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Investigation of functional and aesthetic quality of weld for different arc modes in CMT

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Abstract - *Gas metal arc welding (GMAW) is a fusion welding process, widely used to join both similar and dissimilar metals in automotive industries. The type and mode of arc welding can have an impact in weld quality. There are several modes of metal transfer in GMAW. These modes are combined with pioneering technologies like CMT (*Cold metal transfer) *to suit the welding requirements in industries. This work was carried out to study the effect of different arc modes available in Fronius CMT welding machine, to investigate and compare the different modes in terms of weld penetration, bead geometry and aesthetic appearance of weld bead. Three different metal transfer modes have been identified to conduct this study.*

The three modes considered are CMT, Pulse mode and CMT pulse mode. Assessment has been carried out with proven set of weld parameters i.e. Wire feed speed, current, voltage, shielding gas composition, gas flow rate and filler wire diameter. 4 mm thick low carbon steel material (S275) in square butt configuration were used to perform the study. CMT produced aesthetically good weld bead without any spatters whereas depth of penetration was limited. Pulse mode produced higher penetration than CMT due to higher arc pressure however aesthetic quality of the weld bead was compromised due to uneven weld bead and spatter formation. On the other hand, CMT pulse mode produced deep penetration with good aesthetic quality of weld bead. The combination of CMT and Pulse cycle in CMT pulse mode provided the benefits of both individual modes and eliminates the drawbacks of them. CMT pulse mode proved to be capable of producing welds with deep penetration and good aesthetic appeal comparable with CMT and pulse mode. Therefore, CMT pulse mode provides a good balance in terms of penetration requirement fulfilment and aesthetic appeal.

Key Words: GMAW; CMT; CMT pulse; pulse mode; weld bead geometry; depth of penetration; aesthetic quality

1. INTRODUCTION

In this competitive environment, automotive industries are keen produce products with superior quality. Especially in welded structure, achieving desired weld quality is utmost important to satisfy the design intent of the process. Even though GMAW process is being widely used in the industries, limited depth of penetration, high distortion, high fusion zone and heat affected zone area are the key limitations of conventional GMAW methods. This mainly caused by high heat input of this process. Therefore, industries are keen to implement low thermal input processes [1]. Cold metal transfer (CMT) is one of the emerging welding technology which offers desired weld quality at comparatively low thermal input than conventional GMAW methods [1]. Alternating thermal arc pool of CMT makes this process extremely cold i.e. arc pool is hot during an initiation of arc and cold once the arc is extinguished [1]. The minimum current of CMT arc is less than the regular dip arc transfer [1] as shown in Fig -1. Thus, droplet transfer is being carried out at extremely lower current than other conventional metal transfer mode [1], [2].

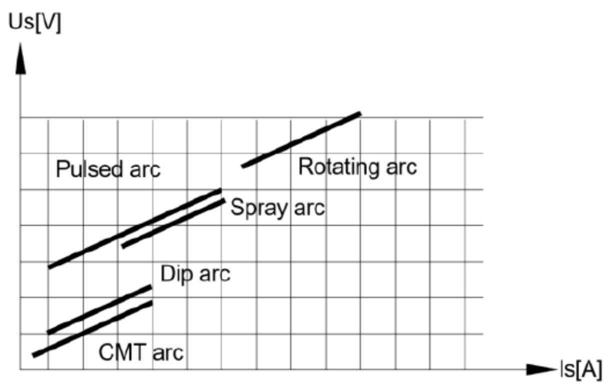


Fig -1 - Comparative of thermal inputs for various metal transfer processes [1]

The peculiar characteristic of CMT technology is a method of droplet detachment which is illustrated in Fig -2. Once the electrode tip makes an interaction with molten pool, the arc is extinguished and the wire is retracted by the digital process control [1], [3]. This retraction of wire leads to detachment of the droplet [1]. Therefore, droplet detachment is happening nearly at zero current [3] whereas in the conventional process it occurs at circuit phase which means at high thermal energy [4]. This unique droplet detachment leads to lower heat input, less spatters, and better aesthetic quality of the weld bead [4].

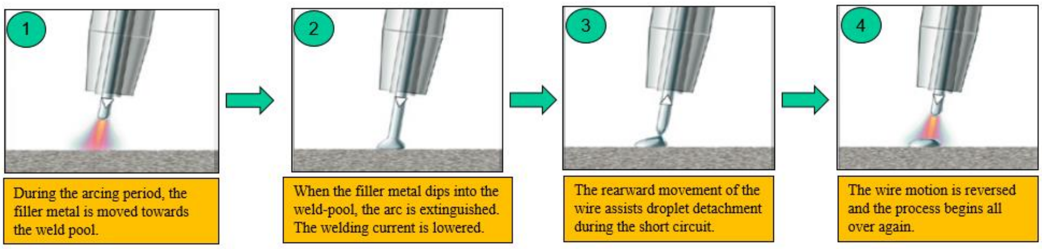


Fig -2: CMT welding process sequence [1]

Comparative study between CMT-GMAW and conventional synergic pulse was carried out by [5]. These two methods were evaluated for thin structural application by using S235 steel of 1.2 mm thick. Geometrical, metallurgical and mechanical characteristics of welds were analysed. They concluded that, CMT process can produce better weld beads than conventional process. Moreover, CMT process produced less fusion zone area, bead width and HAZ width than the other. Mechanical behaviour of both specimen were comparable. As the samples were welded with 0.4 mm gap both the processes has shown better gap bridgeability as well. Bead width and HAZ width of conventional process varied from 4.5 mm to 3.34 mm and 1.55 to 0.47 mm respectively whereas CMT produces 3.34 mm to 2.20 mm and 0.77 to 0.47 mm. Moreover, CMT process is more superior to conventional GMAW methods in the welding of thin structures at comparatively higher welding speed [2].

Also CMT provides spatter free welds with extremely good aesthetic welds [2]. Thus, CMT is successfully being used in automotive (KIA, Opel, Volkswagen, Ford, BMW and Volvo) and air traffic industries [2]. Low thermal input of this process also results in minimal distortion [6].

Synergic lines of CMT technology made this process more user-friendly. Moreover, it comprises of various arc modes such as CMT pulse, CMT advance, CMT pulse advance, and CMT dynamic [4] which can be employed depending on the requirement of weld quality. Compared with conventional pulse welding, CMT showed extensive benefits of less fusion zone area, bead width, HAZ width [5] and low distortion [6].

2. MATERIALS AND METHODS

2.1. Materials

Low carbon steel of S275 grade of base material and ER70S6 grade of filler material were used for the experimentation. The chemical composition and mechanical properties of both base material and filler wire were shown in

and Table -2 respectively.

Table -1: Chemical composition of base material and filler wire

Element	Base material	Filler wire
	% wt (S275)	% wt (ER70S6)
C	0.150	0.079
Si	0.030	0.940
Mn	0.790	1.670
P	0.014	0.011
S	0.002	0.020
Cr	0.010	0.039
Mo	0.000	0.010
Ni	0.000	0.013
Cu	0.010	0.011
V	0.002	0.006
Al	0.060	0.003
Nb	0.002	-
N	0.005	-
CE	**0.289**	**0.370**

Table -2: Mechanical properties of base material and filler wire

Element	Base material	Filler wire
	S275	**ER70S6**
Yield strength (N/mm^2)	329	538
Tensile strength (N/mm^2)	440	595

2.2. Experimental methods

Square butt joint configuration was used with zero root gap. 250 mm x 50 mm x 4 mm thick plates were used for the experimentation as shown in Fig -3. Edges of the specimen were machined for proper butting of plates. Clamping system used for the experimentation is shown in Fig -4. As prior to welding, plates were tack welded by using GTAW process. As complete penetration trails were planned, copper backing bar was used. Fronius Transpuls synergic 5000 CMT R welding machine was used for GMAW experimentation. Shielding gas composition of 80% of Ar + 20% of Co_2 with flow rate of 20 lpm was used.

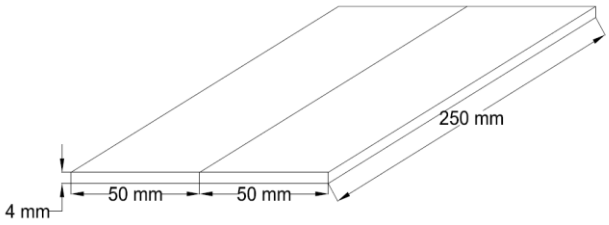


Fig -3: Joint configuration and specimen dimension

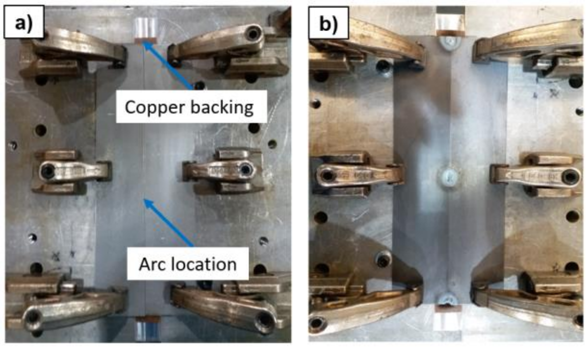


Fig -4: Substrate in a) Clamped condition b) Tack welded condition

Robot torch angle was set perpendicular to the substrate and contact tip to work distance (CTWD) was maintained as 11 mm throughout all the GMAW trials as shown in Fig -5.

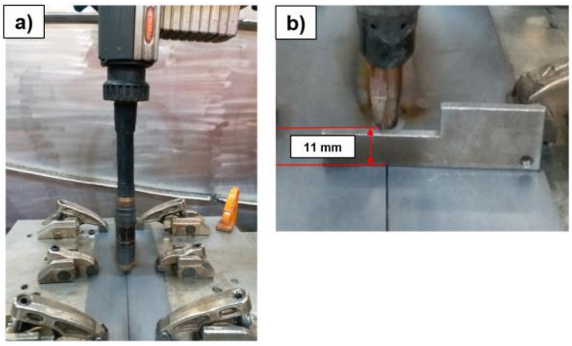


Fig -5: a) Torch angle used for the experimentation and b) CTWD

2.3 Equipment for arc characterization

AMV 4000 data logger was used to record waveform of arc current and arc voltage. The sample rate used for the accusation was 20 kHz. Waveform from the middle block was taken for heat input calculation. Heat input is calculated as a theoretical heat input which is the ratio between input power to welding speed [7] and the process efficiency factor was not included.

2.4 Process conditions

The critical process parameters used for the experimentation were listed in

Table -3. CMT pulse and pulse mode were welded at wire feed speed (WFS) of 13.6 m/min and travel speed (TS) of 0.5 m/min whereas CMT mode was used at WFS of 8.2 m/min and TS of 0.3 m/min. As CMT mode was limited to lower wire feed speed than the other two modes, travel speed was also reduced to maintain the same wire feed speed to travel speed ratio.

2.5 Preparation of samples

Prior to welding, samples were cleaned by acetone for the removal of surface contaminants. Specimen surface were free from oxide layers.

After welding, samples were cut perpendicular to the weld seam using abrasive cutting machine. Then cut samples were cold mounted to carryout grinding and polishing. After grinding and polishing, samples were etched with 2% nital solution for 10 sec. The macrostructure of the specimen were captured by stereo microscope of LEICA E23. Carl Zeiss Axio vision 4.6 image analysis software was used to measure the fusion zone area.

3. RESULTS AND DISCUSSION

The characteristics of CMT standard, CMT pulse mode and pulse mode have been compared in the aspects of weld penetration, bead geometry and aesthetic quality are presented in this section.

3.1 Comparative analysis in the aspect of weld penetration

At same wire feed speed to travel speed ratio, all three modes such as CMT pulse, pulse and CMT mode were compared in the aspect of weld penetration. Weld penetration achieved in CMT mode was 59% whereas both CMT pulse and pulse mode produced 99% and 100% weld penetration respectively. No weld defects were observed in all three samples in the macroscopic inspection. Higher arc pressure in pulse mode results in deeper penetration than CMT mode. Combination of CMT cycle and pulse cycle in CMT pulse mode results in deep penetration with controlled bead width and reinforcement. Macroscopic images of welds are shown in Fig -6.

Moreover, arc current and voltage of waveform of CMT, CMT pulse and pulse mode are shown in Fig -7 and Fig -8**Error! Reference source not found.** respectively.

Therefore, in the aspect of weld penetration both CMT pulse mode and pulse mode were produced deep penetration than CMT mode which indicates that both CMT pulse and pulse mode are suitable to weld higher thickness material whereas CMT mode is suitable for welding of thin structures.

Table -3: Critical process parameters used for the experimentation

Sample No.	Arc mode	WFS (m/min)	TS (m/min)	WFS/TS ratio	Heat input (J/mm)
G-1	CMT Pulse	13.6	0.5	27.2	805.26
G-2	Pulse	13.6	0.5	27.2	992.87
G-2	CMT	8.2	0.3	27.3	660.19
Filler wire diameter = 1 mm					

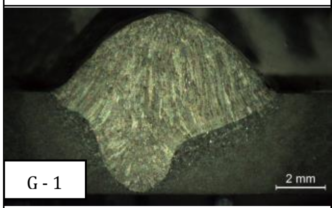
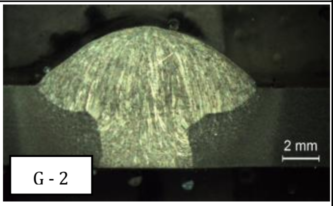
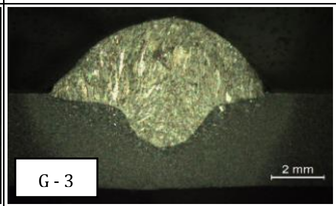
WFS = 13.6 m/min, TS = 0.5 m/min	WFS = 13.6 m/min, TS = 0.5 m/min	WFS = 8.2 m/min, TS = 0.3 m/min
CMT pulse mode	**Pulse mode**	**CMT mode**
		
Depth of fusion = 99%	Depth of fusion = 100%	Depth of fusion = 59%

Fig -6: Macrographs of welds

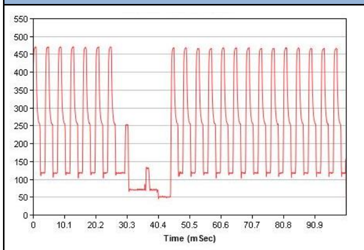
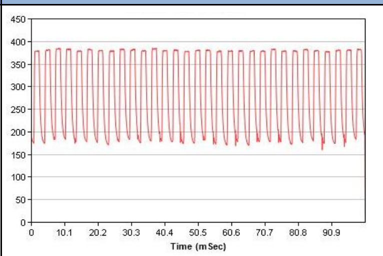
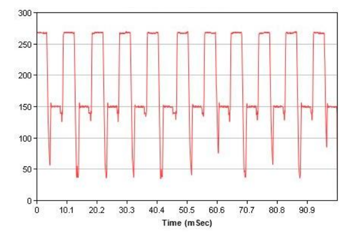
Arc current waveform in CMT pulse mode	Arc current waveform in Pulse mode	Arc current waveform in CMT mode
		

Fig -7: Arc current waveform of CMT pulse, pulse and CMT mode

Arc voltage waveform in CMT pulse mode	Arc voltage waveform in Pulse mode	Arc voltage waveform in CMT mode

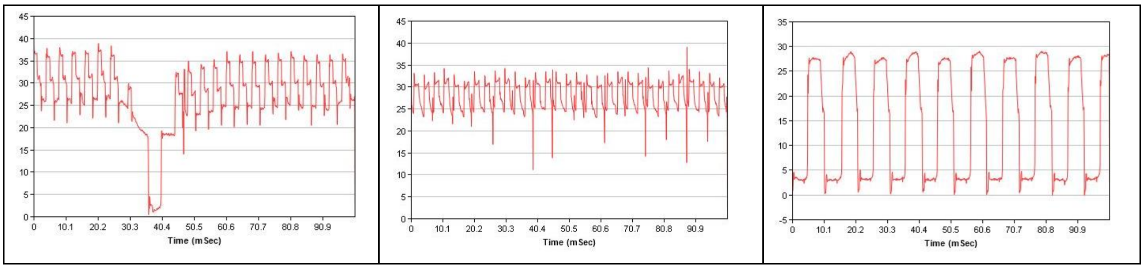


Fig -8: Arc voltage waveform of CMT pulse, pulse and CMT mode

3.2 Comparative analysis in the aspect of bead geometry

Compared with CMT mode both CMT pulse and pulse modes produced higher bead width and fusion zone area. This can be attributed to increase in heat input. Comparatively lower heat input of CMT mode results in lower penetration with less bead reinforcement and bead width than the other two modes. No significant change in bead reinforcement was observed whereas bead width was varied drastically as shown in Fig -9. Pulse mode was produced higher bead width and fusion zone area than the other two modes. Fig - 10 shows the comparison of fusion zone area produced by all three modes.

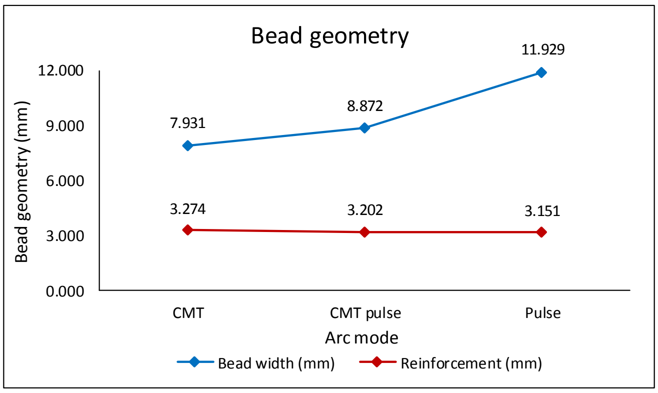


Fig -9: Comparison of bead geometry

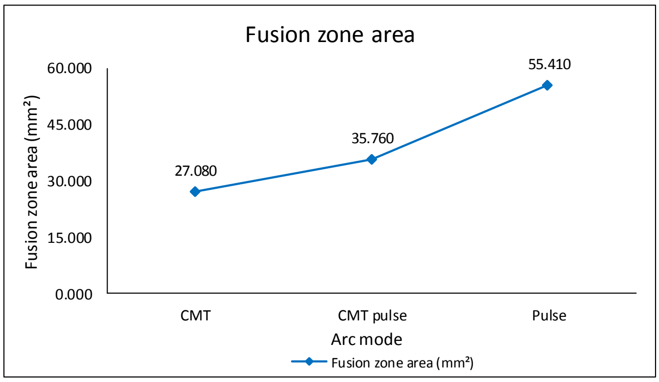
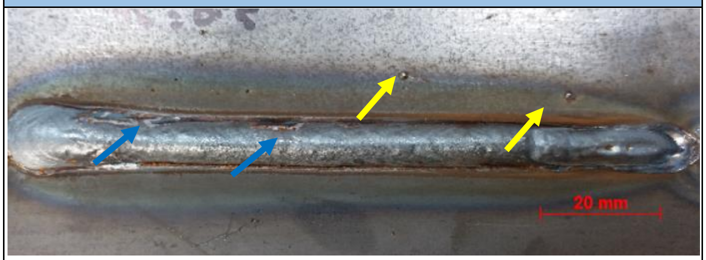


Fig -10: Comparison of fusion zone area

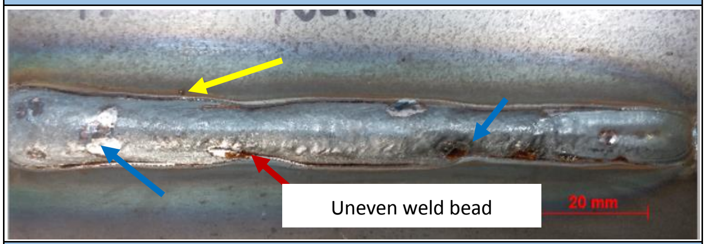
3.3 Comparative analysis in the aspect of aesthetic quality

Weld bead appearance quality of all three weld samples were compared as shown in Fig -11. Glass bead (Silica) formation was found in all three modes. However, intensity of glass bead was high in pulse mode. Moreover, pulse mode produced spatters whereas no spatters were observed in CMT mode. CMT pulse mode was also produced few spatters. Moreover, pulse mode produced uneven weld bead with high bead reinforcement whereas CMT pulse and CMT were produced uniform weld bead. Even though, pulse mode produced deep penetration than CMT mode, aesthetic quality of the weld was greatly compromised. Appearance quality of weld beads are compared in Fig -11. In that, glass bead and spatters are marked by blue and yellow arrows respectively.

CMT pulse mode



Pulse mode



CMT mode

Fig -11: Appearance of top weld bead

In the aspect of aesthetic quality CMT and CMT pulse mode were produced weld beads with better aesthetic quality than the pulse mode. CMT pulse mode was found to be more beneficial as it was provided deep penetration with better aesthetic quality.

4. CRITICAL DISCUSSION

Through this investigation, CMT, CMT pulse and pulse modes were compared in different aspects. Peculiar droplet transfer of CMT mode resulted in lower thermal input and controlled transfer of metal. This results in formation of precise and aesthetically good weld beads. However, CMT mode was limited to lower depth of penetration. Thus, CMT mode is suitable to weld thin structures. On the other hand, higher arc pressure in pulse mode results in deeper penetration than CMT mode. It produced complete penetration in 4 mm thick plate. Nevertheless, pulse mode was produced spatters and uneven weld bead at higher wire feed speed condition. Even though, it was produced complete penetration, aesthetic quality of the weld bead was greatly compromised.

Combination of CMT cycle and pulse cycle in CMT pulse mode combines the benefits of both individual mode and eliminates the drawbacks of them. CMT pulse mode was provided deep penetration with stable weld bead. Moreover, aesthetically good weld beads with less spatters were produced. Therefore, aesthetic quality of the weld was not compromised for the deep penetration. It can be inferred that CMT pulse mode can be used to weld thick structures to acquire better penetration along with good aesthetic quality.

5. CONCLUSIONS

- CMT mode is suitable for thin structures to acquire complete penetration with controlled bead geometry and aesthetically good weld bead with less fusion zone area. However, application of CMT mode is limited to thin structures due to the limitation on depth of penetration.
- Pulse mode was produced complete penetration in 4 mm thick plate however aesthetic quality of the weld was compromised due to spatters and uneven weld bead. Therefore, pulse mode is suitable to weld thick structures where aesthetic quality of the weld is least important.
- CMT Pulse mode was exhibited good result in welding of 4 mm thick sheet with notable penetration depth and stable weld bead with better aesthetic quality.
- Higher heat input of both CMT pulse and pulse mode were resulted in higher fusion zone area compared to CMT mode.
- Overall, CMT pulse mode is found to be an emerging synergic line to weld thick structures as it combines the benefits of both CMT mode and pulse mode also it eliminates the drawbacks of these modes.

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