COMPARATIVE STUDY OF HEAT AND METAL TRANSFER IN GAS METAL ARC WELDING (GMAW)

AUTHOR

Hafiz Muhammad Usman Iqbal

REGISTRATION NUMBER

00000117259

SUPERVISOR

DR. EMAD UD DIN

DEPARTMENT OF DESIGN AND MANUFACTURING ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD

OCTOBER, 2017©

COMPARATIVE STUDY OF HEAT AND METAL TRANSFER IN GAS METAL ARC WELDING (GMAW)

Author

Hafiz Muhammad Usman Iqbal

Registration number

00000117259

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Design and Manufacturing Engineering

Thesis Supervisor:

DR. EMAD UD DIN

Thesis Supervisor's Signature: ____

DEPARTMENT OF DESIGN AND MANUFACTURING ENGINEERING

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,

ISLAMABAD

FORM TH-4

National University of Sciences & Technology

MASTERS THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: **Hafiz Muhammad Usman Iqbal (00000117259)** Titled: **Comparative Study of Heat And Metal Transfer In Gas Metal Arc Welding (GMAW)** be accepted in partial fulfillment of the requirements for the award of **MS Design and Manufacturing Engineering** degree with ………. grade.

Examination Committee Members

1) Name: **Dr. Mushtaq Khan** Signature: ____________________

2) Name: **Dr. Aamir Mubashir** Signature: ____________________

3) Name: **Dr. Nabeel Arif** Signature: __________________

Supervisor: **Dr. Emad–ud-din** Signature: __________________

Date: ____________________

__________________________ __________________________

Head of Department Date

COUNTERSIGNED

Date: ___________________ __________________________

Dean/Principle

Declaration

I certify that this research work titled "Comparative Study of Heat and Metal Transfer in Gas Metal Arc Welding (GMAW)" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Hafiz Muhammad Usman Iqbal

Registration No: 00000117259

Plagiarism Certificate (Turnitin Report)

This thesis has been checked for Plagiarism. Turnitin report endorsed by Supervisor is attached.

Hafiz Muhammad Usman Iqbal

00000117259

Signature of Supervisor

Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

____

Hafiz Muhammad Usman Iqbal

Registration No: 00000117259

____

Signature of Supervisor

Copyright Statement

Acknowledgements

Although only my name appears to be on the cover of this thesis but actually many people have helped me to make my efforts successful. Therefore, I would like to thank everybody who has contributed in the long run of completing the project in due time and making it a memorable one. Firstly, I would like to thank Allah Almighty who blessed me with health, wealth and prosperity that helped me fulfill my dream all the way till the end. Then I would like to thank my parents, without their honest support, it wouldn’t have been possible for me to stand where I am now. My spirited gratitude is to my supervisor, Dr. Emad Uddin. He has been there for me during all the ups and downs of my research work and helped me whenever I failed to do things my way. My G.E.C members, Dr. Nabeel Arif, Dr. Amir Mubashar and Dr. Mushtaq Khan who helped me a lot in the post processing part of my work and were always there to suggest me innovative ways of solving my work.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment.

ABSTRACT

Gas metal arc welding is the one of major process of welding in which an electric arc forms between a consumable wire electrode and the metal work piece, which heat the metal work piece causing them to melt and join. In the recent years great development are being made in this area to optimize and improve the welding performance with high efficiencies and more production rate.

The objective of this research is to find the optimized parameters in gas metal arc welding for the application of steel. The effect of force and velocity with which the droplet fall in the weld pool during the welding process are analyze and effect of different shielding gases used in the welding process are also analyze by varying the percentage of different shielding gases during the welding process.

During the welding process different types of forces are effect on the droplet from which some forces act as an attaching forces and some behave like a detaching forces. These forces are calculated by modified force balance model (MFBM) method analytically. Arc covered angle during the welding process has also influence the metal transfer. In the range of 0^o-30^o angle force on the detaching droplet is lower and the droplet did not follow the path and welding process is not feasible. But in the range of 65^o to 100^o angle variation in the drop detachment is very low so 90^o angle is very feasible for the metal transfer.

To calculate the hitting velocity and force with which the droplet fall in the weld pool, equations of motion are used. To observe the effect of the shielding gas we use different inert gases and reactive gases. Effect of pure argon, different percentage of O_2 mixed with the argon, and different percentage of CO_2 mixed with the argon observed that was show that while increasing the percentage of CO_2 for certain instant till 20% it will show the very good results, after that the heat transfer is increase to the base metal and weld pool has more fluidity then that of pure argon or other blend of shielding gas and calculated results are compared with the experimental data.

Key Words Used: Static Force Balance Model, Pinch Instability theory, Modified force balance model, gas metal arc welding, Tungsten inert gas , Metal inert welding , Shielded metal arc welding. Flux core arc welding.

Executive Summery

Welding is the one of major process of welding in which an electric arc forms between a consumable wire electrode and the metal work piece, which heat the metal work piece causing them to melt and join. In the recent years great development are being made in this area to optimize and improve the welding performance with high efficiencies and more production rate.

The objective of this research is to find the optimized parameters in gas metal arc welding for the application of steel. The effect of force and velocity with which the droplet fall in the weld pool during the welding process are analyze and effect of different shielding gases used in the welding process are also analyze by varying the percentage of different shielding gases during the welding process.

Modified force balance model is used to calculate the effect of forces on the droplet from which some forces act as an attaching forces and some behave like a detaching forces. By using this model it is easy to calculate the diameter of droplet. Drop detaching and hitting force is calculated by using this model. Arc covered angle during the welding process has also influence the metal transfer. Its effect has also observed for different shielding gases

In the first chapter we discuss the background history and the importance of welding in the manufacturing industry. Research objective and motivation is also discussed in the first chapter. In the second chapter of we discuss the gas metal arc welding and different transfer modes available in the gas metal arc welding. In the third chapter we discuss the modified force balance model in details, effect of shielding gas is also discussed in this chapter. In the second last chapter we discuss the results obtained from the experiment and also discuss the analytical results. In the last we discuss the conclusion obtained from the work

Table of Contents

Declaration .... **iv**
Plagiarism Certificate (Turnitin Report) .... **v**
Copyright Statement .... **i**
Acknowledgements .... **i**
ABSTRACT .... **i**
Executive Summery .... **ii**
Table of Contents .... **iii**
List of Figures .... **i**
List of Tables .... **ii**
1 Chapter-1 .... **1**
1. Introduction 1
1.1 Motivation and Scope of research 5
1.2 Objective 5
2 Chapter 2 Literature Review **6**
2.1 Gas Metal Arc Welding 6
2.2 Shielding gas in gas metal arc welding 7
2.3 Modes of Metal transfer 9
2.3.1 Short Circuit Transfer 9
2.3.2 Globular Transfer 9
2.3.3 Spray Transfer 11
2.4 Static Force balance model 12
2.5 Modified force balance model 13
3 Chapter 3 .... **16**
3.1 Methodology 16
3.2 Surface Tension Force 16
3.3 Gravitational Force 16
3.4 Drag Force 16
3.5 Electromagnetic Force 16
3.6 Momentum flux force 17
3.7 Static Force balance model 18
3.8 Modified force balance model 19
3.9 Case-2 98%Argon + 2%O_2 24
3.10 Case-3 Argon + CO_2 Mixture 25
4 Chapter 4 (Results and discussions) **27**
4.1 Results of Pure Argon Shielding Gas 27
4.2 Validation of Hitting Velocity 28
4.3 Results of 98%Argon + 2%O_2 Shielding Gas 29

4.4 Results of Argon + CO_2 Shielding Gas 31
5 Chapter-5 33
5.1 Conclusions 33

List of Figures

Figure 1 Welding Process (GMAW) 3
Figure 2 Gas metal Arc Welding (GMAW) gun 4
Figure 3 Schematic presentation of GMAW with Enlarge Welding Area....................6
Figure 4 Short Circuit Transfer in GMAW....................9
Figure 5 Globular Transfer in GMAW....................10
Figure 6 Axial Spray Transfer Mode in GMAW....................11
Figure 7 Schematic of pendant drop. 14
Figure 8 Forces on the detaching droplet....................17
Figure 9 Schematic of pendant drop....................20
Figure 10 Schematic of momentum flux due to flow within molten 22
Figure 11 Detail Description of GMAW Setup 24
Figure 12 Behavior of different force due to applied current 27
Figure 13 Theoretical and experimental Hitting velocity and force 28
Figure 14 Analytical and Experimental hitting force and velocity....................29
Figure 15 Comparison of forces and velocity for both cases....................30
Figure 16 Experimental and analytical hitting velocity with different percentage of CO2 31
Figure 17 variation of Experimental and Analytical Velocity with different percentage of CO2 32
Figure 18 Variation of Hitting force and velocity with different percentage of CO2....................32

List of Tables

Table 1 Advantages and Limitations of GMAW....7
Table 2 Material properties For Pure Argon....21
Table 3 Material Properties in case of Blend of shielding gases....25
Table 4 Percentage variation of CO_2 and Maximum current plot....26

1 Chapter (Background theory)

1. Introduction

Welding is the process of joining of metal pieces by the application of heat. It is the fundamental part of engineering and manufacturing process that involves a large number of variables contributing towards the quality of finish product. A non-technical definition of welding is that Welding is the joining together of the surface(s) of a material by the application of heat only, pressure only, or with heat and pressure together so that the surface fuse together. A filler material may or may not be added to the joint.[1] Welding is extensively use in the manufacturing of different products ranging from the industrial applications, pipeline fabrication, trains and bridges buildings, medical implants and electronic devices for high precision engineering application in aerospace and marine application. It will reduce the cost involved in the manufacturing and production time considerably. It has also offers significant advantages in material joining compare with the other joining methods which include flexibility in design, material utilization improve structure integrity, weight and cost saving. [2]

The American welding society's (AWS) definition of welding is very technical to reflect the differences in the welding processes used today states that "welding is a localized coalescence of metals and nonmetals produced either by heating the materials to the required welding temperatures, with or without application of pressure and with or without adding the filler materials". The term coalescence means the fusion or growing together of the grain structure of the materials being welded. The definition also includes the term metals or nonmetals because the material such as plastic, ceramics, and so forth nonmetals that will also use in the welding. [3]

There are different types of welding processes used in the industry today from which the most common are the shielded metal arc welding (SMAW), flux core arc welding (FCAW), gas tungsten arc or tungsten inert gas (TIG) welding and gas metal arc welding (GMAW). All these types have different parameters to apply. Shielded metal arc welding are the manual arc welding process in which consumable electrode covered with the flux to lay the weld are used but in the flux core arc welding semi-automatic or automatic process used to continuously fed the tubular electrode containing a flux and constant voltage or constant current welding power supply.[4] In the above two types consumable electrode are used but the gas tungsten arc welding is the process that used non-consumable tungsten electrode and a filler wire to produce the weld. In the gas metal arc welding an electric arc forms between a consumable wire electrode and the metal work piece, which heat the metal work piece causing them to melt and join. In this type of process metal is transfer from the wire tip to the weld pool through the arc in gas metal arc welding. It is very commonly used welding process in which different shielding gas is used for the protection of the molten metal droplet and these gases are very commonly available so it is very low cost welding technique.[4]

During welding process thermal distortion and residual stresses are something that cannot be avoided but with careful utilization and optimization of the welding process it can be minimized to the significant level. These stresses not only slow up the welding process but is will affect the weld quality and also decrease the life of weld.

In gas metal arc welding shielding gas also has a significant effect on metal transfer. This shielding gas plays dual roles in the GMAW. Firstly, it protects the arc and the molten weld metal from the contamination of the air. Second, it affords the desired arc characteristics through the effect on ionization.[5]

A variety of gases are available for use in the gas metal arc welding process. Depends upon the gas properties, it is classified as inert or active. Argon do not react with the liquid metal, they are inert. Carbon dioxide, oxygen, and nitrogen are multiatomic molecules that dissociate when exposed to temperatures in the arc and are able to react with the molten metal. So in many applications, a mixture of gases is used as a shielding purpose. The gas affects the plasma properties and the flow of current as it travels through the electrode and plasma which leads to changes in the Lorentz pinch force in both the plasma and the electrode. Gas composition also affects the surface tension of the metal. There are different types of gases available according to the welding materials. All these gases are used for enhancement of weld quality. Different blends of gases like Argon and carbon dioxide and oxygen are more likely used. According to the requirement of the properties of the weld bead there composition will be added to get the required results.[6]

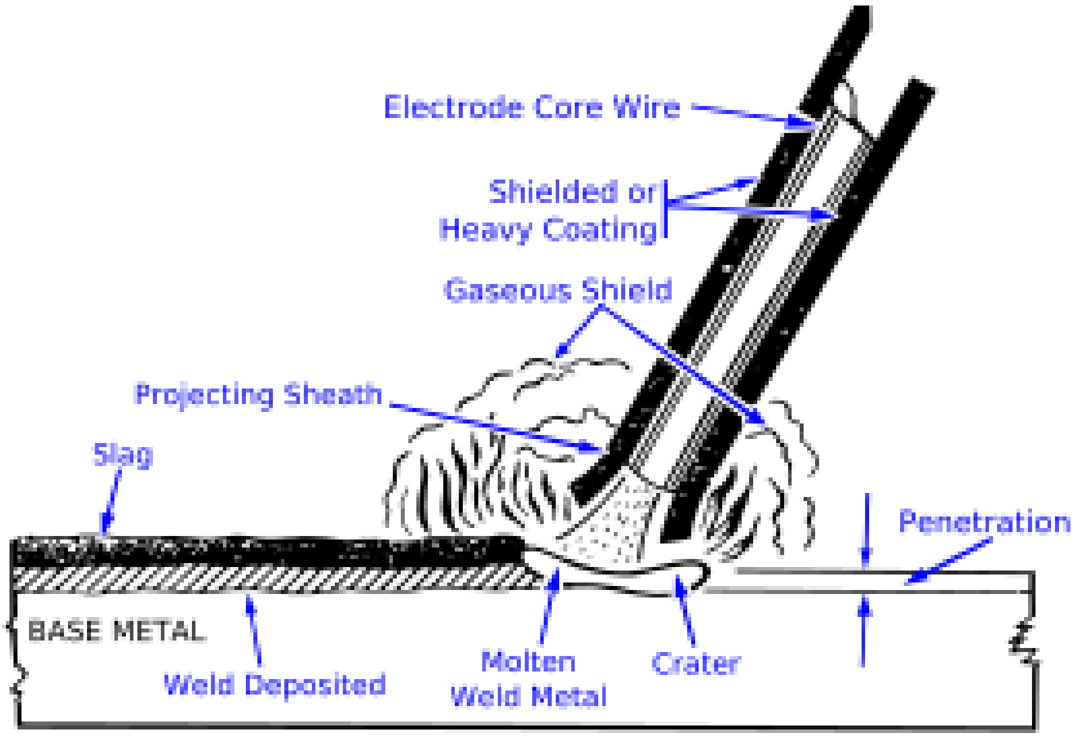

Figure 1 Welding Process (GMAW)

In the gas metal arc welding process, metal transfer has significant effect on the weld quality and arc stability. Metal transfer is the complex phenomenon of the drop growth, neck formation and the drop detachment. Despite extensive attempts at analytical, numerical and experimental modeling, discrepancies still exist between predicted and experimental results. There are various factors that will be affected the analytical and experimental result. Various theories are developed that will be effect the weld quality and arc stability. In these theories static force balance model theory and pinch instability theory is very common. In these theories Static force balance theory is most favorable for globular transfer mode and PIT was most favorable for spray region but none of them is favorite for the transition region. Modification is occurs when momentum flux force is added in the SFBM to improve the accuracy for higher value of current by adding the effect of taper formed during the drop detachment and the momentum flux generated by the axial flow within the drop is also introduced in this work and it is added to the force components of the SFBM that will reduce the effect on the surface tension force and electromagnetic force, Calling name as Modified force Balance model.[6]

Pulse gas metal arc welding utilized pulse current and drop is detached from the wire tip with the each pulse that is called one drop one pulse (ODOP) condition. In this condition drop is detached from the wire during the peak time and arc is maintain during the base time. When the drop is detached it has approximately spherical shape with diameter nearly equal to the diameter of wire, which is similar to the metal transfer in the projected mode. So that, metal transfer is controlled by synchronizing the drop detachment with the pulse current, and the weld quality is improved with the reduction in the thermal distortion and residual stresses.[7]

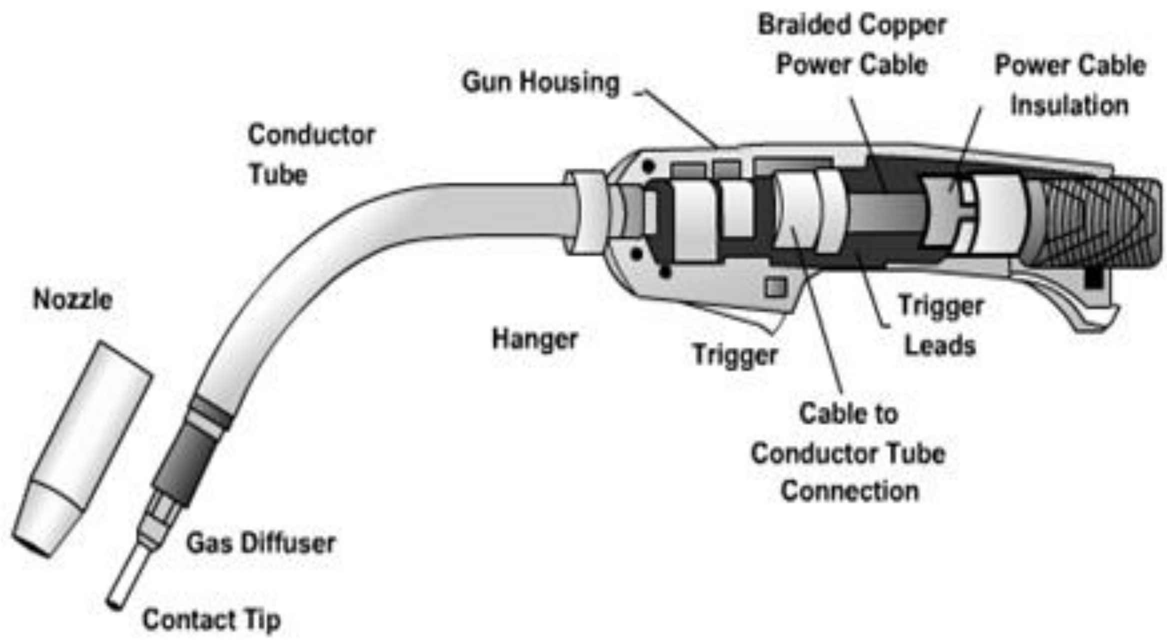

Figure 2 Gas metal Arc Welding (GMAW) gun

Modified force balance model (MFBM) have been used to calculate the effect of forces on the droplet. By using this model force at which the droplet falls in the weld pool will also be calculated. To calculate the velocity through which the droplet hit in the pool equations of motion will be used. Variation in the weld quality will be observed by changing the current intensity, arc covered angle and the shielding gas. Variation in the shielding gas is also observed by using inert gas and reactive gas during the welding process. Pure argon gas and the mixture of 2% O_2 and 98% pure argon will be use as a shielding gas more ever the mixture of CO_2 and argon will also use by changing the percentage of CO_2 with argon with different values of current and observed the variation.[4]

1.1 Motivation and Scope of research

Consider the importance of welding as it is most commonly used welding technique in the manufacturing industry in all over the world encourage the effort to word in the field of welding. It is the fundamental part of engineering and manufacturing process that involves a large number of variables contributing towards the quality of finish product. Considering the growing demand of the manufacturing industry and the products made in that types of industry will offer me to work in the field of welding. As it is very wide field because there are different types of welding process used for manufacturing in the industry but GMAW is very widely used technique for the joining of parts. Considering the low cost per unit in the welding and widely used joining technique there is lot of gap present to enhancing the quality of weld and reduce the cost of joining by optimizing the parameters of welding. If we see the shielding gases used in the welding has also very little in choice so it is very necessary to optimize and used blends of gases to get the very good quality results of welding. Configuration of the blend of gases are available according to the process requirement but very wide gas is also available to making configuration of the blend of gases. Modified for balance model is very commonly used method for the optimization of parameters that is used in our work.

1.2 Objective

The objective of research is to study the different configuration of the shielding gases used in the gas metal arc welding and calculated the detaching force with which the droplet detached from the welding wire, Calculation of detaching velocity of droplet, Calculation of hitting velocity and force with which droplet fall in the weld pool. Optimization of the welding parameters to minimize the post processing in gas metal arc welding And selection of optimal amount of blend of shielding gases for the welding process in pulse Gas metal arc welding. In our research work Pulse Gas metal arc Welding is used with different shielding gases and Modified force balance model is used for calculation of detaching and hitting force and equations of motion is used for the calculation of hitting velocity with which droplet fall in the weld pool.

2 Chapter (Literature Review)

2.1 Gas Metal Arc Welding

Gas metal arc welding (GMAW) that is also known as metal inert gas (MIG) welding or metal active gas (MAG) welding are the major joining method used in the manufacturing industry. In this method an electric arc forms between a consumable wire electrode and the metal workpiece, which heats the workpiece metal(s), causing them to melt and join.[1] During this process heat is produce that causing then to melt and join the work pieces. Welding process can be categories is low current welding process and high current welding process for thin metal working and thick metal working respectively.[2] The welding equipment and enlarged welding area are schematically shown in the Figure 3

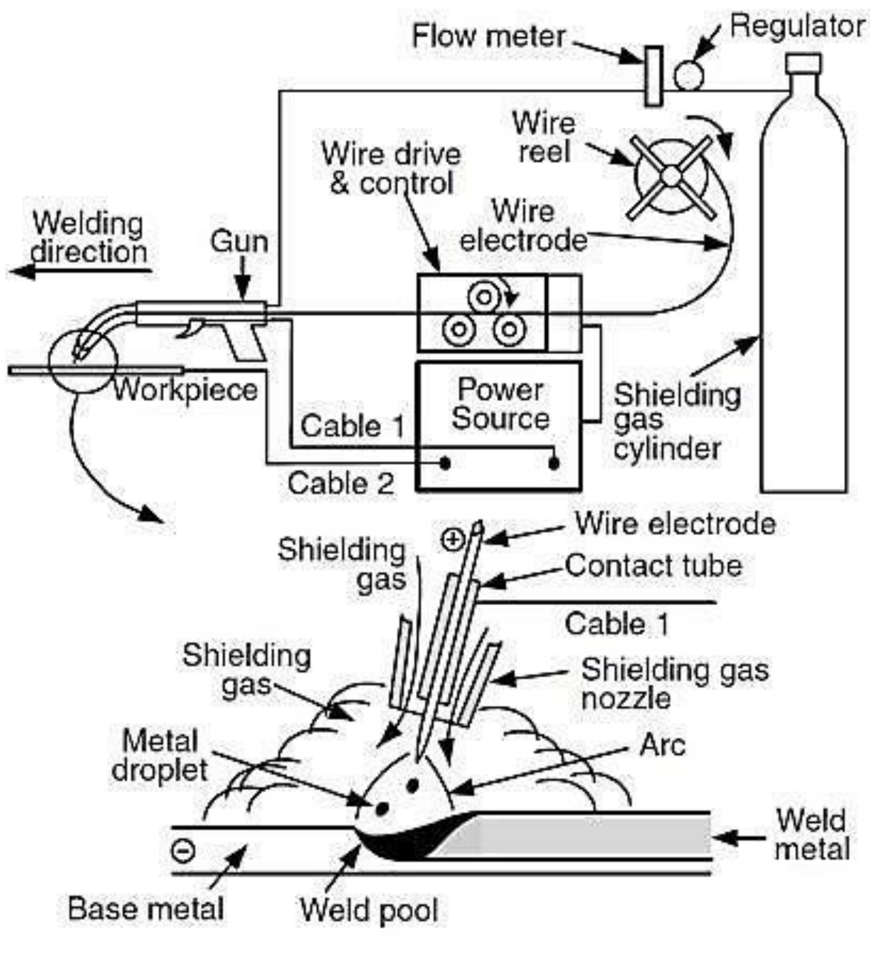

Figure 3 Schematic presentation of GMAW with Enlarge Welding Area

It should be mentioned that for gas metal arc welding (GMAW), direct current is normally used with positive wire electrode (DCEP) but it will produce more effect like spattering and more heat is added to the metal workpiece so now a day pulse current gas metal arc welding (P-GMAW) is widely used for the joining of materials. It has more beneficial for joining of materials. Gas metal arc welding process can be used for welding wide variety of materials like metals steel and other alloyed materials.[8]

This method can be easily modified for the use of semiautomatic and automatic robotic welding applications. There are various heat transfer modes in the gas metal arc welding and are lot of advantages and limitations for the use of GMAW.

Advantages	Limitations
➢ Ability to join wide range of materials ➢ Enhanced mobility due to simple equipment. ➢ Beautiful weld bead appearance. ➢ Lesser welding fumes making the weld process quicker and easily functional. ➢ Easy Automation. ➢ High Process efficiency ➢ Low cost of weld per unit length. ➢ Minimum post processing is possible.	➢ High heat input during the spray mode limit the process for the use in the thicker range of material. ➢ Due to high heat generation limited the application for only flat position. ➢ High rate of spatter so it need a lot of care during application of joining.

Table 1 Advantages and Limitations of GMAW

2.2 Shielding gas in gas metal arc welding

In the gas metal arc welding process there are different types of shielding gases available for the used. From these gases some are inert gases that did not react with the molten droplet and some gases are active gases that will react with the molten droplet and forms oxides of that metal.

Argon is very commonly used shielding gas during the GMAW process. Also O_2, N_2, and CO_2 is also very commonly used shielding gases that behave as an active gases. Shielding gas selection has also influence the selection of mood of metal transfer. And has definite effect on the finish weld profile.[4]

Because the thermal conductivity of Argon is low. Its energy required to give up an electron, ionization energy, is low, and this results in the finger-like penetration profile associated with its use. Argon favorable for axial spray transfer. Nickel, copper, aluminum, titanium, and magnesium alloyed base materials use 100% argon shielding. Argon, because of its lower ionization energy, supports with arc starting. It is the main component gas used in binary (two-part) or ternary (three-part) mixes for GMAW welding. It also increases the molten droplet transfer rate. But in case of CO_2 behave as an inert at room temperature.[9]

In the existence of the arc plasma and the molten weld pool it is reactive. In the high energy of the arc plasma the CO_2 molecule broken up in a process known as dissociation. In this process, free carbon, carbon monoxide, and oxygen release from the CO_2 molecule. This occurs at the Direct current anode region of the arc. At the direct current cathode region, which is invariably the work piece for GMAW, the released elements of the CO_2 molecule experience the process of recombination.

During recombination higher energy levels exist and are responsible for the deep and broad penetration profile that characterizes the use of carbon dioxide.

In case of O_2, it is an oxidizer that reacts with components in the molten pool to form oxides. In small additions (1-5%), with a balance of argon, it provides good arc stability and excellent weld bead appearance. The use of deoxidizers within the chemistry of filler alloys compensates for the oxidizing effect of oxygen. Silicon and manganese combine with oxygen to form oxides. The oxides float to the surface of the weld bead to form small islands, and are more abundant under CO_2 shielding than with blends of argon and oxygen gas.[4]

2.3 Modes of Metal transfer

2.3.1 Short Circuit Transfer

Short circuit metal transfer is a mode of metal transfer, whereby a continuously fed solid or metal cored wire electrode is deposited during repeated electrical short circuits. The short circuit metal transfer mode is the low heat input mode of metal transfer in GMAW. All of the metal transfer occurs when the electrode is electrically shorted (in physical contact) with the base material or molten pool.[4] This transfer mode depends upon the types of shielding gas used and

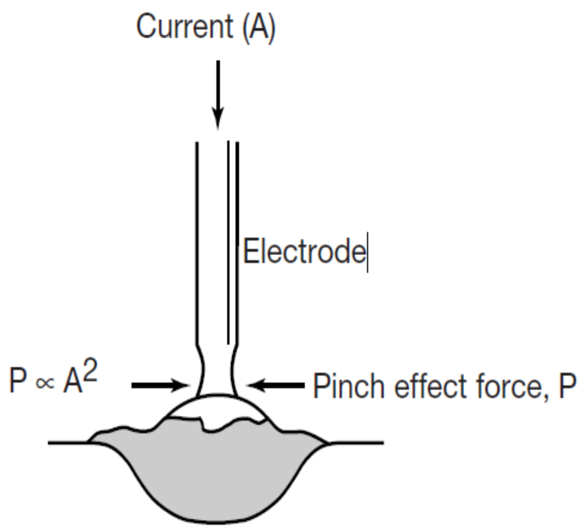

Figure 4 Short Circuit Transfer in GMAW

amount of current flow and wire diameter. This transfer mode is favorable for the low wire diameter of electrode. The low heat input quality makes it ideal for sheet metal thickness materials, so it is limited for the thin sheet application.[4]

2.3.2 Globular Transfer

Globular transfer mode in gas metal arc welding is the mode of molten metal transfer in which a continuously fed solid or metal-cored wire electrode is deposited in combination of short circuit and gravity assisted large droplet. These droplets have irregular shape. During the use of all metal core and solid wire electrode for GMAW there is a transition where the mode is switch from short circuit to the globular mode. In the globular transfer mode large droplet of irregular shape did not follow the axial detachment direction but it will fall out of direction or it will move towards the contact tip. In this process cathode jet forces that move upwards from the work piece are responsible for the irregular shape and the upward spinning motion of the molten droplets.[4]

The process at this current level is difficult to control, and spatter is severe. Gravity is involved in the transfer of the large molten droplets, with random short-circuits.

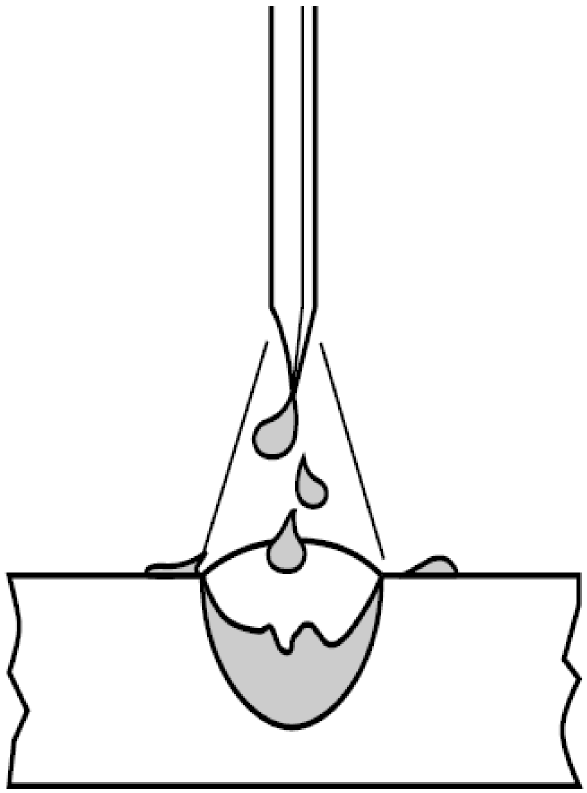

Figure 5 Globular Transfer in GMAW

During the 1960's and 1970's, globular transfer was a common mode of metal transfer for high production sheet metal fabrication. This transfer mode is associated with the use of 100% CO_2 shielding, but it has also seen heavily use with argon + CO_2 blends. In general manufacturing on carbon steel, it provides a mode of transfer, just below the transition to axial spray transfer, which has given itself to higher speed welding. The use of globular transfer in high production rate is being replaced with advanced forms of GMAW. The changes are being made to pulse gas metal arc welding which results in lower fume levels, lower or absent spatter levels, and removal of incomplete fusion defects.[4][2]

2.3.3 Spray Transfer

Spray metal transfer is the high energy mode of metal transfer, whereby a continuously fed solid or metal cored wire electrode is dropped at a higher energy level, resulting in a stream of small molten droplets. The droplets are propelled axially across the arc. Axial spray transfer is the high energy form of metal transfer in GMAW. In order to achieve axial spray transfer, binary blends containing Argon + O_2 and Ar+ CO_2 is used. For minimum application amount of CO_2 is maximum 18%. Axial spray transfer is supported by either the use of solid wire or metal-cored electrodes. Axial spray transfer mode may be used with all of the common alloys including: aluminum, magnesium, carbon steel, stainless steel, nickel alloys, and copper alloys.[4]

For most of the diameters of filler metal alloys, the change to axial spray transfer takes place at the globular to spray transition current.

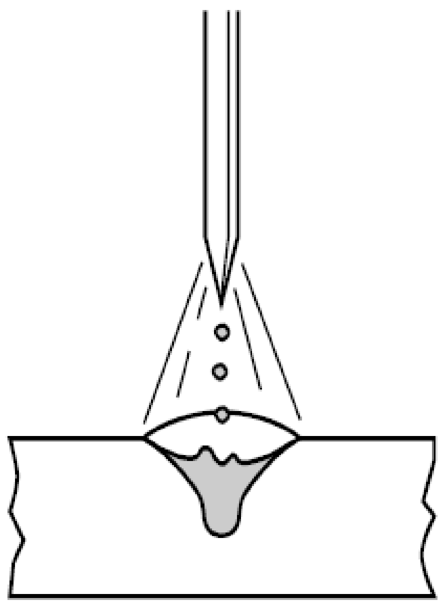

Figure 6 Axial Spray Transfer Mode in GMAW

A stream of fine metal droplets that travel axially from the end of the electrode characterizes the axial spray mode of metal transfer. The high pool fluidity restricts its use to the horizontal and flat welding positions. For carbon steel, axial spray transfer is applied to thicker section thickness material for fillets and for use in groove type weld joints. The use of argon shielding gas compositions of 98%, with a balance of oxygen, creates a deep finger-like penetration profile, while shielding gas mixes that contain more than 10% CO_2 reduce the finger-like penetration profile and provide a more rounded type of penetration. The selection of axial spray metal transfer is dependent upon the thickness of base material and the ability to position the weld joint into the horizontal or flat welding positions. Finished weld bead appearance is excellent, and operator appeal is very high. Axial spray transfer provides its best results when the weld joint is free of oil, dirt, rust, and other particles.[4][9]

2.4 Static Force balance model

Metal transfer is the phenomenon of transferring the molten drop from the wire tip to the weld pool through the arc in gas metal arc welding (GMAW) and is important because it has significant effects on the weld quality and arc stability. Drops are detached in various transfer modes such as the globular, spray and short circuit modes depending on the welding condition such as the shielding gas composition, welding current and voltage.[10]

In order to calculate the metal transfer different analytical and mathematical model has been used. Typically, the static force balance model and pinch in stability theory are very common for the gobbler and spray transfer mode respectively. Static force balance model has been utilized to calculate the detaching drop size in the globular mode, in which the drop diameter is greater than the wire diameter, and the maximum welding current is lower than the transition current.[10]

$$\mathbf{F_r = F_g + F_{em} + F_d} \qquad (1)$$

Surface tension force is

$$\mathbf{F_r = \pi D_w \gamma} \qquad (2)$$

Electromagnetic force is

$$\mathbf{F_{em} = \frac{\mu_o I^2}{4\pi}\left(\ln(\alpha \sin\theta) - \frac{1}{4} - \frac{1}{1-\cos\theta} + \frac{2}{(1+\cos\theta)^2}\ln\frac{2}{1+\cos\theta}\right), \alpha = \frac{D_a}{D_w}} \qquad (3)$$

Gravitational force is

$$\mathbf{F_g = \rho g V_a} \qquad (4)$$

Drag force is

$$\mathbf{F_d = \frac{1}{2} C_D A_P \rho_g U^2{}_p} \qquad (5)$$

Here γ is surface tension coefficient, D_w is wire diameter, μ_o = permeability in free space, θ = angle of arc covered surface, I = Amount of current, ρ = density of material, C_D = Coefficient of drag, A_P = Projected area, ρ_g = density of shielding gas, U_p= plasma velocity

The drop is detached if the detaching force of the gravity, drag force and electromagnetic forces becomes larger than the attaching force of the surface tension.[11]

A feature of the SFBM is the derivation of the axial electromagnetic force in the closed-form equation, which is a function of the current and geometries of the spherical drop and arc. However, a major disadvantage of the SFBM is that the difference between the Analytical results and experimental data increases with increase in the current intensity.[12]

2.5 Modified force balance model

Since the accuracy of static force balance model is limited for low range of current because of non-considering the taper formation during drop attachment and dynamic effect of drop oscillation. So static force balance model is modified by considering the effect of momentum flux, which is generated by the axial flow within the molten droplet. Momentum flux is derived as a function of current and drop geometry.

$$\mathbf{F_r = F_g + F_{em} + F_d + F_{mf}} \qquad (6)$$

Surface tension force is

$$\mathbf{F_r = \pi D_w \gamma} \qquad (7)$$

Electromagnetic force is

$$\mathbf{F_{em} = \frac{\mu_o I^2}{4\pi}\left(\ln(\alpha \sin\theta) - \frac{1}{4} - \frac{1}{1-\cos\theta} + \frac{2}{(1+\cos\theta)^2}\ln\frac{2}{1+\cos\theta}\right), \alpha = \frac{D_a}{D_w}} \qquad (8)$$

Gravitational force is

$$\mathbf{F_g = \rho g V_a} \qquad (9)$$

Drag force is

$$\mathbf{F_d = \frac{1}{2} C_D A_P \rho_g U^2{}_p} \qquad (10)$$

Here γ is surface tension coefficient, D_w is wire diameter, μ_o = permeability in free space, θ = angle of arc covered surface, I = Amount of current, ρ = density of material, C_D = Coefficient of drag, A_P = Projected area, ρ_g = Density of shielding gas, U_p= plasma velocity

Momentum flux force is

$$\mathbf{F_{mf} = \rho A_2 U^2{}_2 (1-\frac{U_1}{U_2})} \quad \textbf{(11)} \qquad \textbf{(11)}$$

A_2 = Area of planeP_2, U_2 = Velocity at planeP_2, U_1 = Velocity at plane P_1

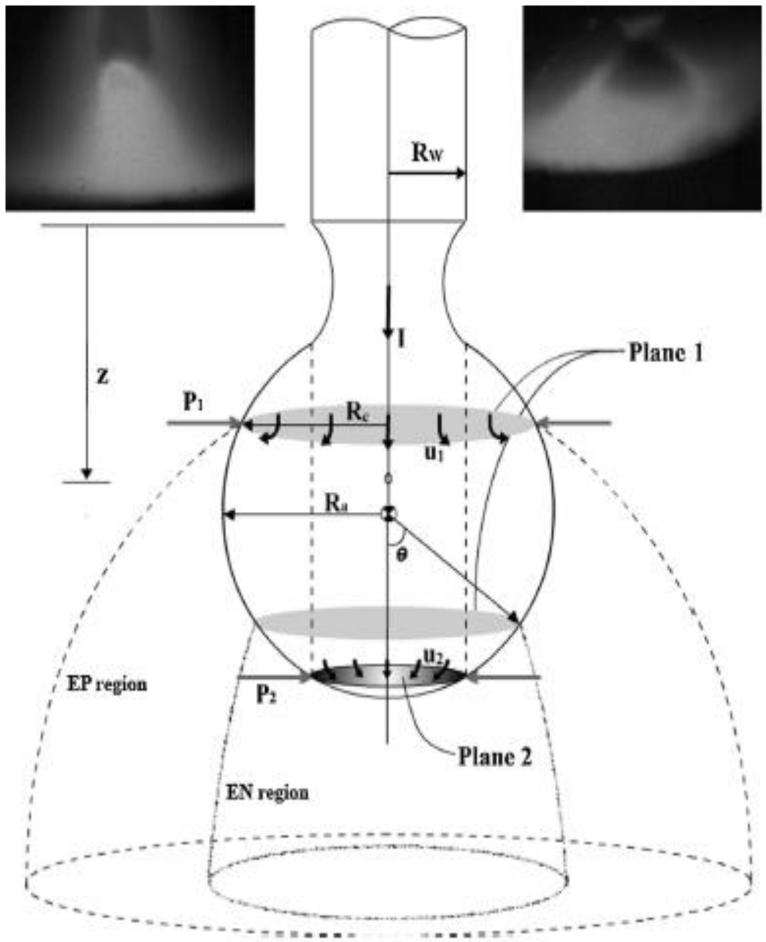

Figure 7 Schematic of pendant drop.

When the drop is detached with large size during the low range of current, the momentum flux has minor effect on the drop detachment But when the current intensity increase the detaching drop size decreases and the effect of momentum flux increase that is nearly equal to electromagnetic force, thus momentum flux has great influence on the drop detachment.[10]

Since the static force balance model used for low value of current to get the accuracy and modified force balance model used only for single shielding gas i.e. Pure Argon to calculate the forces effect on the droplet and detaching drop size. In this research, the objective is to optimize the welding parameters to minimize the post processing in gas metal arc welding and selection of optimal amount of blend of shielding gases for the welding process in pulse Gas metal arc welding. In this regard modified force balance model is used to calculate the drop detaching force and the hitting force with which the droplet falls in weld pool. The hitting velocity of the droplet is calculated by using equations of motion. This method is applied for calculating the forces and velocity by using pure argon shielding gas, 98% argon + 2% oxygen and Argon +

different percentage of carbon dioxide. After calculating these forces and Velocities the calculated result is verified with the experimental data.[13][8]

3 Chapter

3.1 Methodology

Modified Force balance model is used to calculate the forces acts on the molten droplet. According to the modified force balance model there are different types of force effect on the droplet when the current flow through the metal electrode. These forces are attaching and detaching force.

3.2 Surface Tension Force

Surface tension force is the force that responsible for holding the molten weld droplet to detach from the electrode tip. The surface tension force retain the droplet on the electrode behave as an attaching force of droplet towards the electrode. Mathematically,

$$\boldsymbol{F_r = \pi D_w \gamma}$$

Here γ is surface tension coefficient, D_w is wire or electrode diameter

3.3 Gravitational Force

The Force that attract any object with mass is call gravity force. Gravitational force assist the droplet to detach from the electrode tip. Because the molten droplet has some mass so it will tend to drop towards the weld pool. Mathematically,

$$\boldsymbol{F_g = \rho g V_a}$$

ρ = density of material, V_a = Volume of attach droplet, g = gravitational constant

3.4 Drag Force

In the Gas metal Arc welding to prevent the chemical reaction between the molten metal and atmosphere, a shielding gas is used and it is flown through the welding torch tip. This gas protect the droplet from the atmosphere and due to this flow of gas it will be effect on the droplet and push it to flow towards the weld pool, behave as a detaching force.

Mathematically,

$$\mathbf{F_d = \frac{1}{2} C_D A_P \rho_g U^2{}_p}$$

C_D = Coefficient of drag, A_P = Projected area, ρ_g = Density of shielding gas, U_p= plasma velocity

3.5 Electromagnetic Force

When the current flow through the electrode it produce the magnetic field due to that an electromagnetic force is generated due to that field and it is not only acted upon the electrode but also effect on the plasma and force the droplet to detach from the electrode. Mathematically,

$$F_{em} = \frac{\mu_o I^2}{4\pi}\left(\ln(\alpha sin\theta) - \frac{1}{4} - \frac{1}{1-cos\theta} + \frac{2}{(1+cos\theta)^2}\ln\frac{2}{1+cos\theta}\right),\ \alpha = \frac{D_a}{D_w}$$

μ_o = permeability in free space, θ = angle of arc covered surface, I = Amount of current,

3.6 Momentum flux force

When the current flow through the molten droplet electromagnetic force is generated in radial and axial direction the radial electromagnetic force generate an inward pinch pressure and induce axial flow within the molten droplet. Since the axial flow produce the momentum flux that is to be calculated as

$$F_{mf} = \rho A_2 {U^2}_2 (1 - \frac{U_1}{U_2})$$

A_2 = Area of planeP_2, U_2 = Velocity at planeP_2, U_1 = Velocity at plane P_1

According to the MFBM when the current flow through the electrode the above discussed forces are effect on the droplet and droplet is detach when the detaching forces are greater than the attaching forces.

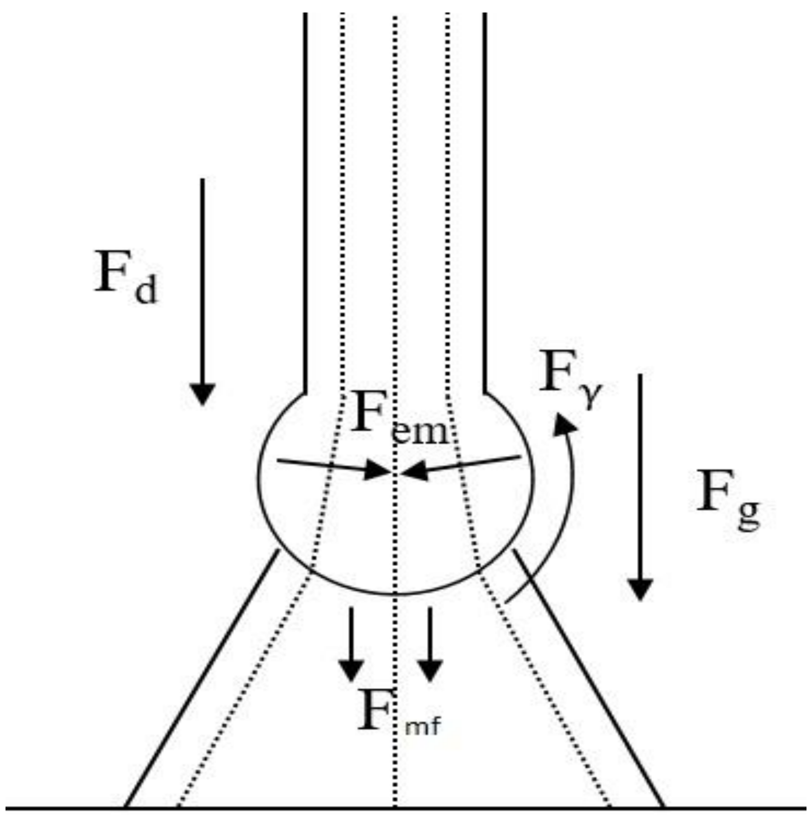

Figure 8 Forces on the detaching droplet

3.7 Static Force balance model

Metal transfer is the phenomenon of transferring the molten drop from the wire tip to the weld pool through the arc in gas metal arc welding (GMAW) and is important because it has significant effects on the weld quality and arc stability. Drops are detached in various transfer modes such as the globular, spray and short circuit modes depending on the welding condition such as the shielding gas composition, welding current and voltage.

In order to calculate the metal transfer different analytical and mathematical model has been used. Typically, the static force balance model and pinch in stability theory are very common for the gobbler and spray transfer mode respectively. Static force balance model has been utilized to calculate the detaching drop size in the globular mode, in which the drop diameter is greater than the wire diameter, and the maximum welding current is lower than the transition current.

$$\mathbf{F_r = F_g + F_{em} + F_d} \quad (12)$$

Surface tension force is

$$\mathbf{F_r = \pi D_w \gamma} \quad (13)$$

Electromagnetic force is

$$\mathbf{F_{em} = \frac{\mu_o I^2}{4\pi}\left(\ln(\alpha \sin\theta) - \frac{1}{4} - \frac{1}{1-\cos\theta} + \frac{2}{(1+\cos\theta)^2}\ln\frac{2}{1+\cos\theta}\right), \alpha = \frac{D_a}{D_w}} \quad (14)$$

Gravitational force is

$$\mathbf{F_g = \rho g V_a} \quad (15)$$

Drag force is

$$\mathbf{F_d = \frac{1}{2} C_D A_P \rho_g U^2{}_p} \quad (16)$$

Here γ is surface tension coefficient, D_w is wire diameter, μ_o = permeability in free space, θ = angle of arc covered surface, I = Amount of current, ρ = density of material, C_D = Coefficient of drag, A_P = Projected area, ρ_g = density of shielding gas, U_p= plasma velocity

The drop is detached if the detaching force of the gravity, drag force and electromagnetic forces becomes larger than the attaching force of the surface tension.

A feature of the SFBM is the derivation of the axial electromagnetic force in the closed-form equation, which is a function of the current and geometries of the spherical drop and arc. However, a major disadvantage of the SFBM is that the difference between the Analytical results and experimental data increases with increase in the current intensity.

3.8 Modified force balance model

Since the accuracy of static force balance model is limited for low range of current because of non-considering the taper formation during drop attachment and dynamic effect of drop oscillation. So static force balance model is modified by considering the effect of momentum flux, which is generated by the axial flow within the molten droplet. Momentum flux is derived as a function of current and drop geometry.

$$\mathbf{F_r = F_g + F_{em} + F_d + F_{mf}} \quad (17)$$

Surface tension force is

$$\mathbf{F_r = \pi D_w \gamma} \quad (18)$$

Electromagnetic force is

$$\mathbf{F_{em} = \frac{\mu_o I^2}{4\pi}\left(\ln(\alpha \sin\theta) - \frac{1}{4} - \frac{1}{1-\cos\theta} + \frac{2}{(1+\cos\theta)^2}\ln\frac{2}{1+\cos\theta}\right), \alpha = \frac{D_a}{D_w}} \quad (19)$$

Gravitational force is

$$\mathbf{F_g = \rho g V_a} \quad (20)$$

Drag force is

$$\mathbf{F_d = \frac{1}{2} C_D A_P \rho_g {U^2}_p} \quad (21)$$

Here γ is surface tension coefficient, D_w is wire diameter, μ_o = permeability in free space, θ = angle of arc covered surface, I = Amount of current, ρ = density of material, C_D = Coefficient of drag, A_P = Projected area, ρ_g = Density of shielding gas, U_p= plasma velocity

Momentum flux force is

$$\mathbf{F_{mf} = \rho A_2 {U^2}_2 (1 - \frac{U_1}{U_2})} \quad \mathbf{(22)}$$

A_2 = Area of planeP_2, U_2 = Velocity at planeP_2, U_1 = Velocity at plane P_1

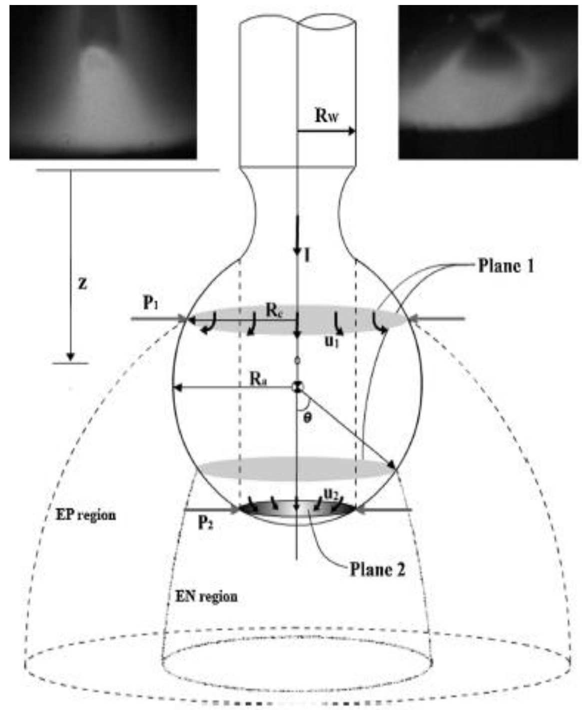

Figure 9 Schematic of pendant drop

When the drop is detached with large size during the low range of current, the momentum flux has minor effect on the drop detachment But when the current intensity increase the detaching drop size decreases and the effect of momentum flux increase that is nearly equal to electromagnetic force, thus momentum flux has great influence on the drop detachment.[10][14]

Since the static force balance model used for low value of current to get the accuracy and modified force balance model used only for single shielding gas i.e. Pure Argon to calculate the forces effect on the droplet and detaching drop size.[10] In this research, the objective is to optimize the welding parameters to minimize the post processing in gas metal arc welding and selection of optimal amount of blend of shielding gases for the welding process in pulse Gas metal arc welding. In this regard modified force balance model is used to calculate the drop detaching force and the hitting force with which the droplet falls in weld pool. The hitting velocity of the droplet is calculated by using equations of motion. This method is applied for calculating the forces and velocity by using pure argon shielding gas, 98% argon + 2% oxygen and Argon + different percentage of carbon dioxide. After calculating these forces and Velocities the calculated result is verified with the experimental data.

Modified force balance model is used to analyse the metal transfer in gas metal arc welding. Modified force balance model calculated the drop size more accurately by using pure argon shielding gas. Pure argon is an inert gas that did not react with the droplet during the application of heat. Compare with the other inert gases like helium its thermal conductivity is low, low ionization energy will results as finger like penetration profile associated with its used. Pure argon used for steel and other metal alloys.

Material Properties and Constants Used For Calculation	
Mass density, steel	7680 Kg m^{-3}
Al	2680 Kg m^{-3}
Surface tension coefficient, steel	1.2 N m^{-1}
Al	0.6 N m^{-1}
Permeability in space, μ_o	$4\pi*10^{-7}$ H m^{-1}
Drag coefficient, C_D	0.44
Density of Shielding gas, ρ_g	1.784 Kg m^{-3}

Table 2 Material properties For Pure Argon

By using the above material properties and constants we will calculate the forces effecting on the droplet. In these forces, the gravitational force, drag force, electromagnetic force and the momentum flux force act as the detaching force and surface tension force act as an attaching force. The pendent droplet is detached when the detaching force become equal to the attaching force, as for the electromagnetic force, it can be an attaching or detaching force depending on the arc-covered angle of a molten drop at the wire tip.

When argon or argon-rich gas is used for shielding, the arc tends to cover most of the drop surface so that the electromagnetic force becomes a detaching force due to the large arc-covered angle. When current flows through the molten drop, electromagnetic force is generated in the radial and axial direction, and the electromagnetic force, F_{em}, in the given equation represents the axial electromagnetic force. Since the radial electromagnetic force is symmetric, it is cancelled and does not contribute to metal transfer. However, the radial electromagnetic force generates an inward pinch pressure and induces axial flow within the molten drop. Since the axial flow produces the momentum flux, it is necessary to consider the effect of the momentum flux on metal transfer.

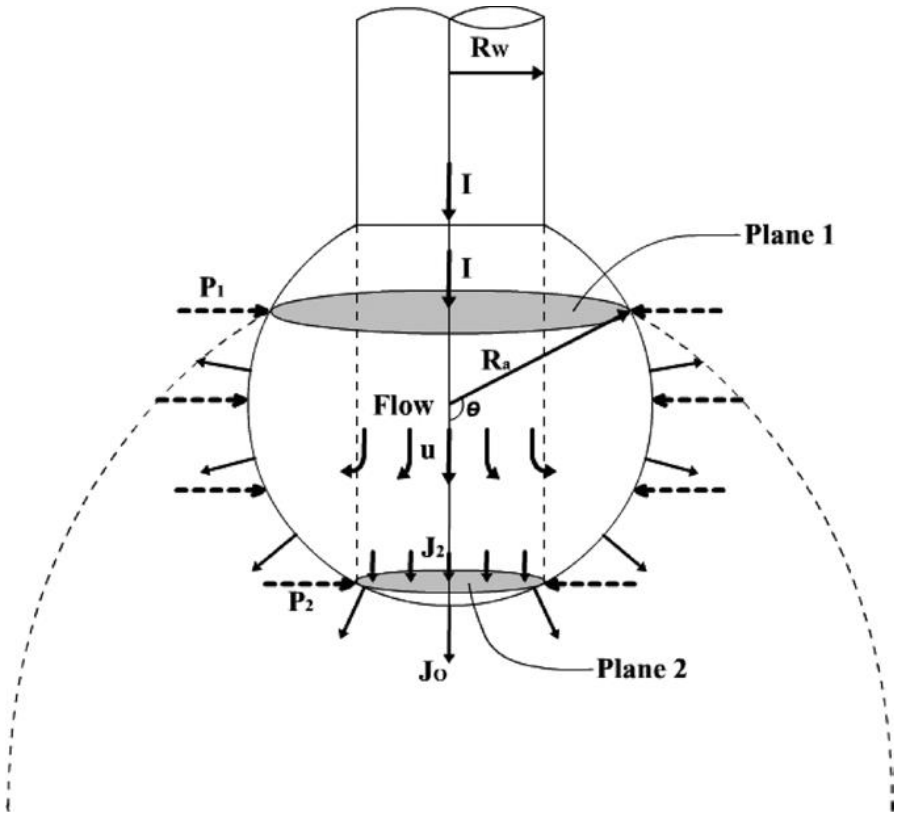

Figure 10 Schematic of momentum flux due to flow within molten

The flow of the molten metal is generated by the pinch pressure as illustrated in figure where plane 1 represents the circular cross-section at the boundary of the arc-covered surface, and plane 2 is the cross-section at the bottom of the drop having the same diameter as the wire diameter. Both planes have geometric features such that plane 1 is the interface of the arc-covered region that is also important for the electromagnetic force, and the diameter of plane 2 is equal to the wire diameter. Assumptions are made to derive the momentum: the drop is of spherical shape, the current density is constant on the drop surface and the flow velocity on plane 1 is negligible compared with the velocity on plane 2. Under these assumptions, the drop detaching condition of the MFBM can be rewritten by adding the momentum flux to the SFBM as

$$\boldsymbol{F_r} = \boldsymbol{F_g} + \boldsymbol{F_{em}} + \boldsymbol{F_d} + \boldsymbol{F_{mf}}$$

When the pendant drop diameter is given, the forces relating to metal transfer are calculated using the initial current. The current of drop detachment is determined by changing the current with a small increment until the drop detaching condition of equation is satisfied, and the detached drop diameter of the sphere is calculated using the pendant drop volume. When the droplet is detach suppose it has spherical shape and it will fall downwards in to the pool with some velocity. To calculate the velocity with which the droplet fall into the weld pool we use equations of motion.

$$V_{hit} = V_i + at$$

$$2aS = V^2{}_{hit} - V^2{}_i$$

$$S = V_i t + \frac{1}{2} a t^2$$

In the above equations V_{hit} is the velocity with which the droplet fall in the weld pool, V_i is the velocity at plane 2, where the diameter of droplet is equal to the wire diameter, a is the acceleration of gravity, t is the time frame with which the droplet travel from plan 2 to the weld pool and S is the distance covered by the droplet from contact tip to the work plate, sometime called arc length here it is the difference of contact tip to work distance and electrode extension with excluding the height of cone. For 1.2mm steel wire electrode it is 5.8030mm

In order to calculate the hitting force of the detached droplet, there are the gravitational, drag and detaching force with which the droplet fall in the weld pool is effected on the droplet. it is calculate as:

$$\boldsymbol{F_{hit} = F_{det} + F_v + F_d}$$

In the above equation F_{det} is the force with which droplet is detached from the electrode and F_v is the force of gravity due to the weight of droplet and F_d is the drag force. All these forces acted downward to fall the droplet in the weld pool

To calculate the experimental hitting force and velocity we use High speed imaging experimental system that is consist of welding system and optical acquisition system. The welding system consist of pulse gas metal arc welding system and optical system include high speed video camera, natural filter, interference filter of large bandwidth and camera lenses. Details description of setup is following:

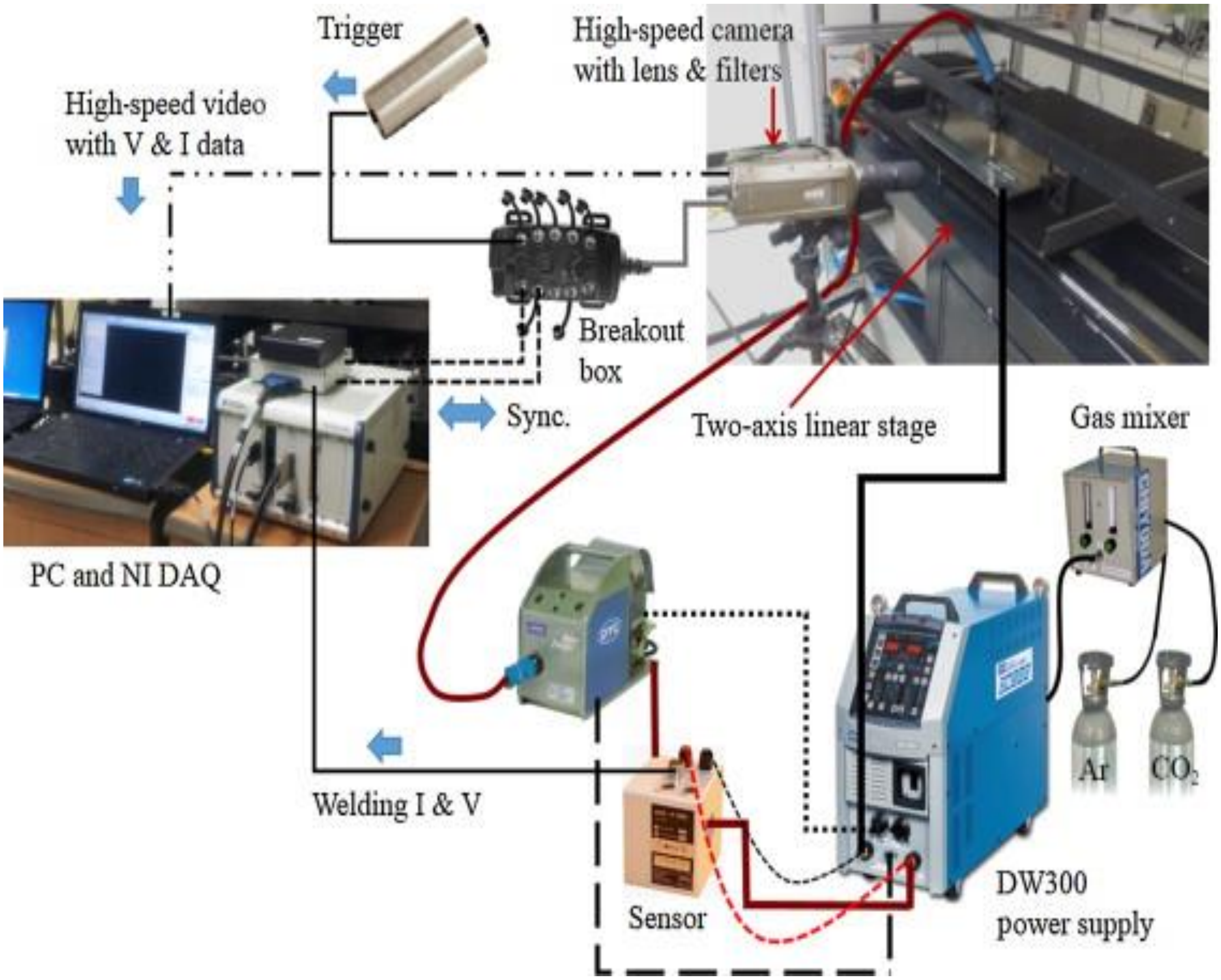

Figure 11 Detail Description of GMAW Setup

By using the above configuration of the experimental setup we can get experimental date. To obtained the experimental hitting velocity of droplet, angle of arc covered and distance covered by the droplet we us phantom camera control software, in which after the celebration we can calculated the experimental hitting velocity, distance covered by the detached droplet and arc covered angle of the detaching droplet.

3.9 Case-2 98%Argon + 2%O_2

Argon + oxygen blends get axial spray transfer at lower currents than other blends. The droplet sizes are smaller, and the weld pool is more fluid. The use of Ar + O_2 has historically been associated with high travel speed welding on thin materials. Both stainless steel and carbon steel benefit from the use of Ar + O_2 blends. The initial use of

Ar + O_2 blends for axial spray transfer mode on carbon steel employed 2% O_2. It is typically applied to applications that require high travel speed on sheet metal. Applied with either axial spray or pulsed spray transfer modes. Stainless deposits are dull gray in appearance. This blend is often used when superior mechanical properties are required from low alloy carbon steel electrodes. By using this blend of gas the properties of shielding gas is change as:

Material Properties and Constants Used For Calculation	
Mass density, steel	7680 Kg m^{-3}
Al	2680 Kg m^{-3}
Surface tension coefficient, steel	1.2 N m^{-1}
Al	0.6 N m^{-1}
Permeability in space, μ_o	$4\pi*10^{-7}$ H m^{-1}
Drag coefficient, C_D	0.44
Density of Shielding gas, ρ_g	1.7769 Kg m^{-3}

Table 3 Material Properties in case of Blend of shielding gases

Modified Force balance model is applied for the calculation of detaching and hitting for of the droplet and equations of motion is used for the calculation of hitting velocity of droplet similar as discussed above case.

3.10 Case-3 Argon + CO_2 Mixture

The most commonly used binary gas blends are that is used for carbon steel GMAW welding. They have also enjoyed success in pulsed GMAW applications on stainless steel where the CO2 does not exceed 4%. Axial spray transfer requires CO_2 contents less than 18%.

Ar + CO_2 combinations are preferred where millscale is an unavoidable welding condition. As the CO2 percentage increases, so does the tendency to increase heat input and risk burn through.

Ar + CO_2 blends up to 18% CO_2 support pulsed spray transfer. Short-circuiting transfer is a low heat input mode of metal transfer that can use Ar + CO_2 combinations. Optimally, these modes benefit from CO_2 levels greater than or equal to 20%. There are different combination used in our case it is shown in the table;

Percentage Amount of Shielding Gas	Maximum Current(A)
CO2 7%and Argon	200
	202
CO2 8%and Argon	140
	168
CO2 13%and Argon	196
	200
CO2 20%and Argon	190
	200
CO2 30%and Argon	200
	300
CO2 50%and Argon	170
	180
CO2 70%and Argon	166
CO2 75%and Argon	180

Table 4 Percentage variation of CO2 and Maximum current plot

Modified Force balance model is applied for the calculation of detaching and hitting for of the droplet and equations of motion is used for the calculation of hitting velocity of droplet similar as discussed above case. When the percentage of CO_2 increase then there is trend to increase the heat input to the work piece that is effect the properties of the material. So to get the good quality of weld it is important to use optimal amount of the blend of both gases.

4 Chapter (Results and discussions)

4.1 Results of Pure Argon Shielding Gas

Pure Argon shielding gas was used with the maximum welding current of 450A, 1.2mm steel electrode, 90^0 arc covered angle and flat welding position.

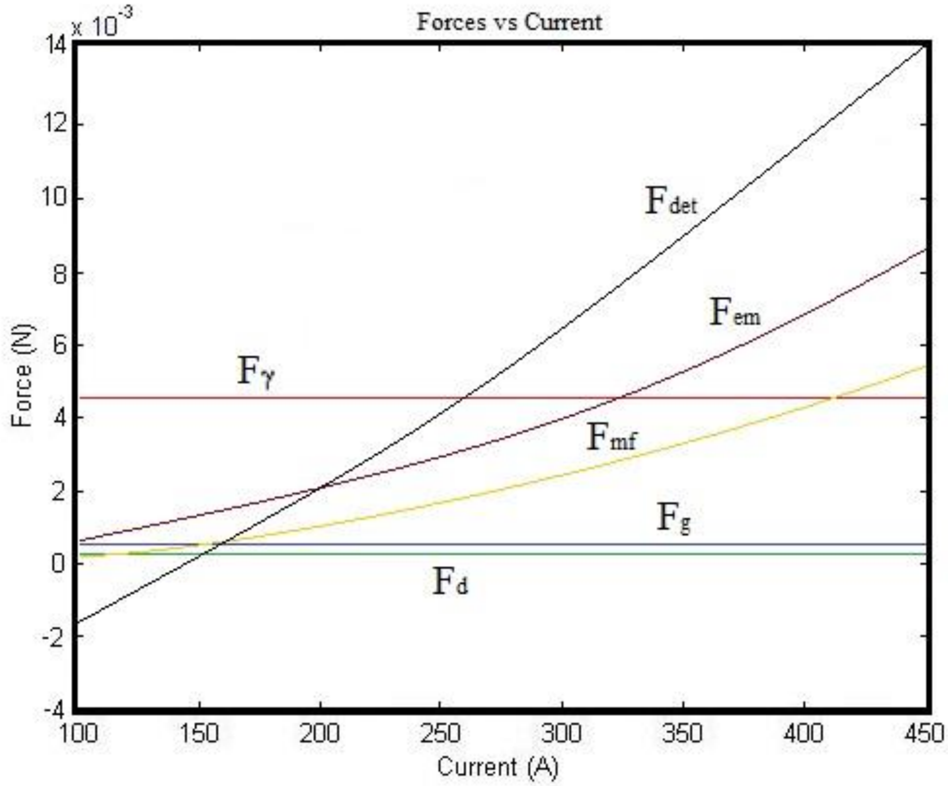

Figure 12 Behavior of different force due to applied current

Discussion:

From the above fig it is shows that when the current is 100A detaching force shows -1.8mN Force at that point the droplet did not detached with that force but due to large increase in the wire diameter of 1.9208mm the droplet is detached and when the current is in the range of 245A to 260A, the detaching force shows that its value is greater than the surface tension force and droplet detached solemnly due to the detaching force. Similarly when current intensity is low as 160A the effect of detaching force is nearly equal to zero but at the same time there is the effect of gravity and drag force due to the flow of shielding gas that will force the droplet to detach from the electrode wire.

4.2 Validation of Hitting Velocity

Force and hitting velocity is calculated and validated with the experimental results by using pure argon shielding gas with the maximum welding current of 450A, 1.2mm steel electrode, 90^0 arc covered angle and flat welding position.

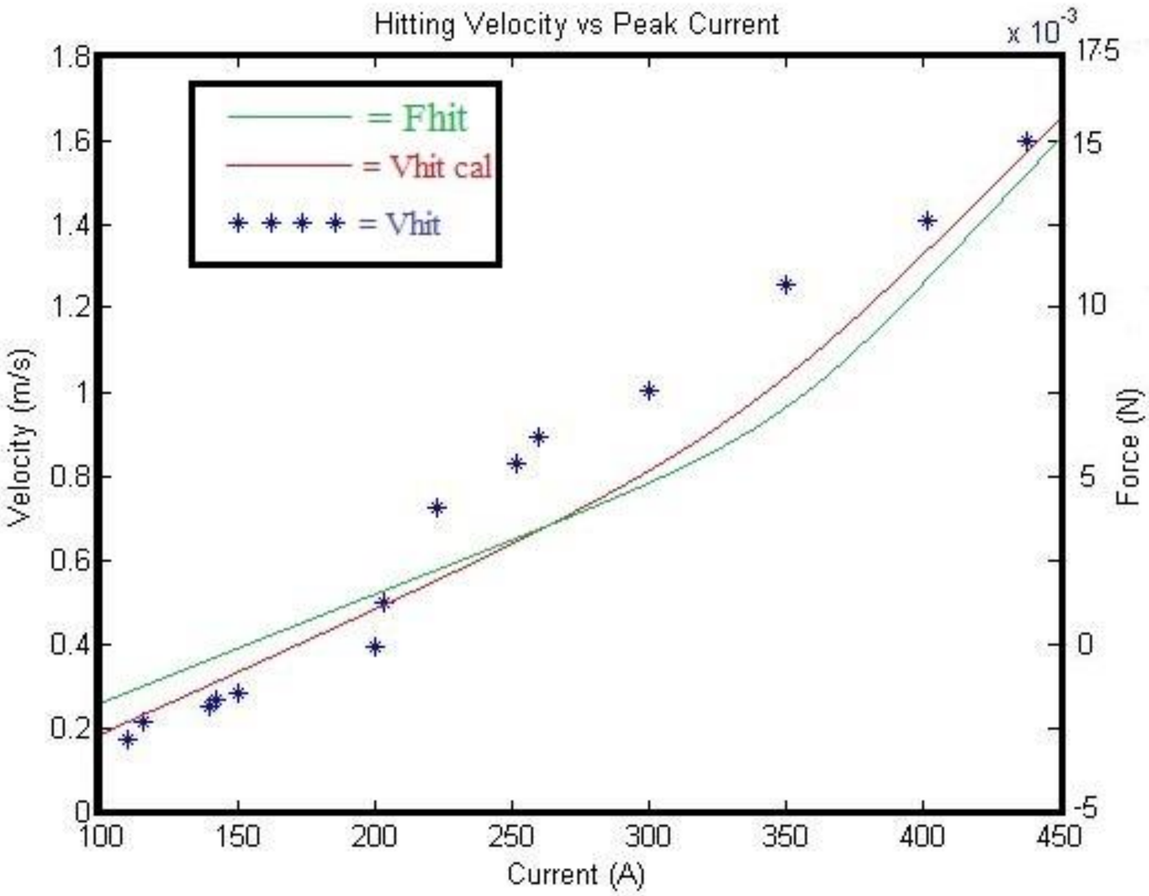

Figure 13 Theoretical and experimental Hitting velocity and force

Discussion:

In the above fig analytical hitting force and velocity is calculated and validate the result with the experimental date. When the current intensity is 100A the hitting force is -1.82mN and hitting velocity is 0.2503 as the current intensity increase the velocity and force both are increase. At the current range of 250A to 280A, velocity and force increase linearly at that point when current is 260A it will show one drop one pulse condition. This is the point of transition of current. At that point mode of globular transfer is switched towards the spray transfer.

4.3 Results of 98%Argon + 2%O_2 Shielding Gas

98%Argon + 2%O_2 shielding gas was used with the maximum welding current of 450A, 1.2mm steel electrode, 90° arc covered angle and flat welding position.

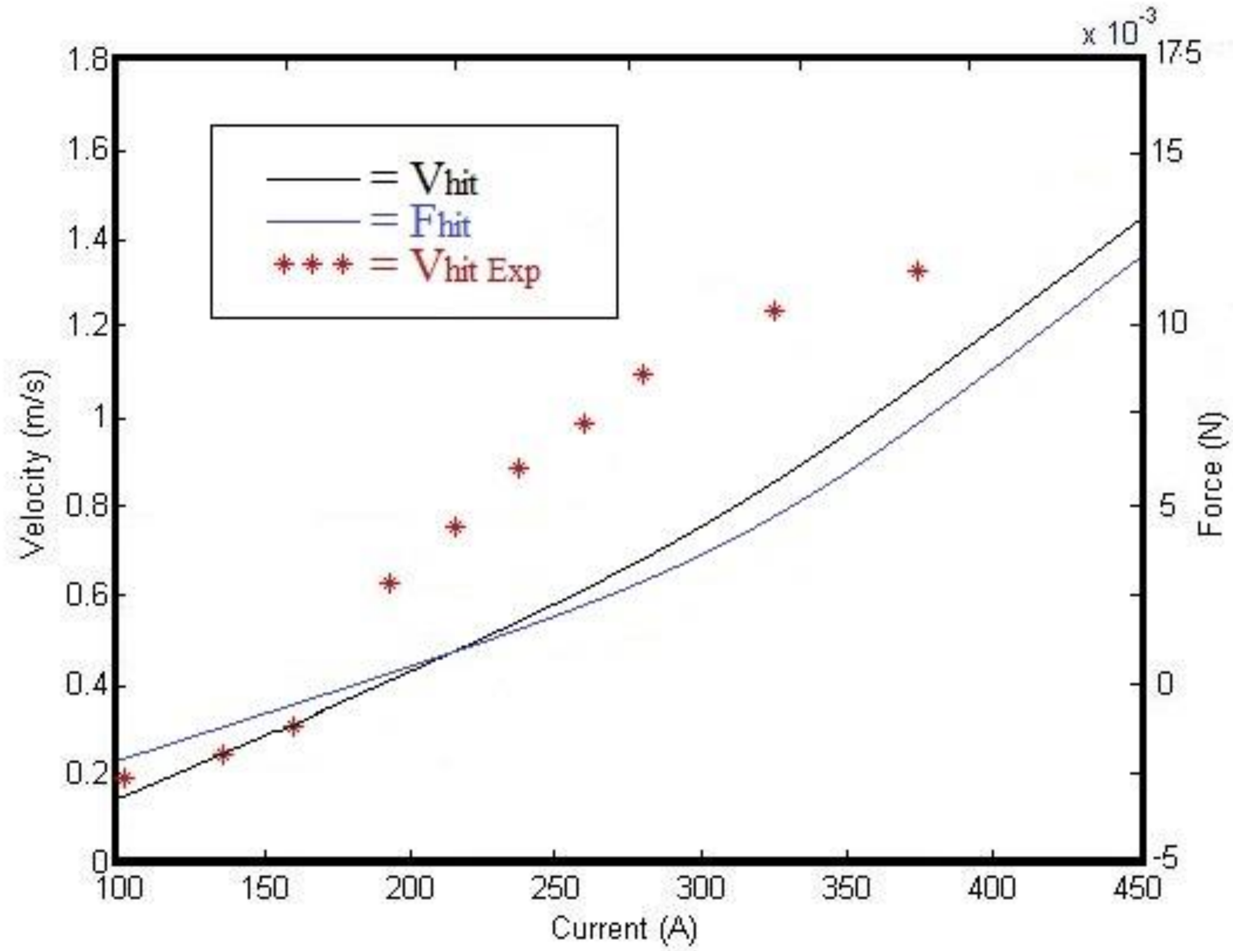

Figure 14 Analytical and Experimental hitting force and velocity

Discussion:

In the analytical hitting force and velocity is calculated and validate the result with the experimental date. When the current intensity is 110A the hitting force is -2.32mN and hitting velocity is 0.1853m/s as the current intensity increase the velocity and force both are increase. At the current range of 200A to 250A, velocity and force increase linearly at that point when current is 225A it will show one drop one pulse condition. This is the point of transition of current. At that point mode of globular transfer is converted towards the spray transfer. Addition of O_2 shielding gas with argon will tend to change the molten droplet detachment due to the formation of oxides, allow the droplet to detach more quickly due to this oxidation.

Comparison of hitting forces and velocities for both case, pure argon and argon and oxygen blend is shown in the figure. Here the maximum value of current is 450A and arc covered angle 90^o

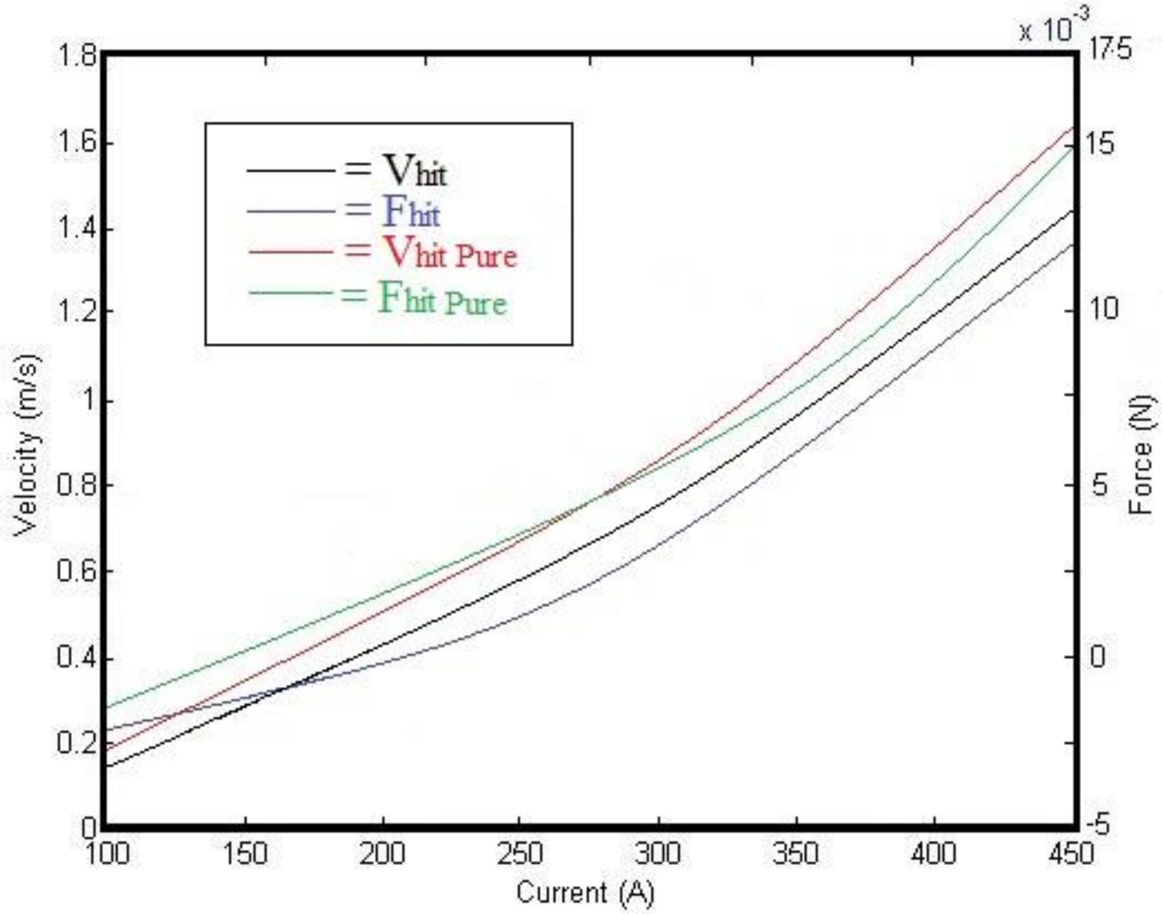

Figure 15 Comparison of forces and velocity for both cases

Discussion:

Comparison of hitting force and velocity in case of pure argon shielding gas and blend of shielding gases with O_2 is shown above. From plot it is shows that velocity of the pure argon case is more dominant as that of shielding gas mixture. When the current is 165A the hitting velocity is 0.3106m/s in case of mixture of argon with O_2 but similarly due to oxidation of the shielding gas with electrode tend to resist the droplet from detachment. So pure argon produce finger like penetration but addition of oxygen tend to shift the transition current value lower due to oxidation with the electrode in case of thin electrode.

4.4 Results of Argon + CO_2 Shielding Gas

Modified Force balance model is applied for the calculation of detaching and hitting for of the droplet and equations of motion is used for the calculation of hitting velocity of droplet. When the percentage of CO_2 increase then there is trend to increase the heat input to the work piece that is effect the properties of the material. So to get the good quality of weld it is important to use optimal amount of the blend of both gases. Different configuration of the mixture of gases with theoretical and experimental results are shown in the figure:

Percentage Amount of Shielding Gas	Maximum Current(A)	Calculated Velocity(m/s)	Experimental Velocity(m/s)
CO2 7%and Argon	200	0.6804	0.6631
	202	0.6855	0.6642
CO2 8%and Argon	140	0.5338	0.5220
	168	0.6001	0.5313
CO2 13%and Argon	196	0.6702	0.6439
	200	0.6807	0.6913
CO2 20%and Argon	190	0.6549	0.6590
	200	0.6829	0.7023
CO2 30%and Argon	200	0.6906	0.7357
	300	0.9483	1.0484
CO2 50%and Argon	170	0.6050	0.5697
	180	0.6298	0.6460
CO2 70%and Argon	166	0.5953	0.6198
CO2 75%and Argon	180	0.6301	0.6568

Figure 16 Experimental and analytical hitting velocity with different percentage of CO2

There is a tendency to increase the detaching force by increasing the value of current but at the same time there is a trend to increase the fluidity in the weld pool by increasing the percentage of CO_2. Experimental trend is shown as:

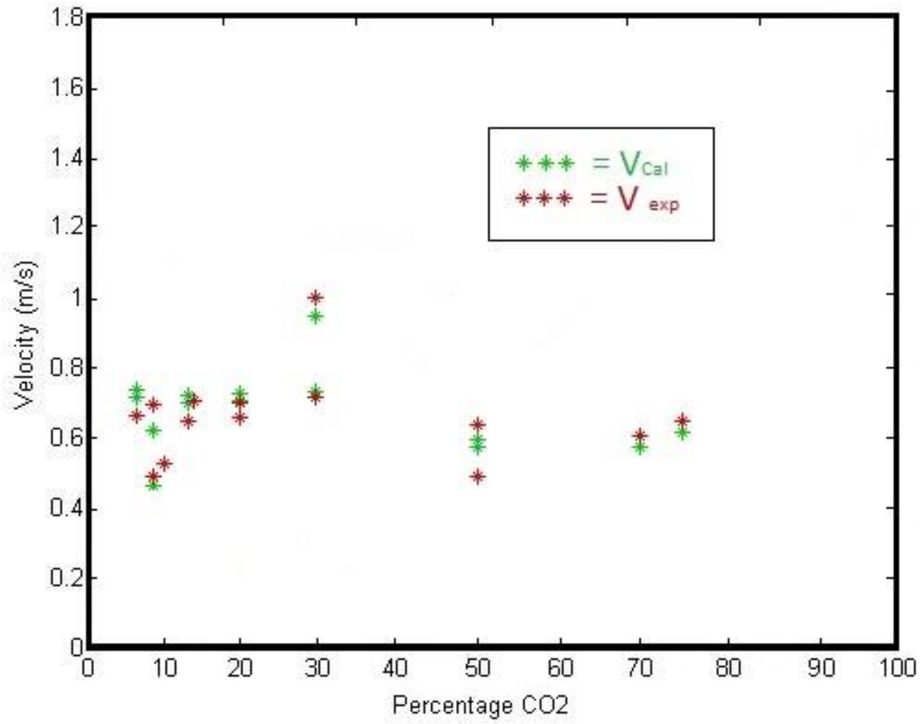

Figure 17 variation of Experimental and Analytical Velocity with different percentage of CO2

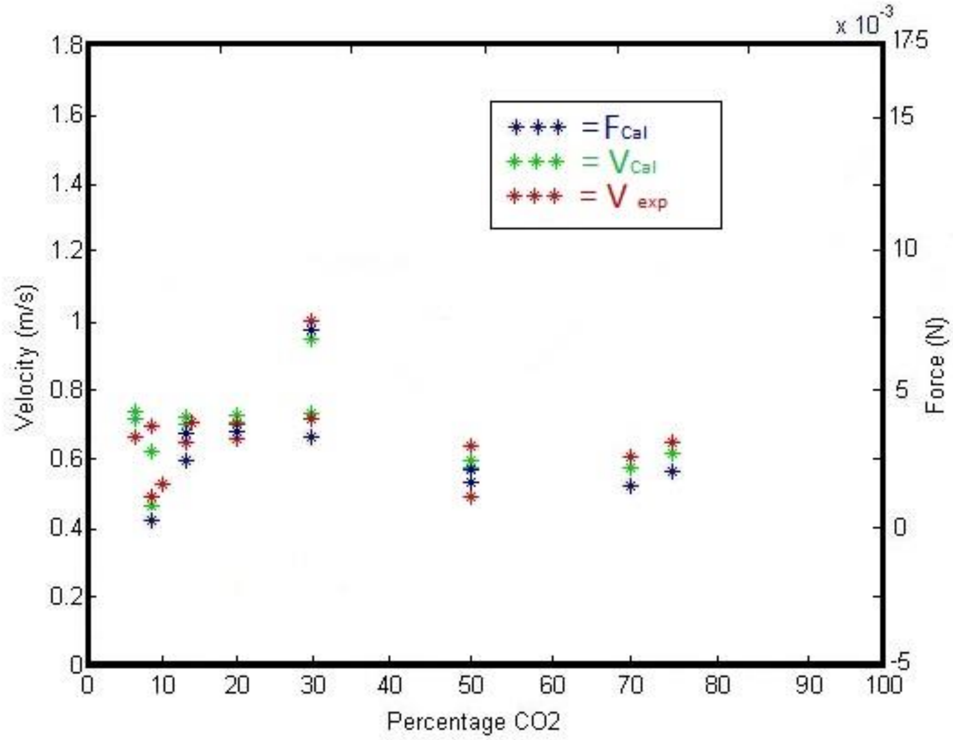

Figure 18 Variation of Hitting force and velocity with different percentage of CO2

5 Chapter
Conclusions

In this work, the influence of different shielding gas (Ar, O2 and CO2) compositions on the welding process and globular and spray transfer mode is studied. On the basis of results of current study following conclusions have been drawn.

Modified force balance model is suitable for calculating the drop detachment forces and force with which the droplet fall in the weld pool. It is applicable for high range of current 450A. Hitting velocity is calculated by using equations of motion was show the behavior of droplet by changing the welding current.

Effect of arc covered angle are observed by changing the arc covered angle for different shielding gases. In case of pure argon shielding gas arc covered angle is optimized at 90^o.

Thermal conductivity of Argon is low. Its energy required to give up an electron, ionization energy, is low, and this results in the finger-like penetration profile associated with its use. Argon favorable for axial spray transfer

In case of O_2, it is an oxidizer that reacts with components in the molten pool to form oxides. In small additions (1-5%), with a balance of argon, it provides good arc stability and excellent weld bead appearance. The use of deoxidizers within the chemistry of filler alloys compensates for the oxidizing effect of oxygen.

For the Ar+CO2 shielding gas mixtures, it is found that a small quantity of CO2 (3.3%) can make a great difference on the weld bead geometry. The influence of CO2 is reflected in two aspects, both of which contribute to a deep penetration and a large fusion area. Firstly, a certain amount of CO2 can also increase the arc voltage and the power of the welding arc.

More importantly, the presence of the surface active element, oxygen which is dissociated from CO2 can largely reduce the surface tension of the liquid metal. As a consequence, the temperature gradient of the surface tension can be changed from negative to positive and the direction of the Marangoni convection which is driven by the surface tension force will be changed from outward and upward to inward and downward. The efficiency of the heat transfer from the surface of the weld pool to the bottom can be enhanced.

References

[1] *Pulsed Gas Metal Arc Welding*. .

[2] J. Ashby *et al.*, *PHYSICS OF*. .

[3] Y.-S. Kim, “Metal transfer in gas metal arc welding.” 1989.

[4] A. G. Kimbrough, R. R. Rothermel, and D. P. Viri, “Gas metal arc welding system,” 1980.

[5] H. G. Fan and R. Kovacevic, “Droplet formation, detachment, and impingement on the molten pool in gas metal arc welding,” *Metall. Mater. Trans. B*, vol. 30, no. August, pp. 791–801, 1999.

[6] E. J. Soderstrom and P. F. Mendez, “Metal Transfer during GMAW with Thin Electrodes and Ar-CO 2,” *Weld. Res.*, vol. 87, no. May, pp. 124–133, 2008.

[7] E. B. F. Dos Santos, R. Pistor, and A. P. Gerlich, “Pulse profile and metal transfer in pulsed gas metal arc welding: droplet formation, detachment and velocity,” *Sci. Technol. Weld. Join.*, vol. 22, no. 7, pp. 627–641, 2017.

[8] M. Mousavi Anzehaee and M. Haeri, “Estimation and control of droplet size and frequency in projected spray mode of a gas metal arc welding (GMAW) process,” *ISA Trans.*, vol. 50, no. 3, pp. 409–418, 2011.

[9] J. ROBERTW. MESSLER, *Principles of Welding*. 1999.

[10] N. Arif, J. H. Lee, and C. D. Yoo, “Modelling of globular transfer considering momentum flux in GMAW,” *J. Phys. D. Appl. Phys.*, vol. 41, no. 19, p. 195503, 2008.

[11] Y. S. Kim and T. W. Eagar, “Analysis of Metal Transfer in Gas Metal Arc Welding,” *Weld. J.*, vol. 1, p. 269s–278s, 1993.

[12] J. I. Achebo, “Complex Behavior of Forces Influencing Molten Weld Metal Flow based on Static Force Balance Theory,” *Phys. Procedia*, vol. 25, pp. 317–324, 2012.

[13] Y. S. Kim and T. W. Eagar, “Modeling of Metal Transfer in Gas Metal Arc Welding,” *Edison Weld. Inst. Annu. North Am. Weld. Res. Semin.*, vol. 1, pp. 1–20, 1988.

[14] V. a Nemchinsky, “Size and shape of the liquid droplet at the molten tip of an

arc electrode," *J. Phys. D. Appl. Phys.*, vol. 27, no. 7, pp. 1433–1442, 1994.