

# **MODE OF METAL TRANSFER AND BRITTLE FRACTURE TENDENCIES OF CO<sub>2</sub> WELDS**

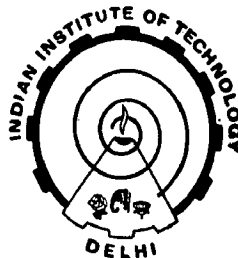
by

**MOHD. KAZEM MONTAZEROLGHAEM**

A Thesis

Submitted in fulfilment of the requirements  
for the degree of

**DOCTOR OF PHILOSOPHY**



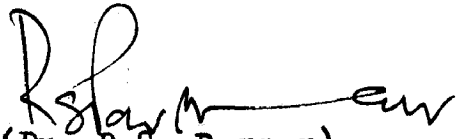
**DEPARTMENT OF MECHANICAL ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY, DELHI (INDIA)  
NOVEMBER 1982**

CERTIFICATE

This is to certify that the Thesis entitled 'Mode of Metal Transfer and Brittle Fracture Tendencies of CO<sub>2</sub> Welds' being submitted by Mr. Mohammad Kazem Montazerolghaem to the Indian Institute of Technology, Delhi, for the award of the Degree of 'Doctor of Philosophy' in Mechanical Engineering is a record of bonafied research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this Thesis which has reached the requisite standard.

The results contained in this Thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

November 10, 1982

  
(Dr. R.S. Parmar)  
Assistant Professor  
Department of Mechanical Engg.,  
Indian Institute of Technology,  
Hauz Khas, New Delhi-110016.

ACKNOWLEDGEMENTS

The author is quite grateful and highly indebted to Dr. R.S. Parmar, Assistant Professor of Mechanical Engineering Department, Indian Institute of Technology, Delhi for his precise guidance, heartily teachings and motivations throughout this course of work. There is no doubt that it was due to his keen interest towards humanity, technology and progress that the author has reached this stage of life.

Thanks are also due to Professor N.K. Tewari and Professor U.R.K. Rao for their help extended in providing material at the critical stages of this work. Professor B.L. Juneja, Dr. Ashok Malhotra and Dr. K.K. Pujara are thanked for their moral support which helped a lot.

Acknowledgements are due to Dr. R.K. Pandey, Applied Mechanics Department, I.I.T. Delhi for his valuable suggestions in carrying out the studies on brittle fracture. Professor V. Raghavan is also thanked for his lectures on metallurgical aspect of the process.

Professor R.L. Apps and Dr. G.J. Allum of Cranfield Institute of Technology, Cranfield (U.K.), and Professor Yoshifumi Suezawa of Aero Space Engineering Department, College of Science and Technology, Nihon University, Tokyo (Japan) are acknowledged for their suggestions on various

aspect of this work, which they made during their visit to I.I.T. Delhi. Mr. R.J. Goode of Naval Research Laboratory, Washington, D.C. (U.S.A.) and Commander T.H. Robinson, Secretary, Ship Structure Committee, U.S. Coast Guard Headquarters, Washington, D.C.(U.S.A.) are thanked for providing upto date technical papers, used for studies on brittle fracture.

Mr. P.N. Arumugham, General Manager, Bharat Heavy Electricals Ltd., Delhi, and Mr. R.K. Thariani, Area Manager, Advani-Oerlikon Pvt. Ltd. Delhi are thanked for their interest in the present research work.

Thanks are also due to a host of friends of Indian, Iranian and Polish nationals for their sincere help rendered from time to time.

Thanks are also due to supporting staff of I.I.T. Delhi, particularly Mechanical Engineering Department for rendering help at different stages of the investigations. Mr. N.K. Choudhry and Mr. V.P. Gulati of Mechanical Engineering Department, I.I.T. Delhi are thanked for drawing the figures and typing of the thesis respectively.



10th Nov' 82

(Mohd. Kasem Montazerolghaem)

ABSTRACT

CO<sub>2</sub> welding is well known for its economy and high deposition rate. The process is easily adoptable to mechanization. It is a versatile Process regarding choice of selection of different welding variables. However, these variables influence different aspects of the process like weld bead shape, quality and strength. Therefore an in-depth study was made on major aspects of the process. The various aspects explored included mode of metal transfer, weld spatter, weld beat<sup>d</sup> geometry and shape relationships, metallurgical transformations and brittle fracture tendencies of CO<sub>2</sub> welds.

The investigations on mode of metal transfer were carried out by studying arc voltage-welding current (V-I) transients across the arc, through multi-channel magnetic tape recorder, two channel storage oscilloscope and U-V recorder. This study was entirely in conjunction with high speed cinematography of the arc zone, using film speeds of 500 and 1000 pictures per sec. (P.P.S.). The welding variables included arc voltage, welding currents, feed wire speed and CO<sub>2</sub>-Ar shielding gas mixtures of different ratios.

For investigating weld spatter both quantitative weight ratio and qualitative approaches were used for which the V-I transients in conjunction with high speed cine films of the arc zone taken at 500, 1000 and 4000 P.P.S. were obtained and analysed.

The welding variables included arc voltage, welding current, feed wire speed, inductive reactance and CO<sub>2</sub>-Ar shielding gases of different ratios.

The weld bead geometry and shape relationships as affected by arc voltage, welding current, feed wire speed, wire diameter, welding speed, nozzle-to-plate distance and torch angles in leading and lagging positions were investigated.

Effect of aforementioned CO<sub>2</sub> welding variables on microhardness and microstructure of single-and multi run welds were also investigated, and the welding parameters were optimized to get the most ductile welds with appropriate microstructure. For these investigations both optical and scanning electron microscope (SEM) were used.

The studies on brittle fracture tendencies of CO<sub>2</sub> and CO<sub>2</sub>-Ar shielded welds with different composition at various welding conditions included investigations on temperature dependence of Charpy V-notch tests for an impact testing temperature range between +80°C and -80°C. This investigation was in conjunction with Light-and SEM-fractography of the fractured facets, under optical magnification of 10X and different SEM-magnifications between 22 X and 5400 X.

v(a)

In the light of the aforementioned experiments some of the conclusions arrived at are as following.

The economic mixture of CO<sub>2</sub> and Ar-shielding comprised of the ratio 90/10. However, for the advantages of improved arc stability, reduced drop size and spattering, increased frequency of droplet transfer, and high toughness of the welds the CO<sub>2</sub>- Ar gas mixture of the ratio 25/75 was found preferable to only CO<sub>2</sub> shielding or the economic mixture of the 90/10 CO<sub>2</sub>-Ar gas.

The weld spattering was dependent on the mode of metal transfer. It was low with either short circuit or dip transfer and high with globular transfer accompanied by droplet explosions. Introduction of a magnetic inductive reactance reduced the weld spatter, except in the free-flight transfer.

Increasing the feed wire diameter from 0.8 to 1.2 and 1.6 mm resulted in increased weld dilution, and it reduced the peak hardness values in multi-run welds. The peak VHN values also decreased with increase in arc voltage and welding current.

Low and turbulent gas flow, large nozzle-t-plate distance and excessively high arc voltage of 40 volts resulted in tunnelling type porosity in welds with increased hardness.

v(b)

High arc voltage welding currents, larger feed wire diameters and 25/75 CO<sub>2</sub>-Ar gas mixture resulted in tougher welds with lesser susceptibilities to brittle fracture.

The tendencies for brittle fracture was the least at the weld metal and the maximum at the HAZ.

The SEM-fractography very clearly supported the toughness results obtained through C<sub>v</sub>-notch impact testing.

..

LIST OF FIGURES

<u>Fig.</u> <u>No.</u>		<u>Page</u> <u>No.</u>
2.1	Experimental set up and welding equipment.	.. 24
2.2	V-I transient and high speed cine stills of CO <sub>2</sub> welds at different arc voltages and high welding current/wire speed.	.. 26
2.3	V-I transients of CO <sub>2</sub> welds at different arc voltages and low welding current/wire speed.	.. 30
2.4	V-I transients of CO <sub>2</sub> welds, using inductive reactance circuit.	.. 33
2.5 to 2.8	V-I transients of CO <sub>2</sub> -Ar welds for study of effect of arc voltage on mode of metal transfer.	.. 35-38
3.1 to 3.3	V-I transients of CO <sub>2</sub> welds at different arc voltages and welding currents/wire speeds for study of weld spatter.	.. 48,50, 51
3.4	Effect of arc voltage on percentage spatter loss at different welding conditions.	.. 53
3.5 and 3.6	V-I transients of CO <sub>2</sub> -Ar and Ar-shielded welds at different arc voltages for study of weld spatter.	.. 55,56
3.7	Effect of arc voltage on percentage spatter loss at different CO <sub>2</sub> -Ar shielding gas compositions.	.. 55,56
3.8	Stills from high speed cine films showing spatter phenomena.	.. 59
4.1	Weld bead geometry and shape relationships of CO <sub>2</sub> welds.	.. 66
4.2 to 4.5	Effect of arc voltage on weld bead geometry and shape relationships, at different welding currents/wire speeds.	.. 70-75

---

4.6	Effect of wire speed and welding current on	
and	weld bead geometry and shape relationships at	
4.7	three different arc voltages, using feed wire	
	diameter of 0.8 mm.	.. 74,75
4.8	Effect of wire speed and welding current on	
to	weld bead geometry and shape relationships at	
4.10	three different arc voltages, using feed wire	
	diameter of 1.2 mm.	.. 77-79
4.11	Effect of wire speed and welding current on	
and	weld bead geometry and shape relationships	
4.12	at two different arc voltages, using feed	
	wire diameter of 1.6 mm.	.. 81,82
4.13	Weld bead shapes of CO <sub>2</sub> welds with different	
	wire diameters.	.. 84
4.14	Effect of welding speed on weld bead geometry	
	and shape relationships.	.. 85
4.15	Effect of NPD on weld bead geometry and	
	shape relationships.	.. 86
4.16	Effect of torch angle on weld bead geometry	
	and shape relationships.	.. 87
5.1	Schematics of macro-structure of single- and	
	multi-run CO <sub>2</sub> welds showing directions of	
	microhardness measurements.	.. 96
5.2	Effect of arc voltage on weldment VHN values	
and	along two different axes.	.. 103,
5.3		104
5.4	Effect of welding current/wire speed on VHN	
and	values along two different axes, using feed	
5.5	wire diameter of 1.2 mm	.. 105,
		106
5.6	Effect of welding current/wire speed on VHN	
and	values along weld axis at two different arc	
5.7	voltages, using feed wire diameter of 0.8 mm.	.. 108,
		109
5.8	Effect welding current/wire speed on VHN values	
	along weld axis, using feed wire diameter of	
	1.6 mm.	.. 110

5.9	Effect of welding speed on microhardness of welds along weld axis.	..	112
5.10	Effect of 'NPD' on microhardness of welds along weld axis.	..	113
5.11 and 5.12	Effect of different torch angles on microhardness of welds along weld axis	..	115, 116
5.13 and 5.14	Effect of CO <sub>2</sub> gas flow rate on microhardness of welds along weld axis, using different feed wire diameters.	..	118, 119
5.15	Effect of oxidation and porosity on microhardness of welds along weld axis.	..	121
5.16	Cross-sectional view of a CO <sub>2</sub> weld bead showing macro-porosity.	..	122
5.17	SEM-micrograph of CO <sub>2</sub> weld metal showing micro-porosity.	..	122
5.18	Microstructure of original base metal.	..	122
5.19	Microstructure of weld metal, fusion boundary and HAZ of a single-run CO <sub>2</sub> weldment.	..	122
5.20	Microstructure of columnar grains in the fusion zone close to fusion boundary of a CO <sub>2</sub> weldment.	..	123
5.21	Microstructure of equiaxed grains in reinforcement portion of weld metal.	..	123
5.22	Microstructure of HAZ of CO <sub>2</sub> single-run weld metal.	..	123
5.23	Microstructure of HAZ of CO <sub>2</sub> multi-run butt weld.	..	123
6.1	Location of the V-groove in the Charpy samples of the CO <sub>2</sub> welds.	..	151
6.2	Effect of arc voltage on temperature dependence of C <sub>v</sub> -notch toughness (impact properties) of multi-run CO <sub>2</sub> butt welds.	..	157

CONTENTS

		<u>PAGE</u>
	Certificate ..	i
	Acknowledgements ..	ii
	Abstract ..	iv
	List of Figures ..	vi
CHAPTER-1	INTRODUCTION ..	1
1.1	Introduction ..	2
1.2	Research Planned ..	3
CHAPTER-2	MODE OF METAL TRANSFER ..	11
2.1	Introduction ..	12
2.2	Experimental Investigations ..	22
2.3	Welding Conditions ..	23
2.4	Results ..	25
2.5	Analysis of Results ..	25
2.6	Conclusions ..	39
CHAPTER-3	WELD SPATTER ..	42
3.1	Introduction ..	43
3.2	Experimental Investigations ..	45
3.3	Welding Conditions ..	46
3.4	Results ..	46
3.5	Analysis of Results ..	47
3.6	Conclusions ..	58

			<u>PAGE</u>
CHAPTER-4	WELD BEAD GEOMETRY AND SHAPE RELATIONSHIPS	..	61
4.1	Introduction	..	62
4.2	Experimental Procedure and Welding Conditions	..	65
4.3	Results	..	68
4.4	Analysis of Results	..	69
4.5	Conclusions	..	88
CHAPTER-5	METALLURGICAL TRANSFORMATIONS	..	91
5.1	Introduction	..	92
5.2	Experimental Investigations	..	95
5.3	Microhardness	..	95
5.4	Microstructure	..	100
5.5	Results	..	101
5.6	Analysis of Results, Microhardness	..	102
5.7	Microstructural Analysis	..	120
5.8	Conclusions	..	125
CHAPTER-6	BRITTLE FRACTURE TENDENCIES	..	128
6.1	Introduction	..	129
6.2	Experimental Investigations	..	150
6.3	Temperature Dependence of $C_v$ -Notch Tests	..	150

	<u>PAGE</u>
6.4 Light and SEM-FRACTOGRAPHY ..	154
6.5 Results ..	155
6.6 Analysis of Results, Impact Tests ..	156
6.7 Analysis of Fractographs ..	176
6.8 Conclusions ..	185
REFERENCES ..	186