 6, pp. 37-44. 2013.
3. Park, J. H., Jeon, S. T., Lee, T. J., Kang. J. D., Knag, M. C., “Effect on Drive Point Dynamic

Stiffness and Lightweight Chassis Component by using Topology and Topography Optimization," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 3, pp. 141-147. 2018.

4. Jeong, Y. C., Cho, Y. T., and Jung, Y. G., "Amonunt of Spatter in Arc Welding for High-Strength Galvanized Steel According to Shielding Gas Composition," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 15, No. 1, pp. 110-115. 2016.
5. Lee, K. J., "Recent Research & Development Trend on Friction Stir Welding and Friction Stir Processing," Journal of Welding and Joining, Vol. 31, No. 2, pp. 26-29. 2013.
6. Tanaka, T., Morishige, T., and Hirata, T., "Comprehensive analysis of joint strength for dissimilar friction stir welds of mild steel to aluminum alloys," Scripta Materialia, Vol. 61, No. 7, pp. 756-759, 2009.
7. Lui, X., Lan, S., and Ni, J., "Experimental investigation on joining dissimilar aluminum alloy 6061 to TRIP 780/800 steel through friction stir welding," Journal of Engineering Materials and Technology, Vol. 137, No. 4, 2015.
8. Coelho, R. S., Kosta, A., Santos, J. F., and Kaysser-Pyzalla, A., "Friction-stir dissimilar welding of aluminium alloy to high strength steels: Mechanical properties and their relation to microstructure," Materials Science and Egineering:A, Vol. 556, pp. 175-183, 2012.
9. Zhang, K. J., Wang, M., Zhu, Z., Zhang, X., Yu, T., Wu, Z. Q., "Impact of shoulder concavity on non-tool-tilt friction stir welding of 5052 aluminum alloy," Vol. 96, No. 1-4, pp. 1497-1506, 2018.
10. Barlas, Z., "Tool Influence of Tool Tilt Angle on 1050 Aluminum Lap Joint in Friction Stir Welding Process," Acta Physica Polonica, A., Vol. 132, No. 3, pp. 679-681, 2017.