AC 2011-110: UNDERGRADUATE DESIGN: DESIGN OF A REUSABLE STIR FRICTION WELDING TOOL

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Courses taught include finite element analysis, material science, statics, strength of materials, materials lab, machine design, product design, production design, plastic design and FE analysis, and engineering graphics. Research interests include design and optimization of elastomer components, elastomeric fatigue properties, hyperelastic modeling of elastomers, failure analysis of elastomeric components, seismic analysis of storage racks, experimental testing and characterization of materials and general machine design. Engineering Consultant provide consulting services to local industry. Services include: elastomeric product design and analysis, machine design, finite element analysis, solid modeling, vibration analysis and diagnostic testing. Bob holds several patents and has several patents pending primarily in the area of noise and vibration isolation products. Bob is a licensed professional engineer in the state of Pennsylvania.

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Undergraduate Design: Design of a Prototype Reusable Stir Friction Welding Tool

At XXX________, undergraduate research is encouraged. The college has worked diligently at developing funding and recognition programs that enhance research opportunities at the undergraduate level. The benefits of undergraduate research are many. This paper will discuss the design of a reusable Stir Friction Welding (SFW) tool performed by two undergraduate Mechanical Engineering Technology students (sophomores).

SFW uses a solid-state joining process, which heats the material by using friction under pressure to heat the material just under its melting point. This heat is used to form the weld along the joint of the two butted substances. This process allows for many advantages over traditional arc welding with electricity.

The design group consisted of two students that were part of a larger group of students conducting funded research in the area of SFW. SFW tools are not standardized. They cannot be purchased off-the-shelf from an industrial supplier. SFW tools are quite often damaged or fractured during their use, especially during research. Common SFW tools that are generally manufactured are tools that include the probe and shoulder as one solid piece. This is a major disadvantage when the welding tip breaks. It may take days if not weeks to have another SFW tool made or repaired. This research project will involve researching and designing a prototype SFW tool that will allow the user to quickly change the welding tip so that it may take minutes instead of days to continue welding. The outcome of this project is to design a Stir Friction Welding tool that can be reusable with minimal down-time.

Introduction

The student's research/design occurred outside of the normal classroom. The project was funded by a small grant from the college and the Engineering Honor Society in multidisciplinary research. The design/research was mentored by an engineering faculty mentor. The students presented their design in front of a group of judges (i.e. professors). A small cash prize was awarded to the best presentation. There were 87 posters and 62 oral presentations at this one day undergraduate research conference. In total, 230 students will present their research findings and 125 faculty members serve as mentors and judges. Ten universities and colleges participated in this conference. The college provides nearly $250,000 to support undergraduate research by its students. The college has developed five programs that promote undergraduate student research and creative accomplishment, including the conference, the Council of Fellows' Undergraduate Student Research Award, undergraduate student research grants, undergraduate student summer research fellowships, and undergraduate student travel grants.

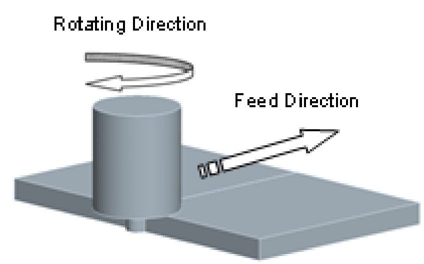

Figure 1
FSW Tool in Operation

This paper will discuss the research and design conducted by the students on a reusable Stir Friction Welding tool.

Stir Friction Welding

Stir Friction Welding is a relatively new development in the welding industry compared to traditional machining processes.[1] Since SFW's invention, SFW has seen much innovation in improving its welding process and is seeing world wide attention with welding aluminum alloys. SFW uses a solid-state joining process, which heats the material just under its melting point by using friction under pressure to heat the material just under its melting point (see Figure 1). This heat is used to form the weld along the joint of the two butted components. This process allows for many advantages over traditional arc welding with electricity. Some of these advantages include ease of automation, good mechanical consumption, no toxic fumes, no consumables, and an overall good weld appearance which requires minimal machining that does not require a great deal of machining. SFW is also able to weld two dissimilar non-ferrous metals such as aluminum and brass.

Stir Friction Welding uses a wear resistance cylindrical shoulder to create friction. This friction is then used to create the heat, which in turn helps stir the material around the joint and soften the oncoming material for the probe. The probe is a small cylinder (see Figure 2) that protrudes from the center of the shoulder, which is rotated and plunged into the two abutting materials. The design of the probe can consist of various sizes, shapes and surface textures. The SFW tool is then moved along the joint of the two butted plates. Friction is then created from the shoulder rotating on the work piece. The friction softens the work piece allowing the probe to traverse through the material along the joint of the two plates. The plasticized material is stirred from the leading edge of the tool to the trailing edge allowing the tool shoulder and the probe profile to bond these two edges of the workpiece together. SFW tools can be attached to most standard manual or computer numerical controlled milling machines for automation.

Design Purpose

SFW tools are often damaged during the welding process. The most common fracture occurs on the probe, caused by the high axial loads acting on the probe during operation. Common SFW tools that are generally manufactured are tools that include the probe and shoulder as one solid piece. This is a major disadvantage when the welding tip breaks. When this failure occurs, the welding operation could see down time until a new tool is produced. The general purpose of this project was to design a tool that can be quickly replaced with a new welding tip (probe) or refaced when the old one breaks. As a result the user can easily be performing the operation within minutes of down time as opposed to days. Allowing the probe to be adjustable rather then fixed will also give the advantage of adjustability of the probe height for different thicknesses of material. The goal was to design a reusable tool with multiple components that can be replaced easily and relatively fast with keeping the high weld quality of a standard solid one piece design. This will reduce costs associated with the creation and maintenance of SFW tools.

Probe Shoulder

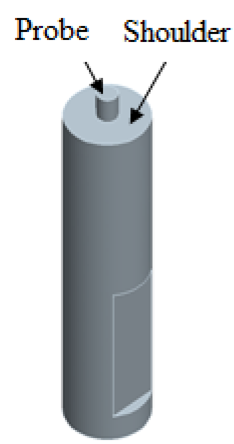

Figure 2
Parts of Tool

Material Selection

The material selection of the SFW tool needed to be abrasion resistant due to the high amounts of friction created between the tool and workpiece. Also, the material needed high toughness because of the forces acting on the probe as it traversed through the workpiece. Hot hardness and machinability were also important properties that were factored into the material selection. With regard to these properties, tool steel was the leading material candidate.[2] Tool steels are known for their distinctive toughness, resistance to abrasion, ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (hot-hardness).[3] There are many kinds of tool steel used in industry today. To determine what tool steel was right for the application the creation of a material selection chart (see Appendix A-1) was used. With the compilation of the chart H13 hot rolled tool steel became the first choice. To increase the hardness of the H13, the material was hardened to R_C56 on the Rockwell Hardness scale. After the material was hardened a cryogenic treatment was done. This treatment involved the part to be quenched in liquid nitrogen which reduces fracturing or chipping of cutting edges.

Initial Design

The initial design was very basic with the adjustability of the probe height. It incorporated the probe being one piece that was fed into the front of the probe. A set screw was added on the end to be able to adjust the probe length. To keep the probe from moving while in use, another set screw was added on the side of the shoulder to secure it in place. This initial design did not allow for much adjustment in the length of the probe causing wasted or less consumable material. Consequently, subsequent designs focused on making the probe as adjustable as possible with minimal waste of the probe material. The holding forces of the set screws were enhanced by including a flat spot on the probe. This reduced the useable area of the probe; however, the flat spot was needed. These set screws were also going to be very small because of the size of the area they needed to be added to. Another issue was that the flats on the shaft of the probe would be difficult to orient with the set screws. To ensure reliability, the least amount of pieces as possible were employed to reduce the chance of failure of the tool.

Initial to Final design

While working to improve the initial design, the set screw that was used to adjust the probe up and down was removed. Adding threads to the probe allowed the probe to still retain its adjustability and give the advantage of removing the rear set screw. The intent of this design was to insert a screwdriver into the end to allow the user to adjust the probe height. Making the probe fully adjustable, will allow the user to be able to disassemble the tool and reface the probe end if it results in a failure during use.

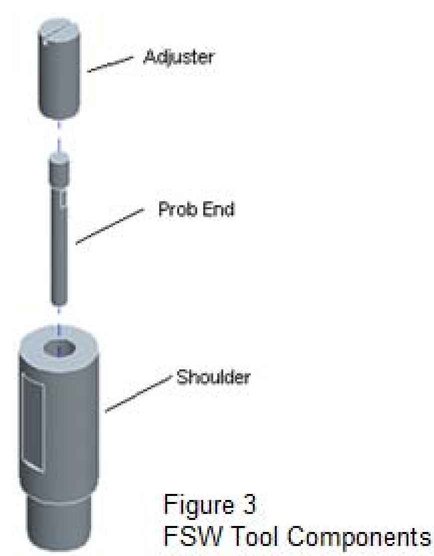

Figure 3
FSW Tool Components

Final Design

To increase the rigidity of the tool due to the small size frame, it was decided to remove all set screws in the final design. Taking the probe and making it a two piece design allowed the probe to be two pieces (see Figure 3). This removed the side set screw that was used to keep the probe from spinning. Incorporating a left handed thread on the probe end as well as the probe adjuster allowed the probe end and the adjuster to be locked together during use. By removing the side set screw it also allowed for the removal of the flat need on the side of the probe needed to properly lock the set screw in place with the probe. With the flat removed it allowed more adjustability of the part due to before the flat was restricting the amount of useable probe material that could be used if the probe failed and needed to be refaced. A close running fit was used for the hole on the center of the shoulder and probe shaft. A small flat just below the threads was included so that a wrench could be used to loosen the probe end from the adjuster (see Figure 4). This fit is used with moderate surface speeds and pressure is involved, where accurate location and minimum play are desired. The design allowed for a standard 1-1/4’’ end mill holder eliminating the need for a custom tool holding device further reduced cost.

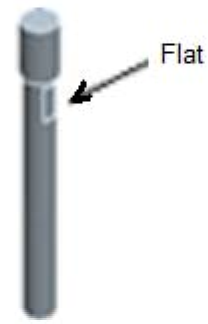

Figure 4
Probe with Flat Spot

Conclusions

The students presented their design at the conference and it was well received by the judges. The experience gained in the first few years of the undergraduates academic career proved to be invaluable as well as their machining experience gained before college. Without the freshman and sophomore level manufacturing courses, the students could not have completed this research. This conference was open to all undergraduate students but few undergraduate students below the senior level participate. Matching the student’s interests and strengths to a research project proved to be the factor which made this research/design a success.

While the SFW tool requires additional design iterations before becoming fully functional or marketable, the design of the tool is a great starting point for future design considerations. This experience has given the undergraduate students an opportunity, outside of their normal coursework, to gain a valuable learning experience with design, research, and communication.

The students found this project to be rewarding. They are grateful for the experience and to be able to add engineering experience to their resume in attempt to obtain an engineering internship.

This project forced the students to employ teamwork and communication skills not usually employed during normal coursework. They had to work with other students because their tool was ultimately going to be used during research

Future Work

The students plan to optimize the design once they have completed the Advanced Strength of Materials and Finite Element Analysis courses.

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