FRICTION STIR WELDING OF STEEL

By

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CERTIFICATE

This is to certify that the thesis entitled "**Friction Stir Welding of Steel**" being submitted to the Indian Institute of Technology Delhi, by Mohd Zaheer Khan Yusufzai is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bona fide research work carried out by him under our guidance and supervision.

To the best of our knowledge, this work in part or full has not been presented to any other university or institute for the award of any degree/diploma.

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ABSTRACT

Friction stir welding is the latest technology in the area of metal joining and is perhaps the most promising of all the welding processes. A lot of research has been carried out in this area but most of the initial work has been done on low temperature softening materials like aluminum alloys. Many of the industries which are involved in welding of steel are now looking forward to the development of friction stir welding for joining of steel. Friction stir welding of steel is a challenging because of its high softening temperature and high strength. Also, since aluminum alloys were more difficult to weld by conventional welding processes than steel, they were the first choice as the material on which this new process was tried. But now that a lot of advantages of this process have been established, it is felt that research on friction stir welding of steel is also essential. With growing concerns about environmental pollution and health hazards created by conventional welding processes, it becomes important to develop this 'green process' for all welding applications.

In this work, friction stir welding of mild steel was carried out on 3 mm thick plates and butt joint was successfully produced between two plates of 220 mm length. Conventional vertical milling machine, capable of withstanding the forces generated during welding and having a powerful spindle motor to generate the torque needed for friction stir welding, was selected for the purpose. A special fixture was designed and fabricated to firmly hold the plates together during welding. To protect the machine spindle from heat, and to firmly hold the friction stir welding tool, a tool holder was designed and fabricated. Based on trial runs, a suitable grade of tungsten carbide (to give longer tool life) was selected.

Extensive trial runs were conducted to develop the correct welding procedure for obtaining defect-free joints. The process parameters that can be varied and can have an effect on

mechanical properties of the weld were identified. The range, within which those process parameters can be varied, were also found out. Based on Taguchi's design of experiment, final experimentations were carried out to study the effect of process parameters on mechanical properties. L9 orthogonal array, with three replicates was chosen for the study.

All 27 welds were checked for defects using X-ray radiography and then samples for mechanical and metallurgical testing were taken out. Transverse tensile test, reduced section tensile test and impact testing were carried out to see the effect of process parameters on weld properties. Fatigue testing was also carried out to compare the behaviour of the weld and the base material under cyclic loading. Metallurgical testing was carried out using microhardness testing, microstructural examination, and spectroscopic analysis of the welds.

The strength, impact energy absorbed and fatigue properties of the weld were all found to have improved over the base material properties. The process parameters, particularly welding speed, were found to have significant effect on mechanical properties. Based on these experiments, statistical models have been developed to correlate the process parameters with mechanical properties. Microhardness in the weld nugget and the heat affected zone were found to be more than the base material. Based on microstructural examination, it has been proposed that discontinuous dynamic recrystallizaion (DDRX) has taken place in the weld nugget.

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