



Faculty of Manufacturing Engineering

**OPTIMIZATION OF WELDING PARAMETERS ON MECHANICAL
PROPERTIES OF ALUMINIUM ALLOY 7075**

Sofia Mulyani Binti Yomli

Master of Manufacturing Engineering (Quality System Engineering)

2019

**OPTIMIZATION OF WELDING PARAMETERS ON MECHANICAL
PROPERTIES OF ALUMINIUM ALLOY 7075**

SOFIA MULYANI BINTI YOMLI

**A thesis submitted in fulfilment of the requirements for the degree of Master of
Manufacturing Engineering (Quality System Engineering)**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019


DECLARATION

I declare that this thesis entitled “Optimization of Welding Parameters on Mechanical Properties of Aluminium Alloy 7075” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :*Sofia*.....
Name : Sofia Mulyani Binti Yomli
Date :

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Quality System Engineering).

Signature : 

Supervisor Name : Assoc. Prof. Ir. Dr. Mohd Amran Bin Md. Ali

Date : 27/8/2019

ASSOC. PROF. IR. DR. MOHD AMRAN BIN MD ALI
Department of Manufacturing Process
Faculty Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

DEDICATION

In the name of Allah, The Most Beneficent, The most Merciful

Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort I dedicate to my sweet and loving

Papa & Mama,

Yomli Bin Ramaini & Adlinda Binti Bahtiar

Whose affection, love, encouragement and prays of day and night make me able to have such success and honour.

Along with helpful and supportive

Beloved friend

Syarool Anies Bin Sazali

ABSTRACT

This project is to study the effects of welding parameters for aluminium alloy 7075 towards the material characterization. The welding process used is Gas Metal Arc Welding (GMAW). The raw material used in this project is Aluminium Alloy (AA) 7075 and welded by using the KUKA robotic welding machine. The AA7075 was butt jointed with constant bevel angle which is 60° . There are three most important parameters of GMAW process that have been identified, which are current (A), voltage (V) and travel speed (S). The experiment is designed by using Design of Experiment (DOE) which is Response Surface Methodology (RSM) method. RSM method and Analysis of Variance (ANOVA) are used to optimize and validate the welding parameters. After that, the workpiece was cut into 11 samples with required dimensions in a dumbbell shape specimen by using wire EDM machine. Then the tensile test is conducted to observe the ultimate tensile strength (UTS), tensile modulus and also percentage elongation. The highest value of UTS obtained is 185.989 N/mm^2 . While the highest value of tensile modulus obtained is 20.44 N/mm^2 . For percentage elongation, the highest value obtained is 6%. Next, the Vickers hardness test is conducted to observe the hardness value which is measured to organize the revolution of mechanical property of weldment area. The highest value of hardness obtained is 89.3 HV. In addition, the microstructure of the sample is observed by using an optical microscope. It is to observe the length of the Heat Affected Zone (HAZ), grain size of weldment area and base metal. Multi-objective result shows that welding current at 143.7855 A and welding speed at 0.5329 m/min which 183.2128 MPa for UTS, 20.4992 MPa for tensile modulus, 6.3539% for percentage elongation and 88.7604 HV for hardness. Multi objective result shows that output of responses become slightly lower than single objective. This due to the multi-objective takes consideration all target.

ABSTRAK

Projek ini adalah untuk mengkaji kesan parameter kimpalan untuk aloi aluminium 7075 ke arah pencirian material. Proses kimpalan yang digunakan ialah kimpalan arka logam gas (GMAW). Bahan mentah yang digunakan dalam projek ini ialah aloi alumina 7075 (AA 7075) dan dikimpal dengan menggunakan mesin kimpalan robot KUKA. AA 7075 adalah punggung yang disambungkan dengan sudut serong yang berterusan iaitu 60 °. Terdapat tiga parameter yang paling penting dalam proses GMAW itu telah dikenalpasti, iaitu arus elektrik (A), voltan (V) dan perjalanan kelajuan (S). Eksperimen ini direka bentuk dengan menggunakan Reka Bentuk Eksperimen (DOE) yang merupakan metodologi permukaan tindak balas (RSM). Kaedah RSM dan analisis perbezaan (ANOVA) digunakan untuk mengoptimumkan dan mengesahkan parameter kimpalan. Selepas itu bahawa, bahan kerja dipotong menjadi 11 sampel dengan keperluan dimensi dalam spesimen bentuk dumbbell dengan menggunakan dawai EDM mesin. Kemudian ujian tegangan dijalankan untuk memerhatikan muktamad kekuatan tegangan (UTS), modulus tegangan dan juga pemanjangan peratusan. Nilai tertinggi UTS yang diperolehi adalah 185.989 N/mm. Manakala nilai tertinggi yang diperolehi untuk modulus tegangan adalah 20.44 N/mm². Pemanjangan peratusan yang tertinggi adalah 6%. Seterusnya, ujian kekerasan Vickers dijalankan untuk memerhatikan nilai kekerasan yang diukur untuk menganjurkan revolusi harta mekanik kawasan kimpalan. Nilai tertinggi yang diperolehi setelah melakukan ujian kekerasan Vickers adalah 89.3 HV. Di samping itu, struktur mikro sampel diperhatikan dengan menggunakan optic mikroskop. Ia adalah untuk memerhatikan panjang zon yang terkena haba (HAZ), saiz bijian kawasan kimpalan dan logam asas. Keputusan pelbagai objektif menunjukkan bahawa arus kimpalan pada kelajuan 143.7855 A dan kimpalan pada 0.5329 m / min yang 183.2128 MPa untuk UTS, 20.4992 MPa untuk modulus tegangan, 6.3539% untuk perpanjangan peratusan dan 88.7604 HV untuk kekerasan. Keputusan pelbagai objektif menunjukkan bahawa output respons menjadi sedikit lebih rendah daripada objektif tunggal. Ini kerana multi-objektif mengambil kira semua sasaran.

ACKNOWLEDGEMENTS

First and foremost praise to Allah, the Almighty, the greatest of all on whom ultimately we depend for sustenance and guidance. I would like to thank Almighty Allah for giving me opportunity, determination and strength to do my research.

Next, I would like to thank and express my deep and sincere gratitude to my supervisor, Associate Professor Ir. Dr Mohd Amran Bin Md Ali from the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his continuous support, guidance and encouragement.

In addition, I would also like to thank to the master and PhD students especially Madam Suraya Binti Laily for the encouragement, thoughtful advices, and guidance along the way I completed this project. Moreover, special thanks to my beloved friends for discussion, suggestions, supporting and encouraging me throughout my study.

Last but not least, I owe everything to my family who encouraged and helped me at every stage of my personal and academic life and longed to see this achievement comes true. Every breath of my life and drop of blood in my body is dedicated to my family.

TABLE OF CONTENTS

	PAGE
DECLARATION	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xi
CHAPTER	
1. INTRODUCTION	1
1.0 Research background	1
1.2 Problem statement	4
1.3 Objectives	4
1.4 Scopes of the research	5
1.5 Significance/ Important of study	6
1.6 Organization of report	6
2. LITERATURE REVIEW	8
2.1 History of Gas Metal Arc Welding (GMAW)	8
2.2 Process of Gas Metal Arc Welding (GMAW)	9
2.2.1 Robotic Gas Metal Arc Welding	10
2.2.2 Butt Joint	11
2.3 Parameters of welding	12
2.3.1 Welding voltage	12
2.3.2 Bevel Welding Angle	13
2.3.3 Welding Current	14
2.3.4 Welding travel speed	15
2.4 Aluminium Alloy 7075	16
2.5 Tensile Test	18
2.6 Hardness Test	18
2.7 Microstructure	20
2.8 Design of experiment (DOE)	21
2.8.1 Response surface method (RSM)	22
2.8.2 Central composite design (CCD)	23
2.8.3 Analysis of Variance (ANOVA)	24
2.9 Dumbbell Shape Specimen	24
3. METHODOLOGY	26
3.1 Introduction	26
3.2 Selection of Materials and Machines	28
3.2.1 Materials used	28
3.2.2 KUKA Robots Machine	29

3.2.3	Wire Electrical Discharge Machine (WEDM)	30
3.2.4	Wire Electrode	31
3.2.5	Record Power Engraver	32
3.3	Parameters Identified	33
3.4	Design of Experiment (DOE) Method Identified	33
3.5	Tensile Test	36
3.6	Microstructure of Specimen	36
3.6.1	Grinding Machine	37
3.7	Vickers Hardness Test	38
3.8	Result Analysis using RSM Method	39
3.9	Result Analysis using RSM Method	40
3.10	Summary	41
4.	RESULT AND DISCUSSION	42
4.1	Result of the experiment	42
4.2	Tensile Test	43
4.3	Analysis result of ultimate tensile strength (UTS)	44
4.3.1	Analysis of Variance (ANOVA) for UTS	46
4.3.2	Mathematical model for UTS	51
4.3.3	Optimization parameter of UTS	53
4.4	Analysis result of tensile modulus	54
4.4.1	Analysis of Variance (ANOVA) for tensile modulus	66
4.4.2	Mathematical model for tensile modulus	71
4.4.3	Optimization parameter of tensile modulus	73
4.5	Analysis result of percentage elongation	74
4.5.1	Analysis of Variance (ANOVA) for percentage Elongation	78
4.5.2	Mathematical model for percentage elongation	81
4.5.3	Optimization parameter of percentage elongation	84
4.6	Result of Analysis for Vickers Hardness Test	85
4.6.1	Analysis of Variance (ANOVA) for hardness	88
4.6.2	Mathematical model for hardness	92
4.6.3	Optimization parameter of hardness	95
4.7	Multiple response optimizer	96
4.8	Microstructure	98
5.	CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH	100
	REFERENCES	103
	APPENDICES	109

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Chemical composition of aluminium alloy 7075	16
2.2	Mechanical properties of aluminium alloy 7075	17
2.3	Physical properties of aluminium alloy 7075	17
2.4	Dimensions of dumbbell specimen	25
3.1	Constant parameter recommended	26
3.2	Mechanical properties of AA 7075	29
3.2	Welding parameters	33
4.1	Experimental result of UTS, tensile modulus, percentage elongation and hardness	43
4.2	Experimental result for UTS	44
4.3	Main effect ranking for UTS	46
4.4	ANOVA analysis of the UTS using full quadratic model	47
4.5	ANOVA analysis after elimination of insignificant term	48
4.6	Coefficient Regression (UTS)	51
4.7	Comparison between experimental and predicted result of UTS	52
4.8	Experimental result of tensile modulus	64
4.9	Main effect ranking for tensile modulus	66
4.10	ANOVA analysis of the tensile modulus using full quadratic model	67
4.11	ANOVA analysis after elimination of insignificant term	68
4.12	Coefficient regression (tensile modulus)	71
4.13	Comparison between experimental and predicted result of tensile Modulus	72

4.14	Experimental result for percentage elongation	77
4.15	Main effect ranking for percentage elongation	78
4.16	Main effect ranking for percentage elongation	79
4.17	Coefficient Regression (percentage elongation)	82
4.18	Comparison between experimental and predicted result of percentage elongation	83
4.19	Experimental result for hardness	86
4.20	Experimental result for hardness	88
4.21	ANOVA analysis of the hardness using full quadratic model	88
4.22	ANOVA analysis after elimination of insignificant term	89
4.23	Coefficient Regression (hardness)	93
4.24	Comparison between experimental and predicted result of hardness	94
4.25	Target and constraint for factor and response	96

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Process of Gas Metal Arc Welding	10
2.2	Sample of butt joint	12
2.3	Bevel angle vs UTS	14
2.4	Materials of AA7075	16
2.5	Graph of hardness on weld	20
2.6	Optical micrographs of weld metal region	21
2.7	Macrostructure of welded joints	21
2.8	Dumbbell shape specimen	25
3.1	The flowchart of Master Project 1	27
3.2	The flowchart of Master Project 2	28
3.3	KUKA Robotic Welding Machine	29
3.4	Welded AA7075	30
3.5	Wire electrical discharge machining (WEDM)	30
3.6	Samples of dog bone shape	31
3.7	Wire electrode	31
3.8	Setting of the sample at the machine to be cut	32
3.9	Record Power Engraver	32
3.10	Design of experiment using minitab software	34

3.11	Design of Experiment using minitab software	34
3.12	Design of Experiment using minitab software	35
3.13	Design of Experiment using minitab software	35
3.14	Universal Testing Machine	36
3.15	Optical Microscope	37
3.16	Grinding machine	37
3.17	Grinding process	38
3.18	Vickers Hardness Testing Machine	39
4.1	Main effect plot for UTS	46
4.2	Normal probability plot of UTS	49
4.3	Contour plot of UTS vs Welding Speed, Welding Current	50
4.4	Surface plot of UTS vs Welding Speed, Welding Current	50
4.5	Graph of actual vs predicted value of UTS	53
4.6	Optimization plot of UTS	54
4.7	Stress Strain graph for sample 1	55
4.8	Stress Strain graph for sample 2	56
4.9	Stress Strain graph for sample 3	56
4.10	Stress Strain graph for sample 4	57
4.11	Stress Strain graph for sample 5	58
4.12	Stress Strain graph for sample 6	59
4.13	Stress Strain graph for sample 7	60
4.14	Stress Strain graph for sample 8	61
4.15	Stress Strain graph for sample 9	62
4.16	Stress Strain graph for sample 10	63
4.17	Stress Strain graph for sample 11	64
4.18	Main effects plot for tensile modulus	65
4.19	Normal probability plot of tensile modulus	69

4.20	Contour plot of tensile modulus vs Welding Speed, Welding Current	70
4.21	Surface plot of tensile modulus vs Welding Speed, Welding Current	70
4.22	Graph of actual vs predicted value of tensile modulus	73
4.23	Optimization plot of tensile modulus	74
4.24	Sample is break after tensile test is conducted	74
4.25	Graph of main effects plot for percentage elongation	77
4.26	Normal probability plot of percentage elongation	80
4.27	Contour plot of percentage elongation vs Welding Speed, Welding Current	81
4.28	Surface plot of percentage elongation vs Welding Speed, Welding Current	81
4.29	Graph of actual vs predicted value of percentage elongation	84
4.30	Optimization plot of percentage elongation	85
4.31	Indentation obtained from Vickers Hardness test	86
4.32	Main effect plot for hardness	87
4.33	Normal probability plot of hardness	91
4.34	Contour plot of hardness vs Welding Speed, Welding Current	92
4.35	Surface plot of hardness vs Welding Speed, Welding Current	92
4.36	Graph of actual vs predicted value of hardness	94
4.37	Optimization plot of hardness	95
4.38	Multiple response optimization	97
4.39	Grain size at base metal (sample 6)	99
4.40	Grain size at weldment area (sample 6)	99
4.41	Grain size at HAZ (sample 6)	99

LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Malaysia Melaka
GMAW	-	Gas Metal Arc Welding
DOE	-	Design of Experiment
AA7075	-	Aluminium Alloy 7075
UTS	-	Ultimate Tensile Strength
ANOVA	-	Analysis of Variance
UTM	-	Ultimate Tensile Machine
WEDM	-	Wire Electrical Discharge Machining
RSM	-	Response Surface Methodology
CCD	-	Central Composite Design

CHAPTER 1

INTRODUCTION

This section clarifies the background, objective, statement of problem, scope of the master project and tracked by the organisation of the report. The background deliberates about the general idea of the process of gas metal arc welding (GMAW) and the parameters involved in the process. Afterward, the objective specifies about the task desired to be attained for this project. Last of all, the scope declares about what is invented to be accomplished in this project.

1.0 Research background

Gas metal arc welding (GMAW) is a welding process which the metal been joined by heating the metals up until it reach the melting point by way of an electric arc that forms in the middle of a usable wire electrode and the workpiece metals. GMAW process can be done in semiautomatic welding, machine welding and automatic welding. In semiautomatic welding, the wire feeding electrode is controlled through the tools, while the movement of welding gun is controlled by hand. In machine welding, gun that attached to a manipulator which is not hand-held is used. The controls need to constantly set and adjust. In automatic welding, the tools that welds devoid of persistent adjusting of controls by user is used. Automatic detecting devices control the precise gun alignment in a weld joint on the same equipment.

There are several advantages of GMAW. Firstly, GMAW is the most widely process used since the process equipment is low, it comes with low cost consumable, it offers high deposition rates as compared to stick welding and it has high electrode efficiencies. Next, it has low hydrogen deposits, comes with low levels of spatter when the right mode of metal transfer is selected. Besides, it does not require manual grinding and scrubbing of slag as the bare electrode wire plus shielding gases remove slag on weld bead. Furthermore, GMAW is the electric arc process where the spool of constantly fed wire been used. That one also able to join the extended elasticities of metal devoid of discontinuing. Other than that, all metals can be weld by using GMAW process by simply exchanging the filler wire.

In the manufacturing, GMAW is the utmost technique which generally utilized intended for welding ferrous and nonferrous materials. It is a melting welding technique applied in mutually industrial and repairing activities. GMAW has different points of interest over other melting welding techniques. According to (Suhail, 2014), high welding speed, huge metal removal, and spatter unrestricted welding at allowable expense than further welding methods in linking comparable and unrelated metals are some of its points of interest. Furthermore, it is pertinent aimed at a widespread assortment of marketable metals and alloys, for instance, carbon steel, stainless steel, copper and aluminum.

The applications of GMAW process for aluminium alloy usually found in aircraft and aerospace, marine fittings, bicycle frames and components, fly fishing reels, brake components, driveshafts, etc (Sivashanmugam *et al.*, 2009). GMAW process is developed to weld aluminium and aluminium alloy by using an inert shielding gas. Moreover, it is an automated technique and allows robot use. With the intention of acquire decent quality of weld, the selection of process parameters play an important key in research. Thus, it is compulsory to select the process parameters more precisely.

Mechanical properties are the properties which involved in reacting to an applied load. Mechanical properties for instance tensile strength, hardness and structure boundary are the most common properties measured especially in the GMAW process. Tensile test is the ultimate mechanical test which can be accomplished on material to measure the strength of a material. Ultimate tensile strength, yield strength and percentage elongation are part of material specification obtained in a tensile test.

Hardness is the resistance of material towards permanent deformation once load is applied for instance indentation, stiffness, abrasion and scratch. When the hardness of the metal is greater, it will result in higher resistance to deformation (Ibrahim *et al.*, 2012a). There are three scales of hardness measurement which are macro, micro and nano depending on the forces applied. Macro hardness can be tested by using Rockwell, Brinell, and Vicker Hardness Test.

Grains and grain boundaries are a small group of atoms which started to assemble into a crystalline form once the metal that has been cooled is reached its freezing point. The small crystals distributed all the way through the body of liquid where it's been oriented in all directions and by way of solidification endures, crystal that formed from the surrounding liquid is increasing. It is in the form of treelike structure or dendrites. (Avinash *et al.*, 2014), the solidified grain size and structure are affected by temperature and cooling rate.

Therefore, this project investigates about the influence of welding parameters for instance Voltage (V), Current (A), and travel speed (m/s) and the output responses which covered in this project are tensile strength, tensile modulus, percentage elongation, hardness at the welded area as well as the microstructure of the base metal and weldment area.

1.2 Problem statement

The entire research, GMAW process parameters play an important factor since it contribute to the good quality of product, the effectiveness of the process and data can be analysed precisely. To acquire a decent welded joint with required quality in strength by controlling the procedure input parameter is the most basic issue encountered by company. In order to give electric flow to soften both the terminal and an appropriate measure of base metal, the procedure requires adequate control parameter.

According to (Ibrahim *et al.*, 2012a) there are a lot of parameters that can greatly influence the mechanical properties of welded aluminium alloy can be used, but the most important parameters must be identified to avoid higher material lost due to trial and error in order to get the suitable one. Thus, DOE is used in this research to reduce trial and error and to discover the optimal quality of welded joint. Besides, this research investigate whether these selected parameters are able to enhance the quality of welding or vice versa.

1.3 Objectives

The main objective of this project is to examine the influence of welding parameter on material characterization of welded Aluminium Alloy 7075. In the direction to accomplish the foremost objective, the three sub-objectives are outline:

- (a) To study the suitable factors of welding such as welding current and welding speed to enhance the good quality of weld.
- (b) To investigate the ultimate tensile strength, tensile modulus, percentage elongation and hardness of weldment area.

(c) To optimize and validate the welding parameters by using response surface method (RSM) and analysis of variance (ANOVA).

1.4 Scopes of the research

This project was conducted at the laboratory in Universiti Teknikal Malaysia Melaka (UTeM) by using KUKA welding machine. KUKA welding machine been used because of its exact positioning accuracy during the operation of welding. This project was carried out by measuring the tensile strength, tensile modulus and percentage of elongation responses by using Tensile Ultimate Machine (UTM) which is compliance to ASTM standard. The speed used to conduct the tensile test is 5 mm/min. The welded sample of aluminium alloy 7075 testing specimen that can be cut by using wire cut machine with the dimension is taken from ASTM E8/E8M-09 standard. The results of ultimate tensile strength, tensile modulus and percentage elongation are calculated and analysed.

In addition, the welding specimens is cut then followed by grind the sample and polished it. Then, the hardness of aluminium alloy can be tested by using Vickers Hardness machine which the testing force is 0.5 kgf and the dwell time is 15 seconds. To observe the microstructure, the sample need to be grind by using grinding machine, then polished it until the mirror surface can be observed. Afterward, the sample is then etched by using Keller's reagent. Microhardness is a dimension of the hardness material when there is huge force applied. The tested been observed and recorded. This research investigates the influence of welding parameters on material characterization of aluminium alloy 7075 and to be optimized by using design of experiment (DOE) through RSM method by single and multi-responses. Besides, the mathematical model will be generated to compare the experimental result and predicted result. The most significant parameter that affected to the responses also

will be analysed through ANOVA analysis which the data will be generated using Minitab software.

1.5 Significance/ Important of Study

The rationale of research as follows:

- (a) From this project, the knowledge about the gas metal arc welding and the important to find the suitable welding parameter can be gained further since there's a lot of articles, journals and reference books that need to be studied and referred in order to complete this research.
- (b) Learn about RSM method where the experiment use a sequence of designed experiments to obtain an optimal response.
- (c) Scientific learn on how to conduct tensile strength test and hardness test in order to ensure a safe and high quality material.

1.6 Organization of report

- (a) Chapter 1 is an introduction part which explains about the background of this project where the objective need to be achieved by following the scope of this project that have been identified.
- (b) Chapter 2 is a literature review part explains about all things which interrelated to this project.

- (c) Chapter 3 is a methodology part which is an overview of study that explains on how the project been done by following the process and method to be used that have been specified.

- (d) Chapter 4 is a result and discussion parts which explains the results that have been collected.

- (e) Chapter 5 is a conclusion and recommendation part where it is an overview of the overall project that have been done.

CHAPTER 2

LITERATURE REVIEW

This section is mainly explain the welding process which interrelated towards GMAW process. It describes about the influence of welding parameters in mechanical properties, the hardness at welded area, microstructure at the base metal, HAZ and weldment area, RSM method and other information. The information is collected from reference books, online article, research journal and other foundations as a study perseverance.

2.1 History of Gas Metal Arc Welding (GMAW)

In the year of 1800, Humphry Davy's discovered the electric arc. Initially, carbon electrode were used, nevertheless in the late 1800s, N.G. Slavianoff and C. L. Coffin have been developed the metal electrodes. The philosophies of MIG Welding past started to be established all over the place. In the year of 1920, the automatic welding was presented by P. O. Nobel of General Electric and developed a plain electrode wire worked on through current and arc voltage in place of the origin of amendable the feed rate. The authorised start of GMAW process was effectively industrialised at Battelle Memorial Institute in 1948 underneath the patronage of the Air Reduction Company. This improvement used a gas shielded arc related to the gas tungsten arc but switched the tungsten electrode with a constantly fed electrode wire.

The small-diameter conductor cables and the continuous-voltage power source is the improvement which made the development more functional. The great removal ratio headed handlers to attempt the procedure on steel. The CO₂ shielding gas straightaway increased