Preheating Effect on the Friction Stir Welding

Jinmyun Jo
Department of Engineering
Virginia State University, Petersburg, Virginia

One of the primary emphases of the engineering senior projects is to provide research experiences to senior students who plan to go to engineering graduate schools. This presentation discusses the process used and the results obtained during proposing and executing a research project. Preheating effect on the friction stir welding (FSW) process was proposed as the topic of the senior researches in which preheating effects were investigated using a sand insulator and donor material. Thermal behavior of these materials were analyzed during FSW in terms of temperature measurements. Both research and design components were included in the research projects, and the latter component was required by the senior design course.

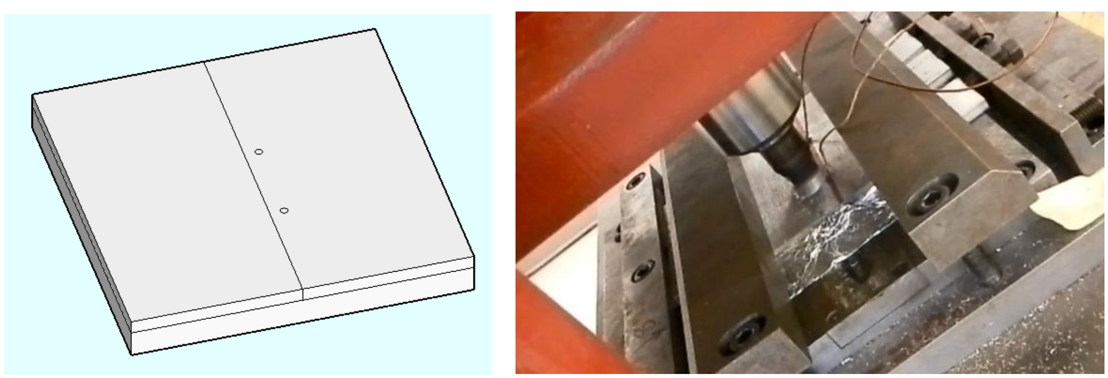
1. Introduction

College of Engineering and Technology (CET) of Virginia State University requires senior students to take senior design courses as part of the graduation requirements. Almost all of the senior students work on industry-related design projects for the senior design projects because the design process should be included as a requirement of senior design course[1]. Further, the senior design project coordinator and the project advisors examine whether the project meets the design requirements as well as ABET's recommendations. It cannot be ignored, however, many students plan to go to engineering graduate schools. After summer internships in a research and development company, many students have expressed strong interest in working at government or private research agencies. CET does not offer Master of Scene in engineering disciplines. However, some faculty is conducting graduate level researches and can provide senior students with research opportunities that also include design components such as a system design. This paper presents senior research projects that incorporated design processes into research. The objective and preliminary plan of these research projects had been established before students started the senior design project. Investigation of preheating effects on the friction stir welding was the topic of the research projects.

Since the friction stir welding (FSW) was introduced in 1991, it has provided a new joining technology for welding soft materials such as aluminum and other alloys[2,3]. It has been reported, however, that FSW of hard materials such as steel has not been successful due to excessive tool wear caused by friction force[4,5]. Most researchers have focused on two approaches for mitigating tool’s wear - increasing tool’s hardness and introducing a preheating source ahead of the stir tool[6]. Since preheating methods have been studied here at CET, the preheating is discussed only in this paper. The preheating significantly reduced the tool’s axial and contact forces acting on the FSW workpiece because the preheating softens the material. As a result, this softening helps to induce the minimum amount of friction on and reduces wear of the tool when the tool is plunged into it[4]. The preheating researches have been conducted experimentally and/or numerically, reporting the localized heating was generated in the donor material by the plunge of the FSW tool[4] or by a preheating-source creating thermomechanical hot channel was used to preheat the workpiece[5]. These two methods have not been experimentally studied in terms of temperatures. For a senior research project, preheating by donor material was only investigated because the local heating system was not available. Since preheating generated with insulator has not been reported as well, this preheating method was investigated as another topic. The preheating by the local heating will be studied as another senior project in the future. The research was conducted with procedure – conduct literature survey, design the experiment, execute experiment, collect data, perform data analysis and report the findings. The insulation preheating research is presented first.

2. Senior Project 1 – Insulation Preheating

The first senior research project was the insulation preheating FSW. Four Al 6061 workpieces were used as shown in Fig. 1 – two for non-insulation and the other two for insulation experiment. Each workpiece milled was 100 mm wide, 150 mm long and 6 mm thick. These dimensions were selected based on the tool size and the previous research on temperature field shown in Fig. 2. For the welding, the tool used had the 15 mm diameter. For friction stir welding (FSW), the work pieces were held using the workpiece fixture on the test bed of a FSW machine (see Fig. 1). To monitor temperatures, four k-type thermocouples were chosen because the thermocouples covers the high temperature range up to 1250 °C[7]. They were prepared using the light-duty-stud-welding which was done with HotSpot II. Before thermocouples were attached to the workpiece, the reliability of thermocouple was evaluated by comparing thermocouple data with a thermometer. The deviation of temperature readings from the thermometer were +/- 1.0 °C.



(a) (b)

Figure 1 (a) Two aluminum workpieces insulated by the sand layer and (b) friction stir welding of aluminum workpieces insulated with the sand layer held in the fixture and two thermocouples attached to a workpiece.

To attach the thermocouples, two 1/8" holes was drilled using a drill machine. One hole was drilled 10 mm away from the weld centerline and the other at the initial plunge position of the tool whereas another hole at the location 50 mm downstream. These locations were selected based on the tool size and the previous research as shown in Fig. 2. Thermocouples were inserted into the holes and fastened with an aluminum foil.

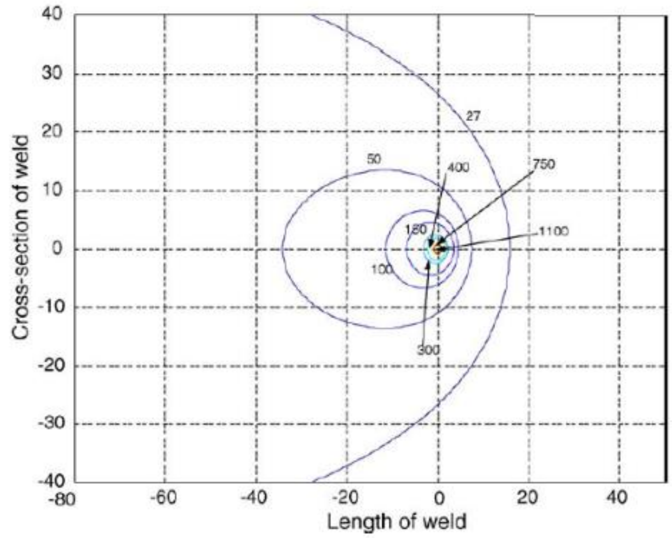


Figure 2. Temperature distribution field calculated numerically[4]

To hold the heat generated during the plunge of the tool during FSW, the sand insulator was placed below the workpiece as shown in Fig. 1(b) whereas the workpieces were held in the workpiece without the sand insulator. This heat was used to preheat the region downstream. For the welding, the tool used had 15 mm diameter. The pin of the tool had 6 mm height and 7 mm diameter. The pin is used to stir the plasticized material around it. The friction induced by the tool shoulder elevates the temperature high enough to plasticize the material. The FSW machine was programmed to have the tool plunge into the workpiece and then to travel at the 4.5 mm/s speed. The plunge force and angular velocity of the tool used were 5 KN and 1200 RPM, respectively. During welding, temperatures were collected using the HH506A Datalogger/Thermometer.

Fig. 3 presents the temperature measured with respect to time at the two locations in the workpieces without and with a sand insulation layer. TC1 and TC2 represents the thermocouples in the not-insulated workpiece. Note that TC1 and TC2 were placed at the start of the welding and 50 mm downstream. 305 °C was observed at 44 seconds from the TC1 whereas 195 °C was observed at 63 seconds from TC2. The means that difference in time between two observations is 19 seconds. Fig. 3 also shows temperatures measurements at thermocouple 1 (TCS1) and thermocouple 2 (TCS2) for the sand-insulated workpiece. Note that TCS1 and TCS2 were placed at the start of the welding and 50 mm downstream, respectively. This figure indicates that 315 °C was observed at 55 seconds from the TCS1 whereas 165 °C was observed at 67 seconds from TCS2. This time observation indicates the heat generated at TCS1 took 12 seconds to reach the TCS2. These calculations suggest that the thermal speed in the insulated workpiece was faster than that in the not-insulated workpiece.

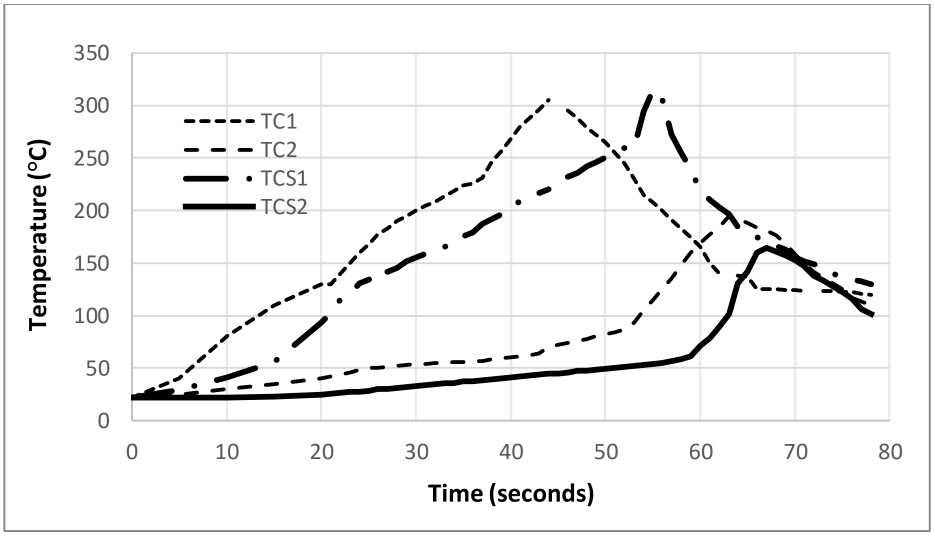
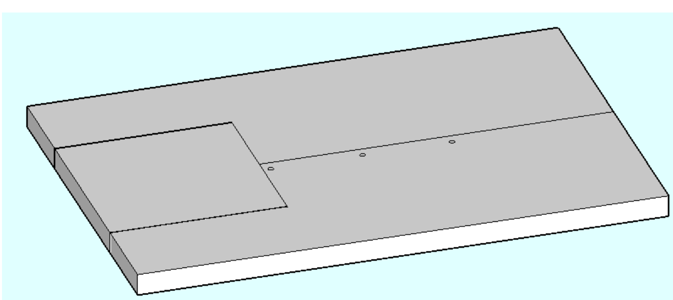


Figure 3 Thermal behavior at Thermocouple 1 (TC1) and Thermocouple 2 (TC2) in the not-insulated workpiece and at Thermocouple 1 (TCS1) and Thermocouple 2 (TCS2) in the insulated workpiece.

3. Senior Research Project II – Donor Preheating

For the donor preheating FSW, two 101 copper workpieces and a Al6061 donor were used as shown in Figure 1(a). The 25 mm x 25 mm donor with the 6 mm thickness was enclosed with the 101 copper in this figure. For friction stir welding (FSW), the work pieces and the donor were held using the workpiece fixture on the test bed of a FSW machine (see Fig. 1(b)). Before thermocouples were attached to the workpiece, the reliability of thermocouple were evaluated. Three k-type thermocouples were attached 6 mm, 25 mm and 50 mm from the boundary as shown in Fig. 4(a). They were placed in front of the tool. For the welding, the same type of the tool used for the insulation research. The FSW machine was programmed to have the tool plunge into the workpiece and then to travel at the 4.5 mm/s speed and the plunge force and angular velocity of the tool used were 5 KN and 1400 RPM, respectively.



(a)

(b)

Figure 4 (a) Two copper workpieces enclosing an aluminum donor and (b) an aluminum donor and two workpieces held in the fixture and two thermocouples attached to a copper workpiece.

The results from Copper/Copper specimen in Fig. 5 show that Thermocouple 1 (TC1) has the highest peak temperature, 133 °C at 38 seconds from the start whereas Thermocouple 3 (TC3) has the highest peak temperature, 203 °C at 81 seconds. The peak temperatures were only recorded in Fig. 5 because the thermocouples were placed in front of the tool and as a result they did not survive. The means that difference in time between TC1 and TC2 peak observations is 43 seconds. The results from Al 6061/Copper specimen in Fig. 5 show that Thermocouple 1 has the highest peak temperature, 672 °C at 50 seconds from the start. Thermocouple 1 (TCD1) was located 6 mm from the boundary between the donor material and the workpiece. Thermocouple 2 (TCD2) shows the lowest peak temperature, 428 °C. Thermocouple 3 (TCD3) had the second highest peak temperature, 599 °C at 90 seconds. The means that difference in time between TCD1 and TCD2 peak observations is 40 seconds. These calculations suggest that the thermal speed in the insulated workpiece was slightly faster than that in the not-insulated workpiece. This result is consistent with that of the insulation research. During welding, the minimal bending and distortion were observed compared with the pervious study[7]. Also, the fumes were not generated during the welding.

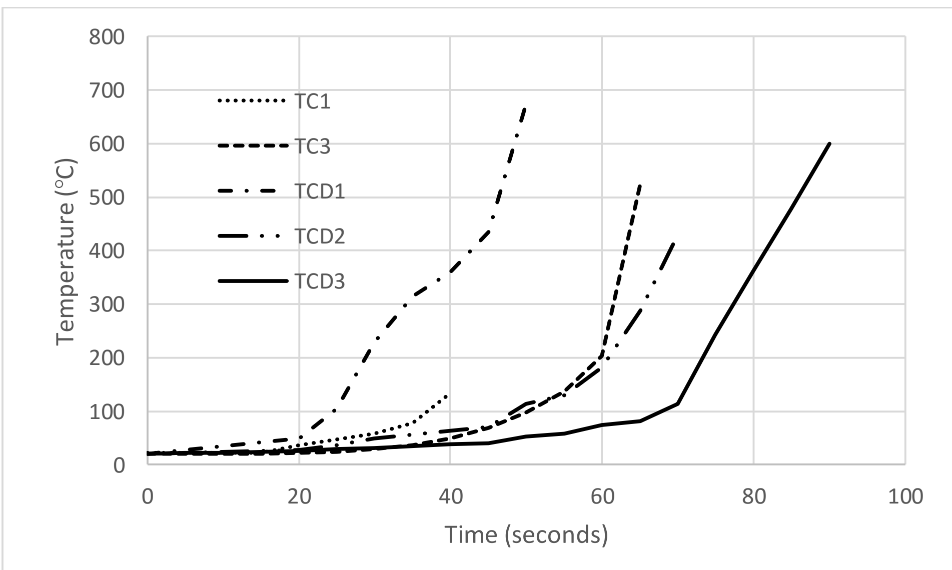


Figure 5 Thermal behavior at Thermocouple 1 (TC1) and Thermocouple 2 (TC3) in the workpiece without an aluminum donor and at Thermocouple 1 (TCD1), Thermocouple 2 (TCD3) and Thermocouple 3 (TCS3) in the workpiece with an aluminum donor

4. Senior Research Project III – Thermomechanical Channel Preheating

This research project will be initiated once the local heating system such as laser will be accessible in the future.

5. Conclusions

The research projects presented are a couple of concurrent engineering and technology researches which senior students participated in. The research projects included both research and design. The research aspect is beneficial to students who plan to go to engineering graduate schools, and the design aspect satisfies the design requirement for the senior design course. The research process used consisted of literature survey, project execution plan, experiment/data collection, data analysis and reporting findings. The design process applied included design of workpieces and welding parameters, selection of thermocouple type and size, estimation of thermocouple locations, attaching thermocouples, and design of the workpiece fixture. It is noted, however, the research advisor may have to repeat teaching students most of the same techniques for hardware and software every year because students do not have prior knowledge and skills necessary to execute the research tasks.

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