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Applications and benefits of adaptive pulsed GMAW

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1. Introduction

Gas metal arc welding (GMAW) is acknowledged as a process that is both easy to operate outside workshops and very economical. However, innovations leading to a constantly growing number of new metals and issues with the stability of the arc have often posed major challenges for the process. For example in ship and offshore terminal construction, the welding condition is difficult, welded cross sections are thick and the number of welds very high. Reduction in the welding operation time improves productivity, decreasing the costs of the work force, and avoids excessive heat, preventing distortion and other weld defects. Innovations in the areas of feedback control, specific current and waveform shape, and highly responsive welding power sources have provided the GMAW process with an ability to adapt to irregularities in the weld zone and have made it possible to effectively regulate key parameters such as current, voltage, and flow gas, thus enabling optimization of process performance. The GMAW process key development has significaly improved robot welding [1] and combination with other processes such as laser welding [2].

State-of-the-art welding equipment integrates electronics and software, and these components allow the process to read the change in the weld area between the workpiece and the torch, and then make corrections to adjust important parameters to ensure optimum results [3]. Modified short circuiting transfer mode processes have been an important research topic in recent decades and have largely proven themselves as stable and efficient processes with lower heat input (Q) even when welding heat sensitive thin sheet sections and dissimilar materials [4]. Research is continuing to extend the applicability of the pulsed process. However, study has been limited, thus far, to a specific number of processes, such as synergic and self-regulation control, which itself dates from the 1970s, and little interest has been shown in study of the shape and combination of current and voltage waveforms[5].

The study presented in this paper describes the improvements that have been made to the basic pulsed GMAW process, reviews latest innovations, and compares adaptive GMAW processes, allowing differences in welding performance to be identified. In the empirical part of the study, three different processes; synergic GMAW, WiseFusion^{TM} and Synergic Pulsed GMAW are used to weld a T-Joint (horizontal position), structural steel (S355MC), thickness (5 mm). Data from this experiment are used for comparison of the performance of the processes, and the microstructure and mechanical characteristics of the joints.

The study is a base line of welding procedure specifications for the case of the adaptive pulsed GMAW process; benefits of control in terms of heat input reduction control, and profile and mechanical characteristics of the weld when welding structural steel are also identified.

2. Pulsed GMAW

In the past, there was little scope for process modification of the GMAW method. Notable exceptions were dual power source concepts for dip transfer and the early introduction of pulsed transfer GMAW using sinusoidal current pulses [6]. Pulsed GMAW (P-GMAW) provided additional control of the GMAW process by using a current waveform consisting of a low background level to maintain the arc and a superimposed pulse current to detach the material.

The objective of P-GMAW was to produce spray type projected transfer at mean currents below the spray transition threshold. The process gave good positional spray performance and was particularly beneficial in the welding of aluminium alloys and stainless steel [7, 8]. The main limitation of the P-GMAW process was the power source design constraint, which meant that pulse frequency was usually a multiple of mains frequency and the pulse profile and duration were dependent on the fixed power source design.

The introduction of solid state power control meant that power source statics, dynamics characteristics and output waveforms could be varied, for example, the relation between voltage and current under various fixed loads or changing load condition. Based on the early work of J. Ma [9] it became possible to produce drop spray transfer mode in a controllable and repeatable manner over a wide current range.

In recent decades, as a result of improvements in power source technology, a number of innovations have been successfully implemented and have dramatically improved the P-GMAW process. Structural steel has been added to the types of material weldable by P-GMAW. The pulsed parameters provide better control of the microstructure of the base and weld metal. For example, the microstructure and grain size change significantly depending on the pulse parameters [10, 11]. Fig. 1 presents a flow chart of the evolution of adaptive pulsed GMAW, its modifications and applications. It can be seen, listed beside processes benefits from synergic and self-regulation control. Moreover, dual pulsed, alternative current (AC) GMAW, electrode extension and modified short circuit mode combined with synergic or self-regulation control improve GMAW process efficiency significantly.

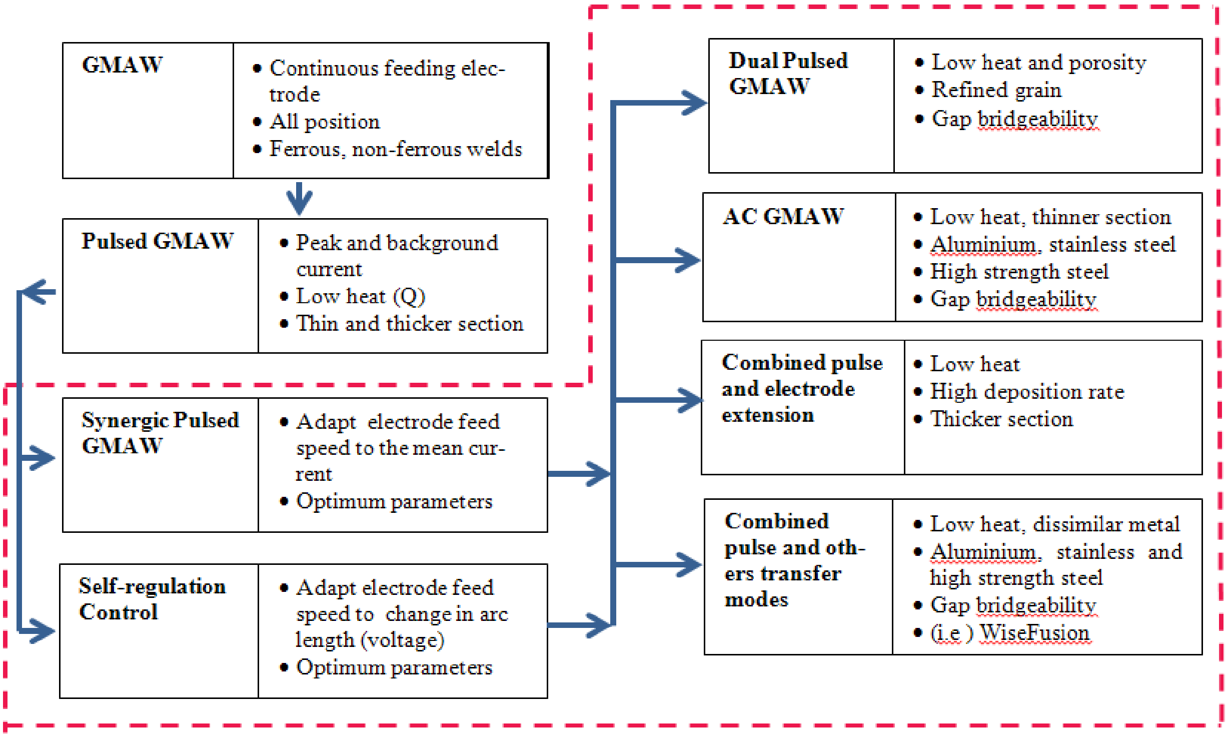


Fig. 1 Evolution of adaptive pulsed GMAW [12-24]

3. Adaptive pulsed GMAW

The adaptive pulsed GMAW process with combined metal transfer mode such as spray and short circuit is designed so as to adjust for parameter variations and disturbances of the process, improving weld quality, process effectiveness and efficiency.

In the normal pulsed GMAW transfer mode, the dissimilar modes occur randomly. For example, during pulsed GMAW four different short circuits can occur [25]:

(1) Instantaneous short circuit; no metal is transferred, occurs with longer and higher peak current and shorter base current;

(2) Base short; metal transfer takes place, occurs generally with longer and smaller base current;

(3) Peak short; metal transfer takes place, occurs at lower peak current, lower base time and higher base current;

(4) Butting the electrode into the workpiece; takes place when the melting rate is lower than the feed rate.

With advanced power sources, however, combined transfer modes are intentionally obtained. The spray and short circuit transfer modes are successfully applied in the same current waveform and the process is continuously adapted by keeping the arc shorter and restricting the occurrence of short circuits.

The main issues in control of pulsed GMAW with a short distance between the tips of the electrode and the weld pool are the occurrence of unexpected short circuits, which happen as the drop grows and touches the weld pool before breaking, and irregularity of the joint and welding feed speed. The short arc increases the pressure, the penetration grows and, consequently, unwanted short-circuits result in more defects and spatter.

The example process considered in this study applies pulses combined with the short circuit metal transfer mode. A Finnish company has recently introduced a process with better control of arc distance and occurrence of short-circuiting. The principle of operation of the WiseFusion^{TM} function is based on controlled regulation of the pulse or spray arc current and voltage waveform, as shown in Fig. 2. The %-value indicates the number of short circuits (SC) in a pulse sequence. The power source monitors the number of short circuits so that it remains at the level defined by the WiseFusion %-value.

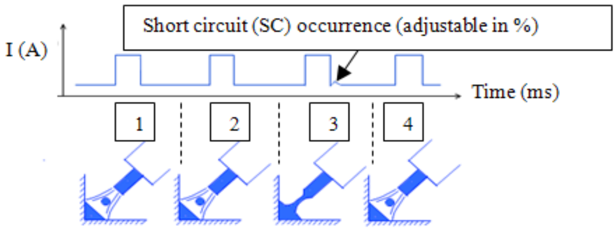


Fig. 2 Pulse sequence where the filler droplet short-circuits before detaching [26]

4. Experimental

The set-up used during the experiment included a gas regulator, welding machine, a support torch mechanized unit, a flexible fume extractor, and workpiece support and fixtures. The power source characteristic and electrode filler wire feeder unit were read from the machine rating data plate. Welding parameters such as welding speed, wire feed rate, gas flow and contact tip to work distance (CTWD) were kept constant, and a calibrated digital oscilloscope was used as data acquisition equipment for amperage and voltage values storage. The power source used in the experiments, FastMIG 450, is digitally controlled multi-process equipment. FastMIG 450 can be changed from normal synergic GMAW to pulsed synergic control and Wise GMAW. The Wise concept software was installed on the equipment prior to the experiment.

Experiments were performed using the Synergic GMAW, Synergic Pulsed GMAW and WiseFusion^{TM} processes to weld a fillet-weld (PB position). The air gap between the parts ranged from 0 to 2.5 mm. The base material was structural, low alloy steel grade S355MC, EN 10149-2 standard. Table 1 presents the chemical and tensile properties of S355MC. The chemical properties of the filler material G3Si1, classification EN ISO 14341-A, are presented in Table 2.

Heat input, mechanical properties and microstructure of the welded joint were investigated. A mixture of 82% Argon and 18% CO_2 was selected as the shielding gas for the experiments. The same welding parameters for wire feeding speed, welding speed, gas flow and contact tip to work distance (CTWD) were used in all experiments. Metallography was performed based on the SFS-EN 1321 standard. Specimens were resized, grinded and finished, after which etching was done to reveal the microstructure using Nital etchants containing 4% nitric acid (HNO_3) in ethanol.

5. Results and discussion

This section is divided into six sub-sections and presents respectively; heat input, micro-section analysis, dilution analysis, microstructure, Vickers hardness test, and processes comparison. The sections present energy and harness data, weld dimension, microstructure details and discuss the processes by comparing weld input energy, the metallographic specimen and the Vickers hardness.

5.1. Heat input

A calibrated digital oscilloscope was used for data acquisition. The equipment captured amperage and voltage values and allowed estimation of the heat input. The heat input (*Q*) of the different processes; Synergic Pulsed GMAW, WiseFusion and Synergic GMAW, was investigated by keeping constant; welding speed, wire feed speed, gas flow rate and contact tip to work distance (CTWD), then voltage and current were measured.

The highest current and voltage were observed with Synergic GMAW and the lowest values were noted with WiseFusion^{TM}. The reduction in current and voltage affected the heat input. Table 3 shows that the percentage number of short circuits has no effect on the heat input when operating with WiseFusion^{TM}. Lower spatter and a more stable arc were found with WiseFusion^{TM} compared to synergic controlled welding, and higher spatter was observed with the Synergic GMAW process. The trends of the results are similar to claims made by the manufacturer in the software manual [26].

Table 1

Chemical and tensile properties of S355 MC [27]

Symbol	Chemical composition, wt%					
	C	Si	Mn	P	S	Al
S355 MC	≤ 0.12	≤ 0.03	≤ 1.50	≤ 0.020	≤ 0.015	≥ 0.015
Symbol	Tensile properties		
	R_e ,MPa	R_m , MPa	Strain at fracture, %
S355 MC	355	430-530	18

Table 2

Chemical properties of the consumable electrode, G3Si1 [28]

Symbol	Chemical composition, wt%								
	C	Si	Mn	P	S	Ni	Mo	Al	Ti+Zr
G3Si1	0.06-0.14	0.70-1.00	1.30-1.60	0.025	0.025	0.15	0.15	0.02	0.15

Table 3

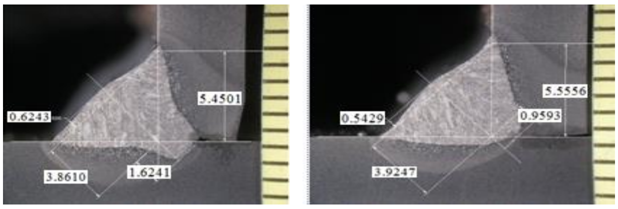
Experiment welding parameters and heat input results

Test	Processes	*I*, A	*U*, V	Welding speed, cm/min	Wire feed speed, m/min	Gas flow rate, L/min	CTWD, mm	*Q*, kJ/mm
1	Synergic pulsed	170	26.7	34	9	14	18	0.64
2	WiseFusion^{TM} (35% SC)	167	25.1	34	9	14	18	0.59
3	WiseFusion^{TM} (50% SC)	167	25.1	34	9	14	18	0.59
4	WiseFusion^{TM} (20% SC)	167	25.1	34	9	14	18	0.59
5	Synergic GMAW	200	24.3	34	9	14	18	0.69

5.2. Macro-section analysis

Macro-section analysis was used to evaluate the wall and root penetration, as well as the throat (Figs. 3-5). Three different categories of air gap were studied (0; 1 and 2 mm) and samples cut from five weld specimens. The images were attached to AutoCAD version 2011, and scaled measurements of convexity, throat, leg length and root penetration were then carried out.

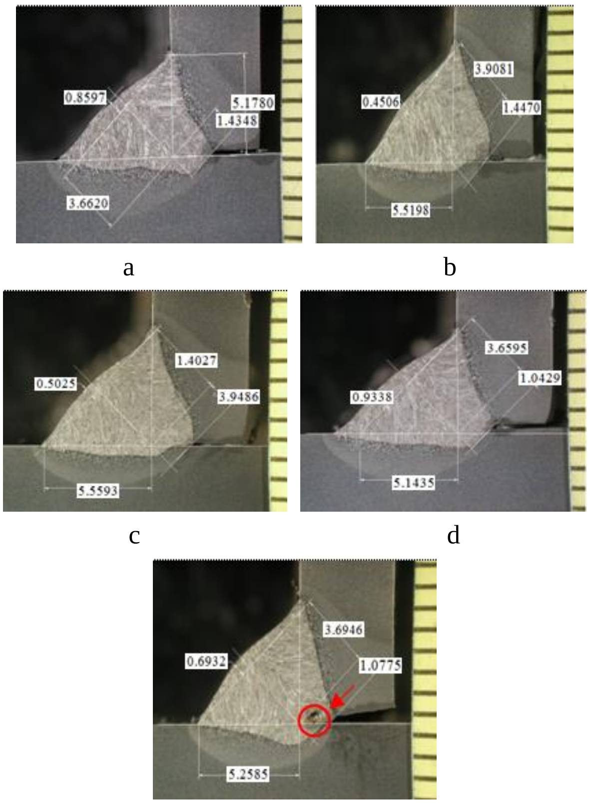
Fig. 3 shows two metallographic cross section specimens for 0 mm air gap of the T-joint with values of weld shape dimensions. Figs. 3 (a) and (b) present, respectively, samples from specimens welded using Synergic Pulsed GMAW and WiseFusion^{TM} at 35% short circuit. It can be seen that the heat affected zone (HAZ) in (a) is larger than that in (b), which confirms the greater heat input when using the Synergic Pulsed GMAW process. In addition, there is a significant difference in root penetration length and profile. Both samples present quite similar legs length.



a b

Fig. 3 Cross section specimens at 0 air gap: a) Synergic Pulsed GMAW; b) WiseFusion^{TM} at 35% short circuit

Fig. 4 presents five metallographic cross-sections from five welded samples of the different welding processes at 1 mm air gap. Fig. 4, a shows a synergic pulsed sample and Fig. 4, b WiseFusion^{TM} at 35% short circuit of a welded specimen with 1 mm gap at the T-joint. The specimen in (a) exhibits larger HAZ than (b), resulting from the greater thermal input of Synergic Pulsed GMAW.



a b

c d

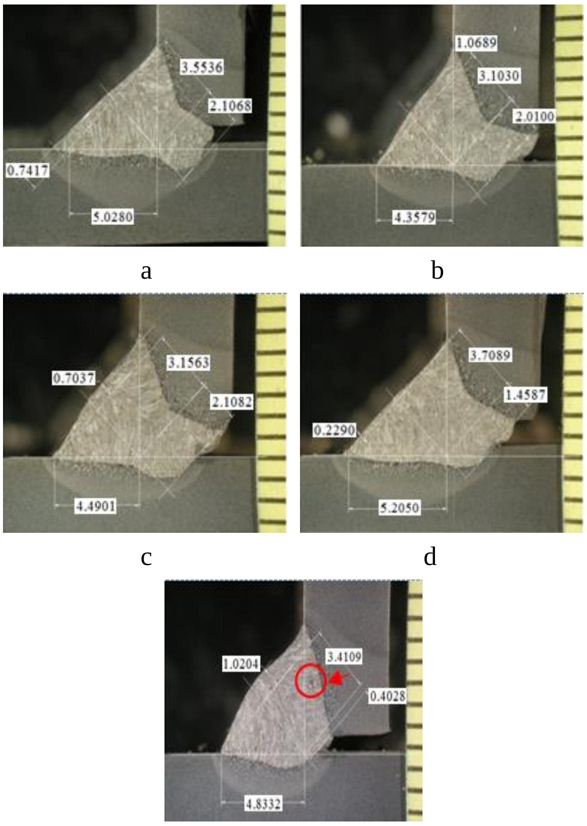
e

Fig. 4 Cross section specimen at 1 mm gap: a) Synergic Pulsed GMAW; b) 35% short circuit; c) 50%, d) 20% short circuit; e) Synergic GMAW

The difference in root penetration length between (a) and (b) is rather small, about 0.01 mm. However, a considerable increase in root penetration can be seen in Fig. 4, c. This change is related to the increase in short circuiting percentage to 50%. Both samples, (a) and (b), present quite similar legs length. It can be observed that the convexity using the curve at 35% short circuit is symmetric, which is advantageous in stress repartition.

Analysis of the effect of the short circuiting percentage on the penetration measurements reveals that wall penetration increases with the increase in the number of short circuits. The penetration is significantly higher at 35% and 50% short circuiting (Figs. 4 b and c) than at 20% short circuiting (Figs. 4, d and e). It can also be observed that the legs lengths in b and in c are longer than in d, about 0.2 mm. Moreover, it is evident that the lower the percentage of short arc, the closer the weld shape is to that of the Synergic Pulsed GMAW process. The Synergic GMAW process, the specimen in Fig. 4, e, presents the lowest penetration and a greater porosity defect, indicated by the red arrow in e.

Fig. 5 shows five metallographic cross sections from five welded samples of the different welding processes at 2 mm air gap. Figs. 5, a and b describe specimens welded using Synergic Pulsed GMAW and WiseFusion^{TM} at 35% short circuit with a 2 mm air gap of the T-joint. The HAZ in sample Fig. 5, a is larger than in b, which indicates increased heat input when using the Synergic Pulsed GMAW process.



a b

c d

e

Fig. 5 Cross section specimens at 2 mm gap: a) Synergic Pulsed GMAW; b) WiseFusion 35% short circuit; c) 50% short circuit; d) 20% short circuit; e) Synergic GMAW

Measurement of the weld indicates that a slight difference appears in root penetration length. The smallest root penetration length can be found from sample (e). It can be observed that the vertical leg length of sample (b) is greater than that of (a) and, inversely, the horizontal leg in (b) is longer than in (a). WiseFusion shows the ability to produce a symmetric share of the weld pool downward and upward regardless of the gravitational force. The sample shown in (d) presents the highest throat (3.7 mm) but also the lowest reinforcement, which can weaken the joint strength.

The gap bridgeability of WiseFusion^{TM} was evaluated and found to depend considerably on the short circuit percentage. It can be noted that the bridge at 35% and 50%

short circuit, Figs. 5, b and c, respectively, is higher than the 20% short circuit specimen, Fig. 5, d. Therefore, it can be concluded that with WiseFusion^{TM}, the bridgeability decreases with the reduction in short circuit percentage. The Synergic GMAW process, Fig. 5, e, exhibits an absence of root penetration and bridgeability. Moreover, the HAZ and porosity defect (red arrow) are greater, as shown in Fig. 5, e.

5.3. Dilution analysis

Dilution analysis was used to evaluate the percentage of weld metal in the base metal. Dilution areas are given in Table 4. The cross section of the weld was divided into three sub-surfaces, a, b and c (Fig. 6), and values were estimated using AutoCAD version 2011 software. The dilution was then calculated based on Eq. (1) [29]

$$\%Dilution = \frac{a+b}{a+b+c} \times 100 . \qquad (1)$$

The dilution at an air gap of 1 mm, presented in Table 4, is at a maximum for WiseFusion^{TM}, particularly at 35% short circuit. The WiseFusion^{TM} software manual states that this percentage is required for steel. The results clearly show different dilution compared with the 0 air gap. The dilution of Synergic Pulsed GMAW is 3.39% lower than that of the WiseFusion^{TM} 35% short circuit. It should be noted that the smaller the number of short-circuits the closer the wall dilution of WiseFusion^{TM} becomes to synergic control and Synergic GMAW.

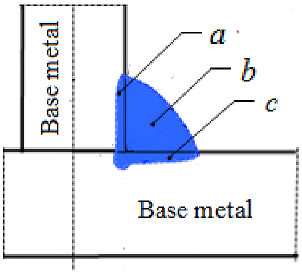


Fig. 6 Repartition of weld area for dilution calculation

Table 4

Dilution comparison at 1 mm air gap

Area, mm^2	Synergic Pulsed GMAW	WiseFusion 35% SC	WiseFusion 50% SC	WiseFusion 20% SC	Synergic GMAW
a	5.2963	9.0672	7.4813	4.9985	5.756
b	18.2772	17.9051	17.9363	17.5121	16.942
c	4.4947	2.0329	2.5838	4.3726	3.2768
Dilution, %	34.8829	38.2693	35.9450	34.8586	34.7752

5.4. Microstructure

The microstructure of the weld and HAZ is shown for different processes and heat-input in Fig. 7 below with a magnification scale 100 µm. Fig. 7, a shows the base metal microstructure. Strength and toughness derive from the very fine ferrite and second-phase microstructure (finely dispersed pearlite) that occur during accelerated cooling of the thermo-mechanically controlled process.

Microstructure analysis of specimens at 1 mm gap, Fig. 7, revealed a greater presence of grain boundary ferrite (GBF) and acicular ferrite (AF) at the fusion zone in (b), (c) and (d). It was observed that the microstructure contains predominantly coarser and elongated primary austenite phases with fine interdendritic structures. The morphology of the dendrites changed with variation of the pulse parameters. There was no significant variation of the weld microstructure in the Synergic and WiseFusion processes at a constant heat input. Specimens in Figs. 7, b and f show slightly lower GBF presence.

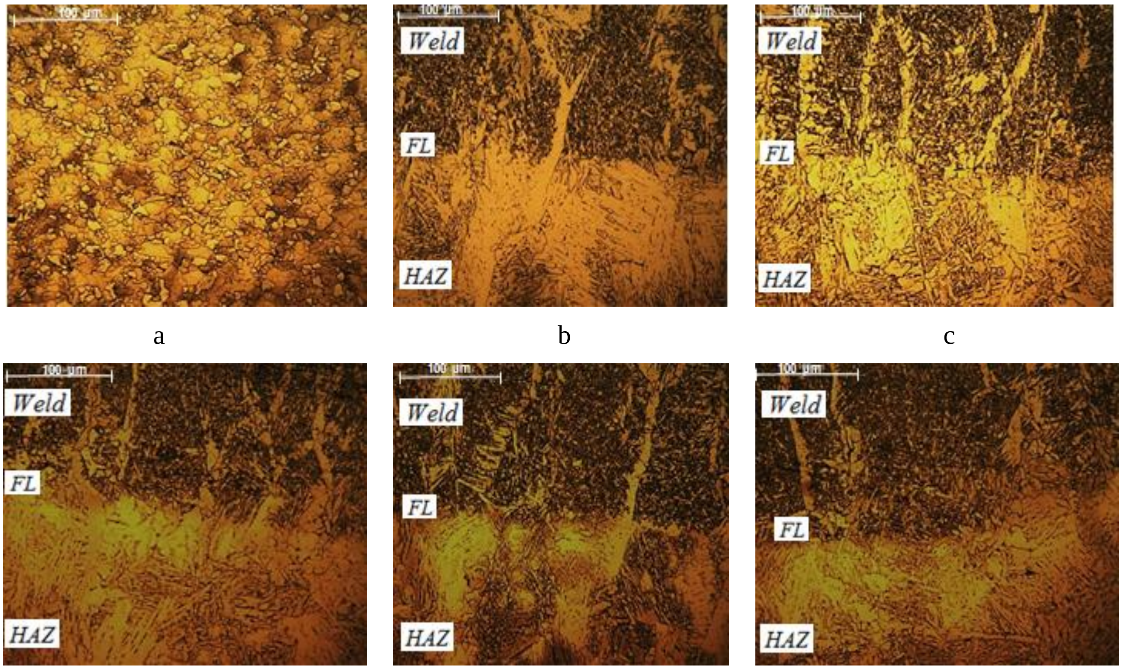
5.5. Vickers hardness test

The hardness test was based on the standard, SFS-EN 1043-2 Destructive test on welds in metallic materials. A DuraScan hardness tester was used. The macro-hardness test was performed from the base metal to the centreline by considering the symmetry of the weld. The analysis compared the same range of air gap for the base metal, HAZ and weld hardness with HV 5.

Results for the macro-hardness test at 1 mm air gap are given in Fig. 8 and show that the Synergic GMAW specimen has the highest hardness, ranging from 3.5 to 6.5 mm. The hardnesses (HV5) of the WiseFusion^{TM} specimens at 35%, 50% and 20% short circuit are, however, very similar. It is observed that the hardness of the Synergic Pulsed GMAW specimen increases sharply at the fusion zone (FZ), while that of the Synergic GMAW sample grows moderately. The hardness growth for WiseFusion at 50% and 20% short circuit is steady and in the same range. The observed fluctuation correlates with the perceived heat input and dilution for the Synergic Pulsed control and Synergic GMAW processes.

5.6. Processes comparison

Table 5 presents a comparison of the adaptive GMAW processes studied. The base of the comparison is the conventional GMAW process. The table compares four processes with five criteria; thermal input, root penetration dilution, microstructure and hardness. Changes in processes welding parameters resulted in specific improvements in the welds characteristics. From this study and related studies mentioned earlier [5, 13, 26], it can be seen that significant benefits can be derived from the improved control of welding parameters possible with Synergic Pulsed GMAW and from the adjustment of short circuit occurrence in WiseFusion^{TM}. The penetration is deeper and the microstructure constituent, such as acicular ferrite, is controlled at the required heat input without compromising the strength of the welded joint.



a b c

d e f

Fig. 7 Comparison of microstructure (magnification 100μm): a) Base metal (S355MC); b) Synergic Pulsed; c) WiseFusion^{TM}35%; d) WiseFusion^{TM}50%; e) WiseFusion^{TM}20%; f-Synergic GMAW

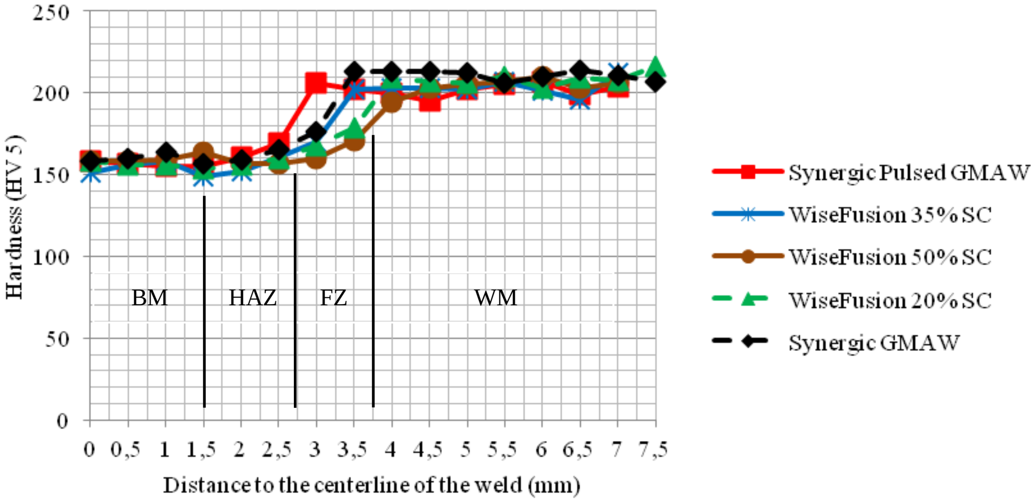


Fig. 8 Hardness test results for Synergic Pulsed GMAW, WiseFusion^{TM} (20, 35 and 50%) and Synergic GMAW. Base metal (BM), heat affected zone (HAZ), fusion zone (FZ) and weld metal (WM)

Table 5

Comparison of processes studied

Feature	Conventional GMAW	Synergic Pulsed GMAW	Synergic GMAW	WiseFusion^{TM}
Thermal input	higher	medium	high	low
Root penetration	lower	deep	low	deep
Dilution	lower	medium	low	higher
Microstructure	poor	good	porosity	good
Hardness	higher	medium	high	low

6. Conclusions

1. The literature review revealed that the adaptability of welding machine to randomly changes while processing with the advanced GMAW process has become possible with a better control of the arc. Be it a dual pulsed, a variable polarity pulsed, an electrode extension or modified short circuit combined with pulsed GMAW. Control *o* the heat input (*Q*) and process optimization have shown to contribute in predicting for adequate weld microstructure and heat affected zone of the base metal to improve the life cycle of the weld joint.

2. Compared to Synergic Pulsed GMAW, the profile of the weld generated with WiseFusion^{TM} is larger, with a deeper side wall, and with a considerably longer root penetration at 50% short circuit. The latter characteris-

tic enables control of the penetration by adjusting the short circuit percentage and, when increasing the welding speed and energy input, reduces the risk of burn-through to weld plate of thin sections smaller or equal to 5 mm.

3. There was no significant variation of the weld microstructure in Synergic Pulsed GMAW and WiseFusion^{TM} but the morphology of the dendrites changes with variation of the pulse parameters. The presence of acicular ferrite (AF) with fine grains, which provides maximum resistance to crack propagation, was observed in the processes investigated. Synergic Pulsed GMAW and Synergic GMAW showed a sharp increase in hardness at the fusion zone which can be a location for stress concentration.

4. Weld penetration has a major impact on joint strength and service life. The weld dilution dictates the degree of base metal fusion and must be adequate to maintain weld quality. The hardness variation at the interface of the weld zone and heat affected zone correlates highly with joint strength. The joint weakening tendency can be significantly reduced in ferrous welds and non-ferrous welds by heat input reduction. The WiseFusion^{TM} process exhibited better wall dilution and penetration. This ability increased as the percentage of short circuits grew. Furthermore, the legs lengths of WiseFusion^{TM} were much longer than synergic GMAW and slightly superior to Synergic Pulsed GMAW.

5. The shape of the weld is defined by the penetration, as well as the dilution of the weld seam. Synergic Pulsed GMAW manifested a straight profile and a longer root, while Synergic GMAW exhibited a straight wall fusion line but short root penetration. The straight fusion line and shorter legs length lead to smaller dilution compared to WiseFusion^{TM}. WiseFusion^{TM} presented a longer legs length and a more rounded seam weld fusion line with relatively symmetric repartition at the side wall of the weld. The shapes of the WiseFusion^{TM} welds demonstrate the factors necessary to guarantee strength rigidity and a long life cycle.

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ADAPTYVUSIS IMPULSINIS DUJINIS LANKINIS METALO SUVIRINIMAS IR JO PRIVALUMAI

Reziumė

Šio tyrimo tikslas ištirti adaptyvųjį impulsinį metalo dujinio lankinio suvirinimo (MDLS) procesą ir nustatyti, ar jį galima taikyti storesnėms kaip 3 mm konstrukcinio plieno sekcijoms suvirinti. Adaptyvusis impulsinis MDLS procesas taikomas, kai elektrodo tiekimo greitis yra automatiškai priderinamas ir koreguojamas pagal srovės ar įtampos pulsaciją. Be to, srovės ir įtampos impulsų forma ir suvirinimo parametrai yra modifikuojami norint pagerinti pasikartojančių maksimumų ir vidutinių reikšmių valdymą suvirinant. Tyrimai patvirtino adaptyviojo suvirinimo proceso pritaikomumą ir nustatė jo poveikį siūlių savybėms, siūlės medžiagos skvarbai ir formai. Darbe apžvelgiamas adaptyvusis MDLS, siekiant įvertinti skirtingus priartėjimus ir jų taikymą ir nustatyti jo privalumus. Literatūros apžvalga rodo, kad, pagerinus srovės impulso formos valdymą ir naudojant šiuolaikinius energijos šaltinius, gerėja plonų metalo lakštų suvirinimo kokybė. Norint nustatyti, ar MDLS galima pritaikyti storesniems metalo lakštams (5 mm) suvirinti, buvo atlikti eksperimentai naudojant sinergetinį MDLS. Sinergetinis impulsinis MDLS ir *WiseFusionTM* pritaikyti juostiniam suvirinimui. Oro tarpas tarp detalių buvo nuo 0 iki 2,5 mm. Pagrindo medžiaga buvo 5 mm storio konstrukcinis plienas S355MC, o siūlės – G3Si1. Eksperimento metu ištirtas šilumos perdavimas, mechaninės savybės ir suvirinimo siūlių mikrostruktūra.

Tyrimai parodė, kad *WiseFusionTM* siūlė dėl savo formos pasižymėjo didžiausiu maišumu ir mažu korėtumu, įgilėjimu ir dideliu arba mažu sustiprinamumu.

Prieita prie išvados, kad adaptyvusis impulsinis MDLS procesas gali būti sėkmingai taikomas daug siūlių turinčioms konstrukcijoms suvirinti. Bendras šilumos sumažėjimas sušvelnina liekamuosius įtempius, o siūlės forma leidžia naudoti didesnes sroves. Lankas suvirinimo proceso metu nesitaško ir leidžia padidinti suvirinimo greitį.

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APPLICATIONS AND BENEFITS OF ADAPTIVE PULSED GMAW

Summary

The aim of this study was to investigate adaptive pulsed GMAW processes, considering possible benefits when welding thicker sections (> 3 mm) and structural steel. Adaptive pulsed GMAW processes are adaptive in that electrode feed speed is automatically adjusted and corrected to the mean pulsed current or voltage variation. In addition, current and voltage waveforms and welding parameters are modified to improve control of repeated peak and background values occurring during pulsed GMAW. The study experimentally tested the usability of adaptive welding processes and evaluated effects on weld properties, penetration and shape of the weld bead. The study first briefly reviewed adaptive GMAW to evaluate different approaches and their applications and to identify the benefits of adaptive pulsed GMAW. The literature shows that better control of current waveform and use of advanced power sources successfully improved welding quality of thin sheet metal. To assess applicability with thicker sheet metal (5 mm) experiments were then performed using Synergic GMAW, Synergic Pulsed GMAW and WiseFusion^{TM} to weld a fillet weld (PB position). The air gap between the parts ranged from 0 to 2.5 mm. The base materials were structural steel grade S355MC, 5 mm thickness, and filler material G3Si1. The experiment investigated heat input, mechanical properties and microstructure of the welded joint.

The WiseFusion^{TM} bead had the highest dilution of the processes tested, due to the weld bead shape, and the weld showed low defects such as porosity, undercut, and excessive or lack of reinforcement.

It was concluded that adaptive pulsed GMAW processes can be a favoured choice when welding structures with many welded joints. The total heat reduction mitigates residual stresses and the bead shape allows a higher amperage limit. The stability of the arc during the process is virtually spatter free and allows an increase in welding speed.

Keywords: Adaptive Pulsed, GMAW, high energy, heat input, weld properties.

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