

FRICTION STIR WELDING OF STEEL

By

Mohd Zaheer Khan Yusufzai

Department of Applied Mechanics

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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.

Dr. Rajesh Prasad, Ph. D.

Department of Applied Mechanics

Indian Institute of Technology Delhi

Hauz Khas, New Delhi – 110016, India.

Prof. Sunil Pandey, Ph. D.

Department of Mechanical Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi – 110016, India.

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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 recrystallization (DDRX) has taken place in the weld nugget.

TABLE OF CONTENT

CERTIFICATE.....	i
ACKNOWLEDGEMENTS	iii
ABSTRACT.....	vii
TABLE OF CONTENT.....	ix
LIST OF FIGURES	xiii
LIST OF TABLES	xxi
NOMENCLATURE.....	xxiii
Chapter-1.....	1
INTRODUCTION.....	1
1.1 Introduction.....	1
1.2 Introduction to friction stir welding process	2
1.2.1 Advantages of friction stir welding.....	4
1.2.2 Limitations of friction stir welding process	6
1.2.3 Variants of friction stir welding process	7
1.2.4 Applications of friction stir welding process	10
1.2.5 Latest trends in friction stir welding	12
1.3 Challenges in Friction Stir welding of steel.....	13
1.4 Objectives of the current research work	16
1.5 Format of the thesis.....	17
Chapter-2.....	19
LITERATURE REVIEW	19
2.1 Introduction.....	19
2.1.1 Steel and its welding	20
2.2 Friction stir welding process	23
2.2.1 Different materials welded by friction stir welding	23
2.2.2 Tools and equipment used in friction stir welding.....	29
2.2.3 Material flow in friction stir welding.....	30
2.2.4 Process modeling of friction stir welding	31
2.3 Friction Stir welding of steel.....	32

2.3.1	Different steels welded by friction stir welding.....	32
2.3.2	Process parameters in friction stir welding of steel	42
2.3.3	Testing of friction stir welds of steel	44
2.4	Gaps in research work.....	44
Chapter-3.....		47
DEVELOPMENT OF EXPERIMENTAL SETUP		47
3.1	Introduction.....	47
3.2	Selection of machine tool.....	48
3.2.1	Vertical milling machine as a friction stir welding machine	48
3.2.2	Machine tool selected for experimentation.....	50
3.3	Design and fabrication of fixture	52
3.4	Design and fabrication of tool holder	55
3.5	Selection of tool material	57
3.5.1	Possible materials for friction stir welding of steel	57
3.5.2	Tungsten carbide as a tool material	63
3.5.3	Selecting correct grade of tungsten carbide.....	65
3.6	Tool grinding facility	72
3.6.1	Tool grinder and grinding wheel.....	72
3.6.2	Tool holder for tool grinding	73
3.6.3	Measurement gauges.....	74
Chapter-4.....		75
EXPERIMENTATION		75
4.1	Introduction.....	75
4.1.1	Types of experimentation approaches	75
4.2	Design of experiment.....	77
4.2.1	The process of design of experiment	77
4.2.2	Taguchi design of experiment.....	81
4.3	Steps followed for experimentation in this study	82
4.3.1	Cause and effect diagram.....	82
4.3.2	Process parameters affecting the properties of the weld.....	83
4.3.3	Process parameters as found from literature	83
4.4	Trial runs for the selection of range of process parameters	86
4.4.1	Tool pin geometry.....	86

4.4.2	Tool tilt and tool shoulder plunge depth	91
4.4.3	Welding speed.....	93
4.4.4	Tool RPM.....	94
4.4.5	Tool shoulder diameter	95
4.5	Design matrix for experimentation	95
4.5.1	Selection of the variables and the levels.	96
4.5.2	Selection of orthogonal array	97
4.5.3	Deciding the number of replicates	98
4.5.4	Run order	99
4.6	Final experimentation as per design of experiment	100
4.6.1	Work material	100
4.6.2	Backing plate	103
4.6.3	Welding of the plates as per design	104
4.6.4	Removal of backing plate	105
4.7	Nondestructive testing of the welds.....	105
4.7.1	Visual examination of the weld	106
4.7.2	Dye penetration inspection	108
4.7.3	X-ray radiography of the welds	108
4.8	Test coupon for further testing.....	115
Chapter-5.....		117
MECHANICAL TESTING OF THE WELDS.....		117
5.1	Introduction.....	117
5.2	Tensile testing of welds	118
5.2.1	Transverse tensile testing of weldments	118
5.2.2	Reduced section tensile testing of welds	123
5.3	Impact testing of welds	126
5.3.1	Charpy impact testing of welds.....	127
5.3.2	Fractography of fractured surface of impact test specimens	130
5.3.3	Fatigue Test.....	132
Chapter-6.....		139
ANALYSIS OF RESULTS.....		139
6.1	Introduction.....	139
6.2	Analysis of mechanical testing of welds.....	139

6.2.1	Analysis of tensile testing of welds	140
6.2.2	Analysis of impact testing of welds	150
Chapter-7.		155
	METALLURGICAL TESTING OF THE WELD	155
7.1	Introduction.....	155
7.2	Spectroscopic Analysis	155
7.2.1	Test procedure.....	156
7.2.2	Results.....	157
7.3	Microstrutural examination.....	160
7.3.1	Test procedure.....	160
7.3.2	Results.....	161
7.3.3	Microstructural evolution in friction stir welding.....	173
7.3.4	Mechanism of phase transformations in different regions of the weldment.....	176
7.3.5	Analysis of micrographs on the top surface of the weld.....	180
7.3.6	Analysis of micrographs on the bottom surface of the weld	184
7.4	Microhardness testing	185
7.4.1	Test procedure.....	186
7.4.2	Results.....	188
7.4.3	Analysis of microhardness testing of the weldment.	199
Chapter-8.		201
	CONCLUSIONS	201
Chapter-9.		207
	SCOPE FOR FUTURE WORK	207
	REFERENCES.....	209