Application of hot forming quenching on patchwork blank using two-stage refilled friction stir spot welding

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Abstract. The purpose of this study is to apply Hot Forming Quenching (HFQ) on Patchwork Blank of AA6061 using Two-stage refilled Friction Stir Spot Welding (TFSSW). TFSSW is a developed joining method to improve joint strength of conventional Friction Stir Spot Welding (FSSW) and it consists of two stages. The first stage is a conventional FSSW process and second stage is a refilling process for refilling keyhole. The Design of Experiment (DOE) was used to optimize the TFSSW process parameters. A hat shape forming test was performed using a patchwork blank manufactured with the optimal process parameters to investigate validity of applying HFQ. Formed hat shape part was sequentially heat treated with artificial aging (T6) condition. The hardness of the weld zone was measured to confirm a drop of mechanical property in comparison with the conventional cold forming, which shows the validity of HFQ application to patchwork blank using TFSSW.

1 Introduction

In the recent years, aluminum alloy has been widely used in automotive industries to achieve higher fuel efficiency and improve crashworthiness. Also, Patchwork blank is adopted to manufacture automotive parts to maximize weight lightening: (1)However, there are several difficulties to improve patchwork blanks particularly for aluminum alloys. Because of their less familiar weldability requirements associated with conventional welding methods such as laser welding and resistance welding; (2)Therefore, in this study, Two-stage refilled Friction Stir Spot Welding(TFSSW) is used instead of the conventional welding method. Fig.1 shows the process flow of FSSW and TFSSW. TFSSW is a developed joining method to improve joint strength of conventional FSSW process and it consists of two stages; (3)TFSSW and FSSW is a solid state welding process that is

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convenient for welding of aluminium alloys. FSSW has various advantages of low cost and low energy compared with the conventional welding method. Furthermore, recent studies on FSSW have been actively conducted. Effect of welding parameters on mechanical performance and microstructure of welded specimens(4-6), optimization of FSSW process parameters(7,8) and effect of tool geometry on joint strength(9-11) were investigated.

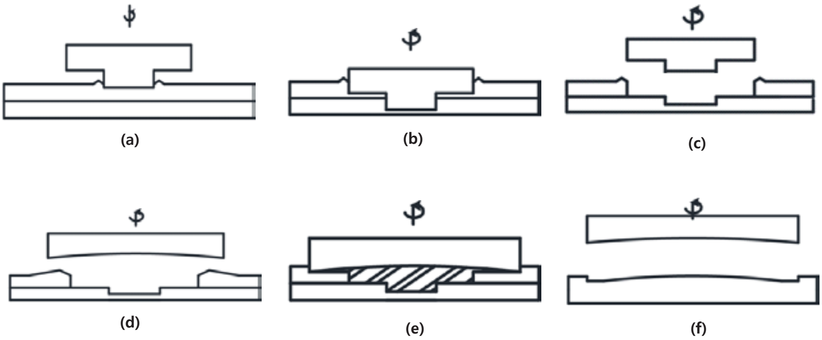

Fig. 1. Two-stage refilled Friction Stir Spot Welding process (a)-(c) first stage(conventional FSSW process), (d)-(f) second stage(TFSSW refilling process).

However, there is no study on forming of patchwork blank applying FSSW and TFSSW yet. Therefore, this study applied the forming of patchwork blank with Hot Forming Quenching(HFQ) using FSSW and TFSSW. The process flow is a step of forming the welded patchwork blank by heating it in a furnace, followed by press forming. HFQ is a process of hot forming a plate heated to a solution treatment temperature quenching it by a cooling channel provided in the die, and simultaneously performing hot forming and quenching(12-13).

In this study, a hat shape forming test was performed using a patchwork blank manufactured with the optimal TFSSW process parameters obtained by Design Of Experiment(DOE) to investigate validity of applying HFQ. Formed hat shape part was sequentially heat treated with artificial aging (T6) condition. The hardness of weld zone was measured to confirm drop of mechanical property in comparison with the conventional forming method, which shows the validity of HFQ application to patchwork blank using TFSSW.

2 Optimization of TFSSW process parameters

In order to manufacture patchwork blank using TFSSW, TFSSW process parameters and tool were selected. Many studies conducted on the optimization of FSSW process parameters. Based on previous studies, the TFSSW process parameters were selected as the tool rotational speed, plunge depth and dwell time, which have the greatest influence on joint strength. According to previous study (3), the tool of TFSSW 1stage(conventional FSSW) tool has pin diameter of 3mm, height of 1mm and shoulder diameter of 10mm, concaveness of 3°, 2stage(refilling process)tool has no pin, 15mm of shoulder diameter and concaveness of 5° as shown in Fig.2.

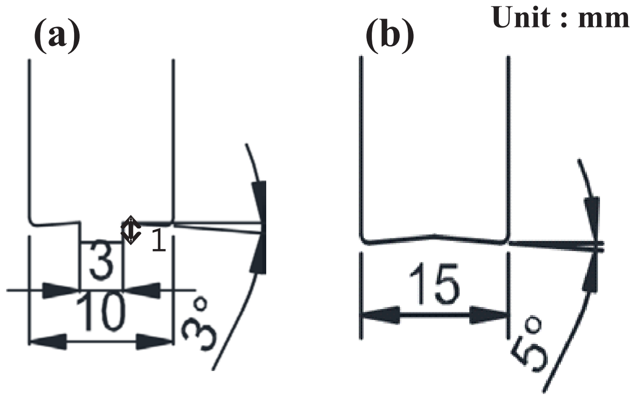

Fig. 2. (a) TFSSW 1stage tool (b) TFSSW 2stage tool.

The Patchwork blank was manufactured with AA6061-T6 (1.2t, 1.5t) and the process parameters of TFSSW and FSSW were optimized to best joint strength using the Taguchi method, one of the DOE. All experiments were carried out using a Friction Stir Process Machine Seeing Fig.3.

Fig. 3. Friction Stir Process Machine.

All specimens were welded by friction stir welding using fixtures. Lap shear test was carried out to evaluate the joint strength and it performed on a MTS machine. Fig.4 shows the appearance of a typical lap shear test specimen after TFSSW process. In order to perform TFSSW process parameters optimization, the L9 orthogonal array table was prepared and lap shear test was performed accordingly. The influence of each process parameter on the maximum shear force was evaluated using the Taguchi method, one of the Design Of Experiment, and the average values at each level of process parameters are the main effect plot. In first stage, Taguchi method results showed that tool rotational speed is the most significant factor with a percentage contribution of 44.57% followed by plunge depth and dwell time with a contribution of 13.88% and 9.04% respectively. In second stage, Taguchi method results showed that plunge depth is the most significant factor with a percentage contribution of 44.57% followed by tool rotational speed and dwell time with a contribution of 13.88% and 9.04% respectively. In addition, the optimal levels of the rotational speed, dwell time and plunge depth were found to be 1400rpm, 8seconds and 2.6mm in first stage and 1400rpm, 4seconds and 0mm in second stage.

Fig. 4. appearance of a typical lap shear test specimen.

3 Application of hot forming quenching

3.1 Experimental procedure

A hat shape forming test was performed using a patchwork blank manufactured with the optimal process parameters. Fig.5 showed a patchwork blank with a 300mm×260mm AA6061-T6 1.5mm thickness and a 150mm×120mm AA6061-T6 1.2mm thickness with 9 spot weld points. The tools consisted of punch, pad and die. A total of 21 cooling channels were used to overcome the non-uniformly distributed temperature of the tools and cooling water constantly flowed through the channels to cool the tools during hot forming quenching. Next, the patchwork blank heated at the solution temperature for 15minutes is transferred to the hat type die and press formed. During Forming, the punch speed was fixed at 20mm/s and the holding force were 48000N, respectively. In addition, due to the cooling channel in the die, quenching was performed simultaneously with forming and for sufficient quenching time, a quenching time of 10seconds was given after forming. Subsequently artificial aging (T6 condition) was performed. Fig. 6 showed the state of patchwork blank after hat shape forming.

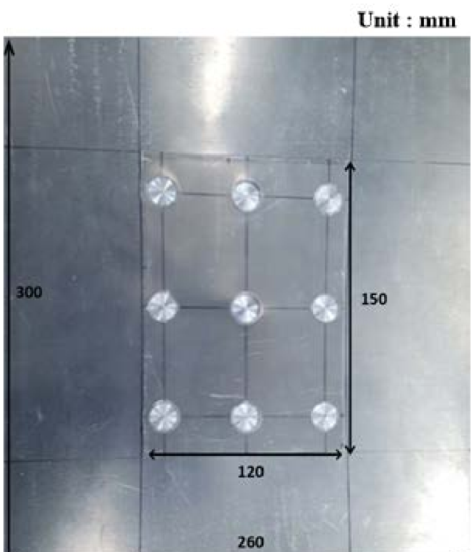

Fig. 5. Appearance of patchwork blank using TFSSW.

Fig. 6. Appearance of formed hat shape.

3.2 Measurement of weld zone hardness

The hardness of the weld zone before and after the forming was measured to confirm that a drop of the hardness of the weld zone, which is one of the disadvantages of the TFSSW. Formed hat shape part was heat treated with artificial aging (T6) condition. Sequentially after cutting the hat shaped part, the hardness from the center of the weld zone to 12mm was measured at intervals of 2mm. The results of Vicker's hardness measurements are shown in Fig.8 as the average hardness of the left, center, and right. It can be confirmed that the hardness is restored when hot forming quenching is applied.

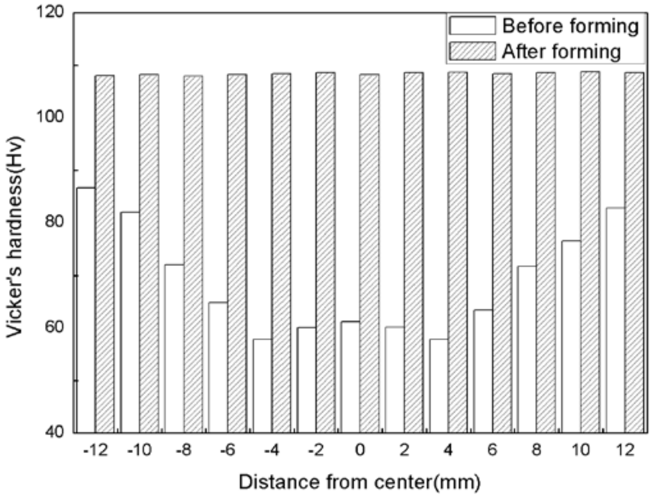

Fig. 8. Result of hardness measurement.

4 Conclusions

The objective of this study is to apply hot forming quenching on patchwork blank using TFSSW. Using the Taguchi method, one of the design of method, the optimal process parameters with the best joint strength were selected. Rotational speed, dwell time and plunge depth were found to be 1400rpm, 8seconds and 2.6mm in first stage(conventional FSSW) and 1400rpm, 4seconds and 0mm in second stage(refilling process). Also, a hat shape forming test was performed using a patchwork blank manufactured with the optimal process parameters. As a result of forming, forming was performed without defect. Formed hat shape part was heat treated with artificial aging(T6) condition. The hardness of weld zone before hot forming quenching is average 70Hv and after hot forming quenching is average 110Hv, respectively. It can be seen that the hardness of the material recovered.

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