DETERMINATION OF THE BEST FIT MODEL FOR BEAD CROSS-SECTION PROFILE DURING WELD-DEPOSITION

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I declare that this written submission represents my ideas in my own words, and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

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Approval Sheet

This thesis entitled "Analysis of the bead profile of the CMT weld" by Piyush Sharma is approved for the degree of Master of Technology from IIT Hyderabad.

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Dedicated to my Parents

Abstract

Weld deposition based Additive Manufacturing enables the capacity of fabricating fully dense components with low cost for rapid manufacturing. During the additive manufacturing of forming metal parts, the cross-sectional profile of a single weld bead is critical for improving the surface quality, dimensional accuracy. This work present the experimental study carried out to determine the best fit model to define the bead cross-section profile. The profile of the single bead was fitted by three curve functions, namely parabola, circular arc, and cosine function and the “accuracy” of the fit was determined based on regression coefficient. Both pulsed and CMT weld-deposition modes were analyzed to generate conditions for high and low penetration respectively.

Contents

Chapter 1

Introduction

1.1 Introduction

Rapid Manufacturing (RM), also referred as Additive Manufacturing, Layered Manufacturing and 3D Printing is the process of automatic manufacture of objects directly from their CAD models. RM applications for realising metallic objects employ laser, electron beam or arc as the sources of thermal energy for sintering/melting, in the order of their present popularity. Components manufactured through laser and electron beam can give high accuracy and surface finish, but are expensive and slower due to lower material deposition rates. Components manufactured through arc-based deposition techniques on the other hand are economical and faster, but give low surface finish and accuracy. Thus, finish machining is invariably necessary for components manufactured through arc-based deposition techniques. Depending on considerations like laser source, build environment etc., the accuracy of components manufactured through laser based processes may vary from 0.07mm (ProMetal ExOne) to 0.25mm (LENS MR-7). Finish machining is optionally carried out in some laser based systems with low accuracy, where the focus is on higher deposition rates. Integrating the near-net shaping and finish machining operations into a single machine can make these processes faster and economical. Lumex 25C, developed by Matsuura Machinery Corporation in Japan, 3D Welding and Milling, developed at Korea Institute of Science and Technology (KIST) are some examples of RM technologies combining material addition and subtraction into a single machine. Yasa et al. took this integration further by using the laser for both material deposition and erosion in Selective Laser Melting.

1.2 Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG)welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not use a shielding gas, but instead employs an electrode wire that is hollow and filled with flux.

For most of its applications gas metal arc welding is a fairly simple welding process to learn requiring no more than a week or two to master basic welding technique. Even when welding is performed by well-trained operators weld quality can fluctuate since it depends on a number of external factors. All GMAW is dangerous, though perhaps less so than some other welding methods, such as shielded metal arc welding.

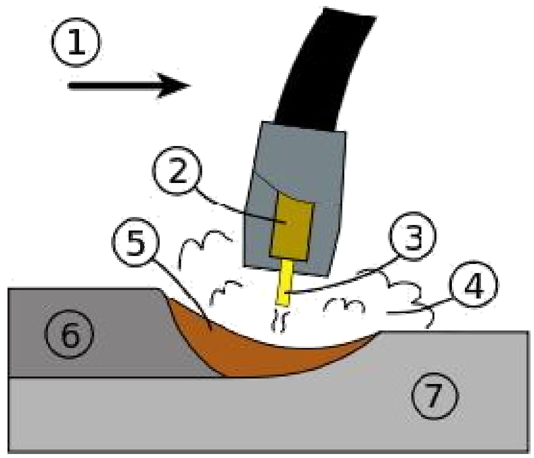

FIG 1.1GMAW weld area. (1) Direction of travel, (2) Contact tube, (3) Electrode, (4) Shielding gas, (5) Molten weld metal, (6) Solidified weld metal, (7) Workpiece [1]

The basic technique for GMAW is quite simple, since the electrode is fed automatically through the torch (head of tip). By contrast, in gas tungsten arc welding, the welder must handle a welding torch in one hand and a separate filler wire in the other, and in shielded metal arc welding, the operator must frequently chip off slag and change welding electrodes. GMAW requires only that the operator guide the welding gun with proper position and orientation along the area being welded.

Keeping a consistent contact tip-to-work distance (the *stick out* distance) is important, because a long stickout distance can cause the electrode to overheat and also wastes shielding gas. Stickout distance varies for different GMAW weld processes and applications. The orientation of the gun is also important—it should be held so as to bisect the angle between the workpieces; that is, at 45 degrees for a fillet weld and 90 degrees for welding a flat surface. The travel angle, or lead angle, is the angle of the torch with respect to the direction of travel, and it should generally remain approximately vertical. However, the desirable angle changes somewhat depending on the type of shielding gas used—with pure inert gases, the bottom of the torch is often slightly in front of the upper section, while the opposite is true when the welding atmosphere is carbon dioxide.

1.3 Cold Metal Transfer

There are material and application which cannot withstand the constant heat of welding process. In order to avoid poll drop through to be spatter free and to be amenable to metallurgical joining they need lower temperature. With CMT this is possible. CMT stands for Cold Metal Transfer. Of course, the term “cold” has to be understood in terms of a welding process. But when compared to the conventional MIG/MAG process CMT is indeed a cold process[1].Its characterstic features are hot, cold, hot, cold, hot, cold. This alternating hot cold treatment has been made possible by a new technological development from “Fronius” and above all, by incorporating the wire motions into the process control. “Fronius” is a company in Austria which has created this CMT welding process and further doing research and development in order to obtain not only a good weld but also enhancing the process capability beyond certain limits. CMT is used for thin sheets upto 3mm thick since metal deposition is less as compared to other process. CMT is an automated welding process based upon dip transfer welding characterized by controlled material deposition during short circuit of wire electrode to work piece [2].CMT exhibits high electrode melting coefficient in comparison to MIG PULSE or any other process[3].

CMT is a newly developed process which is still a going under lot of advancement and modification in order to obtain better control over the process. This process has brought a new revolution in the field of welding. It took near about 5 years of research by Fronius to achieve this milestone, a good thing about CMT is it can be combined with other processes like MIG, TIG, PULSE and other processes [3].

Fronius has also developed a new process under CMT i.e CMT Advanced in which alternating positive and negative process cycles can be set by the user as required. This modern joining method satisfies increasingly stringent demands,. some of the most important of which are process stability, reproducibility and cost-effectiveness [4].

Figure 1.2 CMT Machine [2]

The bundling together of specific material properties opens up a number of interesting possibilities. Material compounds impart to a component or product the desirable properties of the constituent. The main focus in this respect is on the joining of steel and aluminium, as this will be of particular interest to the automotive sector, where it could spawn a whole range of previously undreamt of innovations.

This shows that how the combination of both welding and automation has not only increased the feasibility of the process but also enhanced the workability. CMT overall is a simple to understand and learn, it is a package of welding under different circumstances in which important parameters like peneteration, deposition can be controlled.

The current work is totally based upon the welding process. Welding is a method used in our day today life in some way or the other. There are many applications of welding being used in our life every now and then. Welding has created a revolution not only in industries but also in the house hold applications so now it has become a primary tool of the manufacturing and the assembly unit. Welding is the joining of two similar or dissimilar metals by the use of heat and pressure. Welding assembly consist of a power source could be either AC or DC, electrode, base or parent metal, welding torch. Here the power source generates an arc which heats the base metal which in turn melts the electrode that acts as a filler material thus forming a puddle on the base metal which helps in joining the metals. The process parameters used in welding are the torch speed, current, voltage, arc length and the electrode extension.

The output result that we get after the setting of the parameters are the material deposition, weld width, penetration, dilution. These results depend upon the operating variable which in turn can be modified in order to get a good bead profile. So it is very important to analyse the bead geometry and structure since it could be helpful in getting the right parameter set of wire and torch speed. There are various types of welding which could be helpful in obtaining a good bead. Welding are classified under categories as solid state or liquid state. GMAW (MIG and MAG), SMAW (Submerged arc),TIG comes under Arc welding. Resistance welding, soldering, brazing comes under the category of the solid state welding.

Mechanical properties of the joint produced between the metals depend upon the process, filler metal, power requirement, travel speed. So it is very important to keep a watch if one parameter changes then the other parameter needs to changed in order to get the desired output as per the customer need

Chapter 2

Literature Survey

2.1 Advances in Welding Processes

This is the process in which is based upon droplet detachment in which the time of short circuit is controlled [10]. This process is further modified by varying the current which helps in maintaining the correct proportion of deposition rates and penetration [9].CMT(Cold Metal Transfer) welding results in welds with high levels of accuracy on thin-section materials usually reserved for TIG (tungsten inert gas) welding. And CMT welding may well be the way of the future [7].CMT welding technologies could overtake and dominate manual TIG welding in sheet-metal arc welding applications. The improved efficiencies available through CMT unlock a host of potential new applications for robots in markets that were previously dependent upon costly highly skilled labour. Until now sheet-metal product manufacturers have faced a choice between TIG or MIG(metal inert gas) welding for arc welding sheet metal [7].MIG welding has covered much of the market, while TIG welding is most commonly used for welding thin-section material. CMT is a good tool for overcoming the limitation of both MIG and TIG [11].

The wire movement is intergraded into the process. The wire moves alternately forward and backward. The droplet detachment and the arc resignation happens almost current less. The wire oscillation detaches the droplet mechanical once the wire moves backwards. The arc length and arc regulation is very precise due to the repeating short circulate and the defined backward movement of the wire. The arc length is adjusted mechanically. In conventional MIG welding the arc length regulation and the process measurement happens through the voltage, disadvantage is that the surfaces conditions and travel speed influence the voltage, whereas in CMT the arc length regulation and the process measurements happen mechanically.

Advantage is that the surface conditions and travel speed have no arc length influence [8].

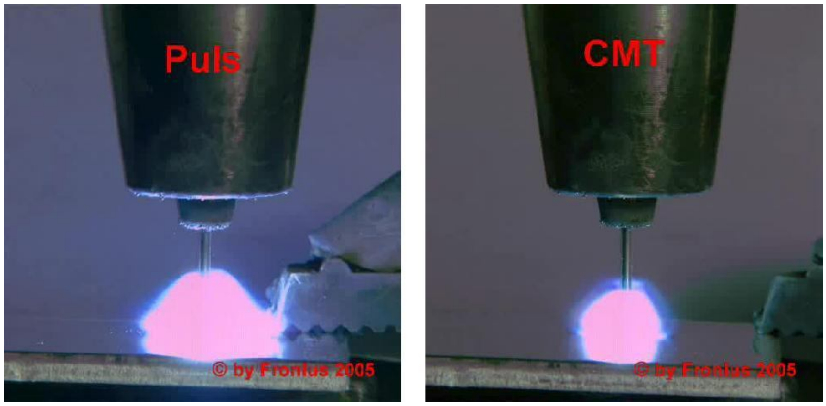

Fig 2.1 CMT Process Arc Regulation [4]

Figure 2.1 shows that how CMT process regulates arc at 81 amp and 11.2 volt and arc for pulse at 111 amp and 17.87 volts. Here in CMT we get precise arc length regulation, virtually spatter free, extremely high arc stability as compared to the conventional pulse welding. CMT requires lessamount of current and voltage in order to get a precise arc and takes less time too.CMT welding is carried out exclusively using digital inverter power sources. The welding system basically uses the same latest state-of-the-art hardware as a MIG/MAG system, while at the same time taking certain specific requirements into account.

Particularly noteworthy is the highly-dynamic wirefeeder mounted directly on the welding torch. The moment the power source detects a short circuit, the welding current drops and the filler wire starts to retract. Exactly one droplet is detached, with no spatter whatsoever. The filler wire then moves forwards again and the cycle is repeated. High frequency and extreme precision are the basic requirements for carefully controlled material transfer. The wire drive on the welding torch is designed for speed, not high tractive forces. The wire is therefore fed by a more powerful but, due to the above, slower main wirefeeder. A wire buffer on the wirefeeding hose is used to convert the superimposed, high-frequency wire movement into a linear wirefeed.

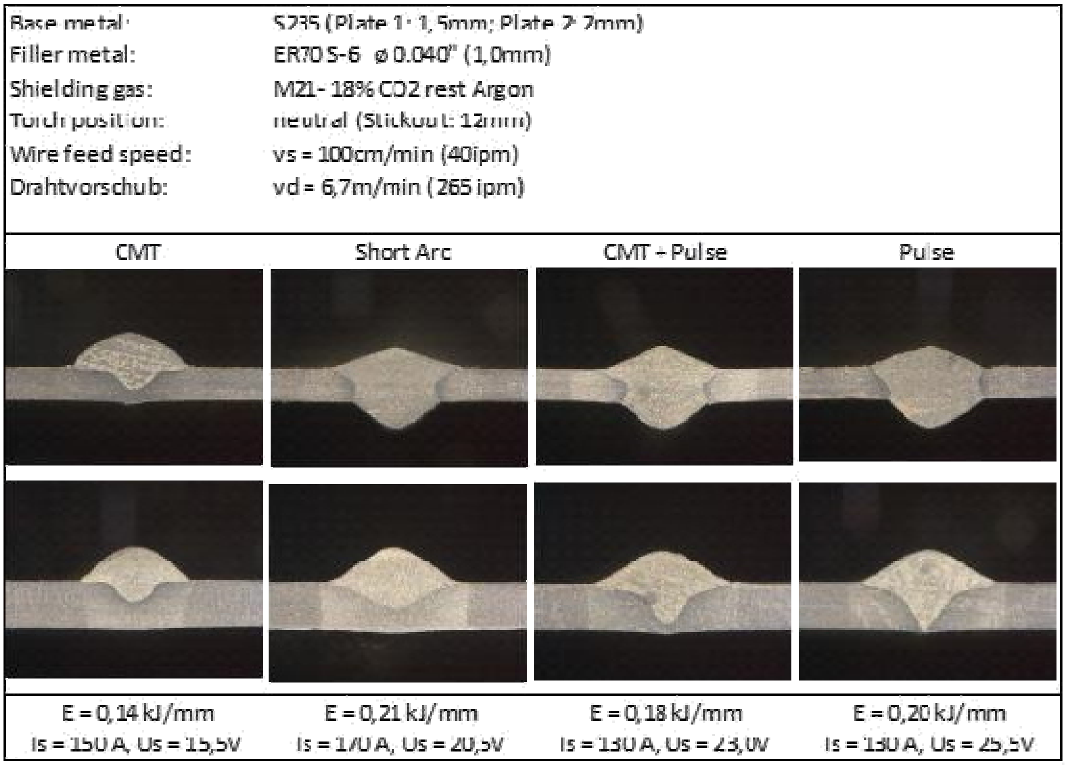

Fig 2.2:Comparison of weld shape in various processes in 1.5 and 2 mm thick steel plate[4]

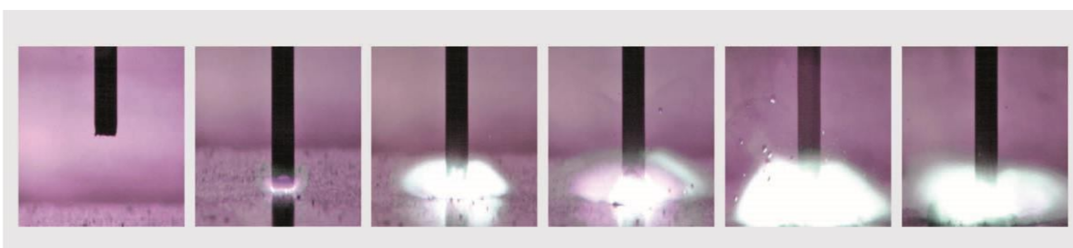

Figure 2.3 Ignition in other process[4]

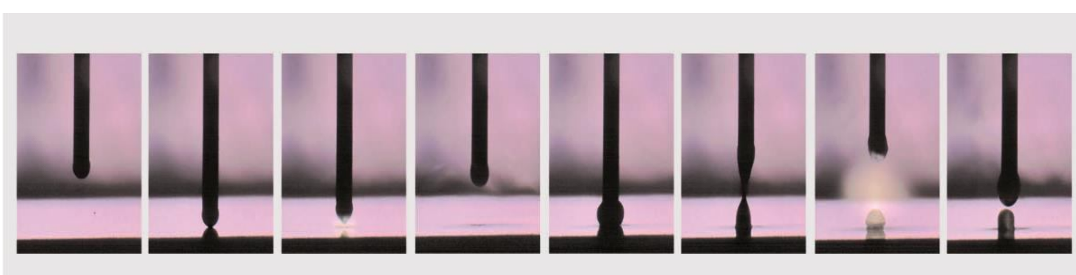

Figure 2.4 Ignition in CMT[4]

The limitation of the pure CMT process is the beginning of the globular arc. The minimum power range is limited on the seam cosmetic. The CMT + Pulse process can reach the area of the Pulsed arc. The ignition on conventional machines happens through a short circuit. Once the wire touches the work piece an arc gets ignited. For such an ignition a high current peak is required. This causes spatter due to the high arc pressure.

CMT uses the SFI (Spatter Fee Ignition) technology. The SFI technology doesn´t require a high current since no short circuit happens due to the wire movement. The result is a smooth, fast and spatter free ignition.

2.2 CMT Process

The process of CMT is a simple and based upon the droplet detachment process. It takes place in four steps:

1. During the arcing period, the filler metal is moved towards the weld pool.
2. When the filler metal dips into the weld-pool, the arc is extinguished. The welding current is lowered.
3. The rearward movement of the wire assists droplet detachment during the short circuit. The short-circuit current is kept small.
4. The wire motion is reversed and the process begins all over again.

CMT utilizes an innovative wire feed system integerated to high speed digital control in order to control not only the arc length during welding but also the method of material transfer and the amount of thermal input transfer to workpiece[2].CMT process control both the material transfer and both the initiation and duration of short circuit mechanically by feeding the wire electrode forward into the weld pool then retracting after a defined duration. By incorporating this mechanical process into electrical process control, the point of short circuit can be detected.

2.2.1 Principle of Operation

The basic operation mode of CMT is characterised by an arcing phase during which a molten droplet is formed on the end of the wire electrode and a weld pool created. After a set duration the wire electrode is fed forward to make contact with the weld pool / base material creating a short circuit. During this phase material transfer is initiated and the arcing current substantially reduced. After a defined period the electrode is mechanically retracted, this rearward motion aiding in pinching the molten globule into the weld pool [6].

The arc is then reignited and the cycle repeats. The process is unique in that not only is deposition controlled by the forward and rearward motion of the electrode, the electrical characteristics are also controlled with the result that material transfer takes place at both low current and low voltage. The joining of dissimilar materials requires precise knowledge of the properties of each material. Aluminium is highly regarded due to its low specific weight and its excellent usability and processing characteristics. On the other hand, its strength and low cost make steel indispensable in many areas of industry. [2]Other requirements primarily address anti-corrosion features, thermal expansion coefficient, and atomic properties. When joining steel and aluminium under the influence of heat, what is known as an intermetallic phase is created at the interface between the two materials. The more heat that is applied, the more extensive the intermetallic phase and the poorer the mechanical properties of the join will be. However, the chemical and physical properties also require appropriate measures to be taken. The different thermal expansion coefficients of the two materials create a stress field around the join.[4]There is also a marked tendency for corrosion to form as a result of the large electrochemical potential difference of steel compared with aluminium. All the technologies that have been used to join steel and aluminium in the past have only been able to deal with certain geometries or have required extensive control inputs. Although the perceived wisdom among many metallurgists was that steel and aluminium could not be welded together, extensive research in the field of MIG/MAG welding indicated that arc welding was indeed a potential way of joining the two materials [4].

The CMT process evolved from the continuous adaptation of the MIG/MAG process to resolve the problems posed by the joining of steel and aluminium. CMT is a controlled process and allows the material transfer to take place with barely any flow of current. The aluminium base material melts together with the aluminium filler material, with the melt wetting the galvanised steel. The filler wire is constantly retracted at very short intervals. The precisely defined retraction of the wire facilitates controlled droplet detachment to give a clean, spatter-free material transfer. The wire movement takes place at a very high frequency and requires a quick-response, gearless wire drive directly on the torch.

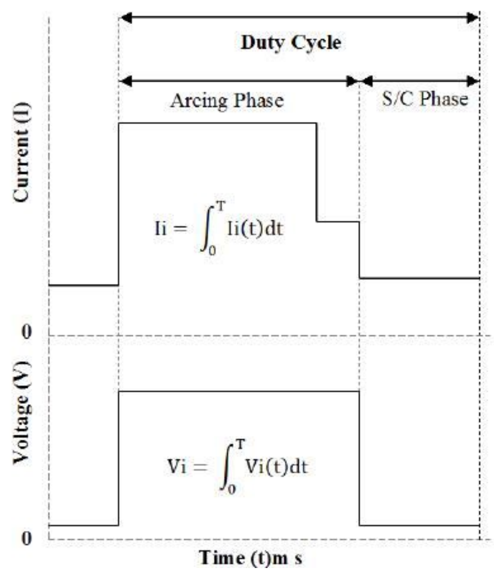

Figure 2.8 CMT Cycle Instantaneous Current And Voltage Values Based On Electrical Transients

Obviously the main wirefeeder will not be able to keep up with these movements. The wirefeeding hose is therefore provided with a wire buffer that compensates for the additional forward and backward movement of the wire. *Figure 1.4* given below shows how the current and voltage varies with the change of phase. In the beginning of the arcing phase current increases to a maximum and when it touches the weld pool there is a rapid decrease or the current gets lower and this low current shows the initiation of the short circuit phase after which further retraction

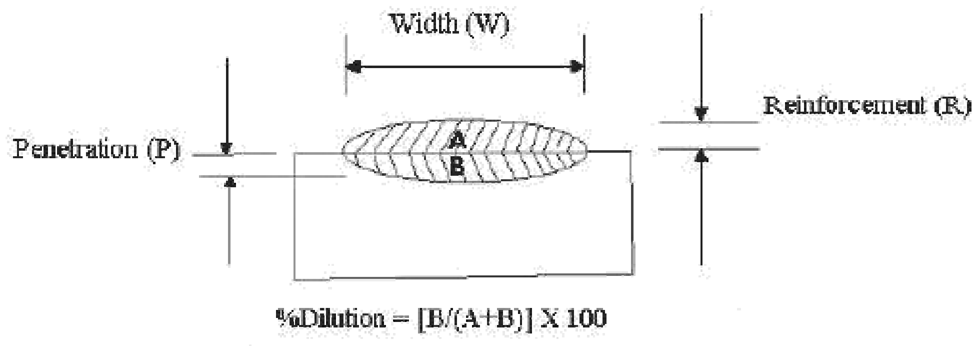

Figure 2.10 Bead Profile Parameters[20]

2.3 Geometric Modelling of Weld-Bead

Bead geometry includes bead height, width and penetration. These are important physical properties of a weldment. The bead cross-sectional area together with its height and width affects the total shrinkage, which determines largely the residual stresses and thus the distortion [27]. A number of welding process models exist that cover various aspects including the relationship between the welding process parameters and the bead geometry. Many research groups have used *Artificial Neural Networks (ANN)* models to predict the geometric parameters of the bead from the process parameters [27-29]. As their primary focus is on the joining applications, good fusion and fast joining are their major concerns. The penetration characteristics influence the former. In addition to the bead height and width, the area of the cross-section of the bead has been adequate for the latter.

Many researchers have explored the use of arc weld-deposition for the near-net manufacture of the objects till early 2000. The research groups of Dickens, Kovacevic, Printz and Song are some of the early contributors to this area [30-33]. Some of them have also considered the bead profile as it is important for the RM application. Aiyiti et. al., in their analysis using plasma arc welding have assumed the beads as overlapping circular arcs and arrived at the most desirable scan spacing (Figure 2.12 & 13) [34]. However, they have not accounted for the additional material in the overlapping zone. Some researchers including Chan et. al. have used the parabolic approximation for the cross-sectional profile [35]. These guided the assumption of parabolic bead profile in this thesis too. Furthermore, how the overlapping material is distributed is also explained in the present thesis.

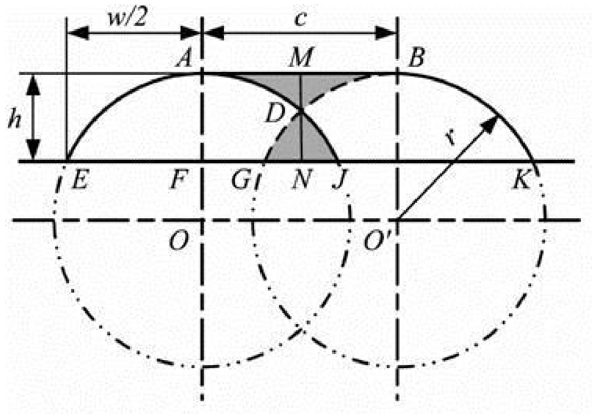

Figure 2.12 Bead overlapping model for MPAW [34]

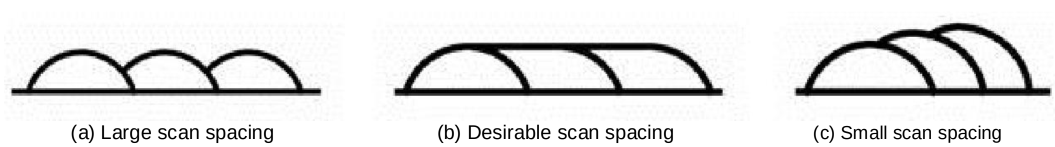

Figure 2.13 Overlapping for different scan spacing [34]

2.4. Motivation for the Current Work

Although many researchers have explored the geometry of the bead profile, a comprehsesive comparison of various alternative models was founf lacking. The current work discussed the work done to evaluate the best fit curve model for the weld-bead.

Chapter 3

Experimental Methodology

3.1 Experimental Setup

A CMT power source mounted on a bagometric table was used for the weld-deposition. The following are some of the control aspects of the CMT machine:

1. *TPS 3200 / 4000 / 5000 CMT power source:* Fully digitised, microprocessor-controlled and digitally regulated GMA inverter power source (320 /400 / 500 A) with an integral functional package for the CMT process.

2. *RCU 5000i remote-control unit:* Remote-control unit with full-text display, weld-data monitoring with Q-Master function, easy-to-follow user guidance, systematic menu structure, user administration features.

3. *FK 4000 R cooling unit:* Sturdy and dependable, ensures optimum cooling of water-cooled robot welding torches.

4. *Robot interface:* Suitable for all customary robots, irrespective of whether these are addressed digitally, in analogue or via field-bus

5. *VR 7000 CMT wirefeeder:* Digitally controlled wirefeeder for all common types of wirepack.

6. *Robacta Drive CMT:* Compact robot welding torch with digitally controlled, gearless, highly dynamic AC servo motor. For precision wirefeed and constant contact pressure.

7. *Wire buffer:* Decouples the two wire-drives from one another and provides additional storage capacity for the wire. Formounting on the balancer (preferably), or on the third axis of the robot.

8. *Wire supply*

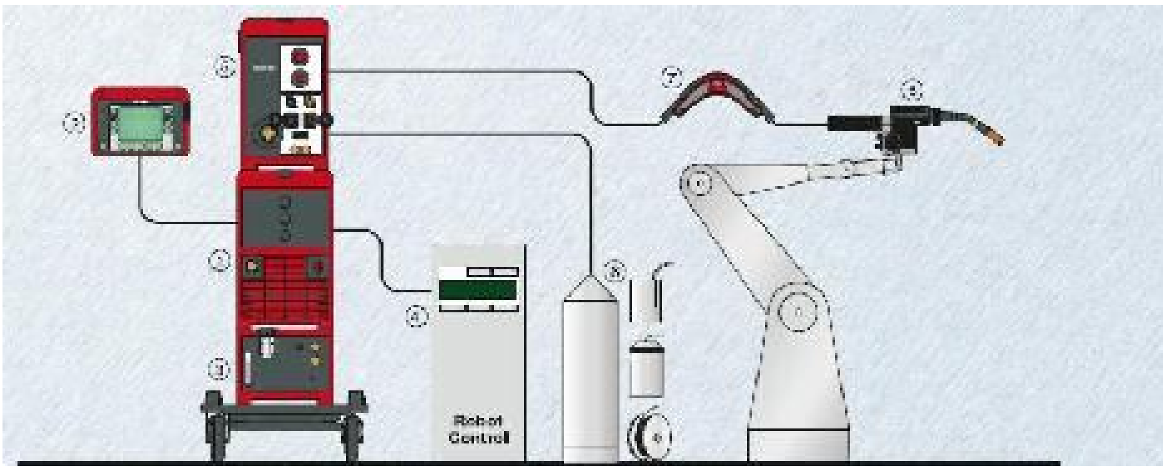

FIG 3.1 CMT Machine Setup [2]

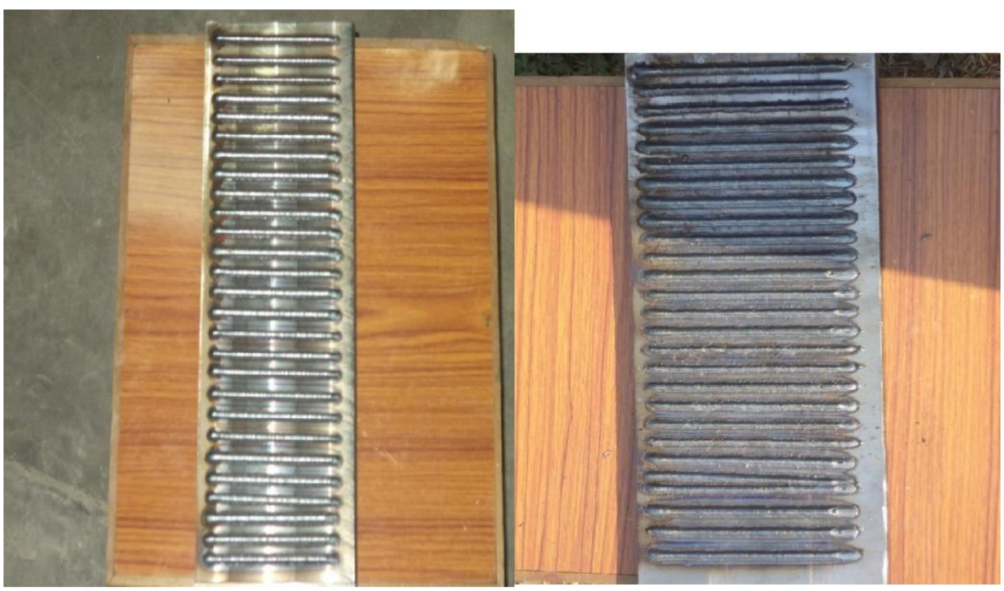

Figure 3.2 CMT and Pulse Beads

Table 3.1 Sets of Parameters	
Wire speed in m/min	Torch Speed in mm/min
7	500
7	700
7	900
9	500
9	700
9	900
11	500
11	700
11	900

Figure 3.3 Cross section profiles of CMT and Pulse beads

3.2 Experimental Methodology

A combination of three wire and torch speeds, as shown in Table 3.1 was used for the analysis. Each combination was repeated 3 times. The beads were then cut into thin section with the help of an EDM, as shown in Figure 3.3. The bead cross section was subsequently digitized with the help of a scanner and the various points on the surface noted and curve fitted (as explained in the subsequent section).

Chapter 4

Experimental Results

4.1 Results

The bead cross section was fitten to the following three forms of curves:

1. Parabolic $= (-)^2 +$
2. Circular Arc $= - \sqrt{\ ^2 - (-)^2}$
3. Cosine Function $= \cos$

The following tables 4.1 to 4.3 summarizes the results for the bead geometry and curve fit accuracy (presented in the form of correlation coefficient).

Table 4.1 Parabolic $= (-) +$

Wire speed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	CMT	4.57E-01	1.29E+01	-2.287	9.95E-01	8.51E-02
7	700	CMT	3.70E-01	6.87214	-1.6604	9.93E-01	7.82E-02
7	900	CMT	4.59E-01	7.05565	-1.36532	9.92E-01	7.14E-01
9	500	CMT	2.81E-01	9.9164	-2.1996	9.97E-01	5.99E-02
9	700	CMT	2.99E-01	8.62009	-1.8013	9.94E-01	7.29E-02
9	900	CMT	3.28E-01	8.4311	-1.60465	9.97E-01	5.13E-02
11	500	CMT	2.30E-01	9.6797	-2.2248	9.93E-01	9.99E-02
11	700	CMT	3.33E-01	9.9599	-1.33611	9.87E-01	8.61E-02
11	900	CMT	2.22E-01	8.800138	-1.9797	9.88E-01	1.15E-02

Table 4.2 Circular Arc = − √ − (−)

Wirespeed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	CMT	1.28E+01	-7.50E-02	2.05E+00	0.921124	8.51E-02
7	700	CMT	6.8571	0.48	2.071	0.916383	7.82E-02
7	900	CMT	7.0587	0.3764	1.6934	0.956071	7.14E-01
9	500	CMT	9.9352	0.651	2.7499	0.963034	5.99E-02
9	700	CMT	9.9352	0.651	2.7499	0.97896	7.29E-02
9	900	CMT	8.6168	0.7398	2.4651	0.99876	5.13E-02
11	500	CMT	9.6898	1.0277	3.1627	0.904308	9.99E-02
11	700	CMT	9.96E+00	0.7707	2.0757	0.920719	8.61E-02
11	900	CMT	8.8047	1.171	3.0981	0.918283	1.15E-02

Table 4.3 Cosine Function =

Wirespeed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	CMT	-1.90072	0.9742	0	1.0386	-1.90072
7	700	CMT	-1.7035	0.90071	0.66706	0.461709	-1.7035
7	900	CMT	-1.39607	0.889845	0.99388	0.059917	-1.39607
9	500	CMT	0.980847	0.93866	0	1.350158	0.980847
9	700	CMT	0.76054	1.08304	0	1.124705	0.76054
9	900	CMT	1.02779	1.1073	0	0.8852	1.02779
11	500	CMT	0.54892	0.9217	0	1.47104	0.54892
11	700	CMT	1.41211	0.941345	0.78995	0.3214	1.41211
11	900	CMT	0.327389	1.00347	0	1.29634	0.327389

Table 4.4 Parabolic = (−) +

Wire speed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	PULSE	3.12E-01	9.0756	-1.89234	9.92E-01	9.21E-02
7	700	PULSE	3.42E-01	7.08829	-1.69153	9.77E-01	1.47E-01
7	900	PULSE	3.50E-01	6.2099	-1.13938	9.73E-01	1.04E-01
9	500	PULSE	2.13E-01	7.7836	-2.15489	9.95E-01	8.35E-02
9	700	PULSE	1.73E-01	7.5934	-1.4743	9.62E-01	1.72E-01
9	900	PULSE	2.03E-01	8.3126	-1.4084	9.50E-01	1.80E-01

11	500	PULSE	2.08E-01	8.01045	-2.38864	1.08E-01	9.93E-01
11	700	PULSE	1.82E-01	7.71579	-1.86694	1.56E-01	9.77E-01
11	900	PULSE	1.92E-01	8.53071	-1.539	1.34E-01	9.79E-01

Table 4.5 Circular Arc = − √ − (−)

Wirespeed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	Pulse	9.069	0.5378	2.5724	0.961734	8.51E-02
7	700	Pulse	7.0744	0.4631	2.13	0.904084	7.82E-02
7	900	Pulse	6.2035	0.7084	1.8411	0.901066	7.14E-01
9	500	Pulse	7.7748	1.1968	3.2786	0.924743	5.99E-02
9	700	Pulse	7.5943	1.1968	3.2786	0.869775	7.29E-02
9	900	Pulse	8.3024	1.422	2.8613	0.899478	5.13E-02
11	500	Pulse	8.0176	1.1039	3.4256	0.941781	9.99E-02
11	700	Pulse	7.7221	1.614	3.4704	0.917557	8.61E-02
11	900	Pulse	8.5271	1.6581	3.1973	0.981334	1.15E-02

Table 4.6 Cosine Function =

Wirespeed	Torch Speed	Mode	a	b	c	Corr coeff	Error
7	500	PULSE	1.18684	1.02836	0	1.1052	-1.90072
7	700	PULSE	0.62476	1.28876	0	0.11428	-1.7035
7	900	PULSE	-1.25277	1.00453	0.87699	0.205805	-1.39607
9	500	PULSE	2.9432	1.007377	0	1.5287	0.980847
9	700	PULSE	2.93747	1.15275	0	1.03792	0.76054
9	900	PULSE	0.64801	1.08634	0	1.730449	1.02779
11	500	PULSE	0.447587	1.08565	0	1.100791	0.54892
11	700	PULSE	-1.06345	7.86344	0	1.100791	1.41211
11	900	PULSE	0.498241	1.08084	0	1.032941	0.327389

Chapter 5

Conclusion & Future Scope

5.1 Conclusions

A study of weld-bead geometry based on experiments was carried out. Two modes of welding were examined viz., pulse and CMT (with low penetration than conventional GMAW welds). The curve was analyzed for three different possibilities viz., parabola, circular arc and cosine curve.

It is observed that the curve is closer to a parabola at smaller torch speeds. But as the torch speed increases, it moves closer to cosine and arc. This may be due to the fact that when the torch moves at higher speed, the deposition is closer to cladding with lesser penetration.

5.2 Future Scope

The current study was limited to only torch speed and wire speed, considering both as independent variables. The interaction between the parameters was not considered. Also, the curve fitting at the corners was not accounted properly. A improved curve fitting model may be explored which accounts the corner fillets also.

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