# MECHANICAL PROPERTIES OF PULSED CURRENT MULTIPASS GMA WELD OF Al-Zn-Mg ALLOY

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***Synopsis :*** *The growing interest of using thick section of high strength aluminium alloy like Al-Zn-Mg in fabrication of light weight large transport container and pressure vessels necessitates the gas metal arc welding (GMAW) of this alloy. Due to its high strength the weld joint of Al-Zn-Mg alloy is highly sensitive to fatigue failure, thus in any engineering application an assurance about its desired tensile, fatigue and fracture toughness properties are of utmost importance. In the light of the recent observations on superiority of using pulsed current GMAW over the conventional continuous current one to improve the mechanical properties of single pass weld of Al-Zn-Mg alloy, the present investigation has been planned to study the characteristics of multipass weld of thick section of this alloy prepared by employing pulsed current GMAW process. The multipass welding of 25mm thick extruded section of an Al-Zn-Mg alloy has been carried out using pulsed current and continuous current gas metal arc welding (GMAW) processes. The welding has been carried out by employing l.6mm diameter Al-Mg (AWS ASME: SFA-5.10 ER 5183) filler wire and commercial argon as shielding gas. The pulsed current welding has been performed by varying the pulse pararneters such as the pulse frequency and duration and their effects on dilution, zinc pick-up, precipitation behaviour, porosity content and tensile properties of the weld are studied. It is observed that the variation in pulse parameters effects the microstructure and dilution of weld deposit. The change in weld dilution has been found to control its chemistry (especially zinc level) and precipitate content dictating tensile properties of the weld. The characteristics of the pulsed current weld has been compared to those of the weld prepared by continuous current GMAW. The properties of the pulsed current weld are found superior to those of the conventional continuous current weld.*

***Keywords :*** *Al-Zn-Mg alloy, pulsed and continuous current GMAW, multipass weld, weid chemistry, XRD analysis, porosity, microstructure, fractography, mechanical properties.*

## INTRODUCTION

Al-Zn-Mg alloy has gathered wide acceptance in fabrication of light weight structures requiring a high strength to weight ratio, such as transportable bridge girders, road tankers and railway transport systems [1,2]. In any structural application of this alloy, consideration of its weldability is of utmost importance, because welding is largely used for joining of structural components. Welding of Al-Zn-Mg alloy is frequently preferred to be carried out by gas metal arc (GMA) welding process due to its comparatively easier applicability and better economy [3]. In case of single pass GMA welding of thinner sections (≤ 10mm) of this alloy the use of pulsed current has been found beneficial due to several advantages over the conventional continuous current process, like better control on metal deposition [4,5] and weld thermal cycle [6]. In most of the weldments of Al-Zn-Mg alloy fracture has been found to take place in weld region under static and dynamic loading [7-9]. The use of pulse current GMA welding has been found to improve the tensile and fracture toughness properties of the weld in comparison to those of conventional continuous current GMA weld of this alloy [7-11]. The improvement in mechanical properties of the weld is found to be largely governed by the microstructure, chemical composition and porosity content of the weld, varying with the pulse parameters [9,11-13].

The increasing demand of using comparatively thicker sections of Al-alloys in several fields, such as pressure vessels, structural columns and transport systems [14], necessitates the use of multipass welding for joining of those sections. In multipass welding the nature of weld thermal cycle, weld geometry, dilution, weld metal composition, porosity content and microstructure of the weld differs from those af the single pass weld. Thus, mechanical properties of a multipass weld may be different, along with their correlation with the pulse parameters, from those of single pass weld. Due to application of this alloy in high strength structures, it is imperative to characterise its tensile properties. However, very little knowledge has been acquired so far regarding tensile properties of a multipass pulsed current GMA weld of comparatively thicker section of Al-Zn-Mg alloy.

In this investigation an effort has been made to study at a given mean current the influence of pulse parameters, namely pulse frequency and pulse duration on the chemical composition, porosity content, microstructure and tensile properties of multipass pulsed current GMA weld of an Al-Zn-Mg alloy. The weld characteristics such as the microstructure, zinc pick-up and porosity content are also correlated with the tensile properties of the weld. Finally the tensile properties of the weld prepared by pulsed current GMA welding are compared with those of multipass continuous current GMA weld.

## EXPERIMENTAL PROCEDURE

Pulsed current GMA welding of extruded section (40 x 25 mm) of an Al-Zn-Mg (7005) alloy was carried out using 1.6 mm diameter filler wire (DIN 1732; AWS/ASME SFA-5.10 ER5183) and commercial argon (99.98%) as shielding gas at a flow rate of 20 L. min$^{-1}$. The welding was carried out by filling the weld groove (Fig. 1) with multiple passes (Fig. 2). Prior to welding, the plates were thoroughly cleaned to remove the oxide layer and any dirt or grease adhering to the groove surface. The pulsed current welding was carried out at a given mean current, arc voltage and welding speed of 220 A, 23 V and 5 mm/sec respectively where, the pulse frequency and pulse duration were varied in the range of 25-100 Hz and 4.5-8.5 ms respectively as stated in Table-I. The mean current was selected on the basis of earlier observations [6-12], showing improvement in weld properties of single pass weld. Before welding the plates were arranged side by side, so that their grooves are properly aligned for weld pass, and rigidly held in a fixture. The welding was carried out on a stainless steel backing plate. Both the preheat and interpass

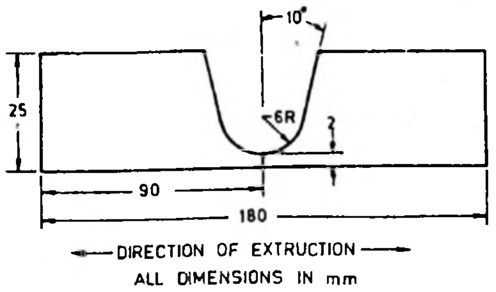


**Fig. 1** : Schematic diagram of weld groove

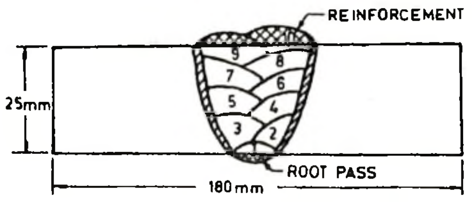


**Fig. 2** : Schematic diagram of the sequence of weld pass

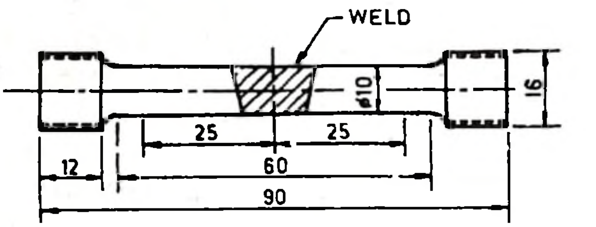
**TABLE - I : Welding Parameters**

| Specimen Designation | Mean Welding Current [A] | Pulse Frequency [Hzj | Pulse Duration [msj | Base Current [A] | Peak Current [A] |
|---|---|---|---|---|---|
| A | 220 | 0 | 0 | – | – |
| B | 220 | 25 | 4.5 | 190 | 373 |
| C | 220 | 50 | 4.5 | 160 | 366 |
| D | 220 | 100 | 4.5 | 110 | 352 |
| E | 220 | 25 | 6.5 | 160 | 438 |
| F | 220 | 50 | 6.5 | 120 | 421 |
| G | 220 | 100 | 6.5 | 60 | 361 |
| H | 220 | 25 | 8.5 | 150 | 455 |
| I | 220 | 50 | 8.5 | 110 | 424 |
| J | 220 | 100 | 8.5 | 50 | 376 |

temperatures were maintained as 393 K. During deposition of weld bead adjacent to the groove edge a gap of about 1.5 mm was maintained between the wire tip and the groove edge to ensure proper fusion of base metal. In between subsequent filling passes surface of earlier deposit was thoroughly cleaned using a stainless steel wire brush. For a comparative study similar welds were also produced by conventional continuous (without pulse) current GMA welding process using a welding current same as that of the mean current used in pulsed current welding. The arc voltage and welding speed were always kept constant. During welding the pulse characteristics were recorded and the peak current ($I_p$), pulse duration ($t_p$) and pulse off time ($t_b$) were estimated (Table-I) with the help of a digital oscilloscope, whereas the mean current ($I_m$) and base current ($I_b$) were recorded from the ammeter fixed in the welding power source.

Before collecting specimens for various testing, the weldments were stored at room temperature (295 K) for more than 30 days so they would naturally age for sufficient extent. The zinc content of the weld deposit and chemical compositions of the base and filler materials were analysed by Atomic Absorption Spectrometer. The samples for chemical analysis were collected by drilling out material from different locations on cross section of the weld. Specimens for metallographic examination were cut from the central part of the weldment to ensure a true representation of the weld microstructure. Transverse section of the specimens was prepared by standard metallographic technique and etched in Keller's reagent (HF 1 ml, HCl 1 .5 ml, $HNO_3$ 2.5 ml and water 5 ml) to reveal the microstructure. Microstructure of the weld was studied under optical and scanning electron microscopes. Quantification of coarse and fine dendritic portion of the matrix of a weld was carried out by standard lineal intercept method [15], An X-ray diffraction study of powder sample collected from the weld metal was carried out using $CuK_a$ radiation with nickel filter in a Philips model PW 1140/90 X-ray diffractometer, to determine the presence of intermetallic precipitate in it. Porosity content of the weld (excluding reinforcement), revealed as dark spots on the polished and unetched transverse section of the weld, was estimated under optical microscope by following standard point counting method [15]. An hardness distribution along the centre line across the weld, revealed on the metallography specimens, was studied by Vicker's diamond indentation at a load of 5 kg.

Tensile test of the weld joint was carried out under servo hydraulic universal testing machine using round tensile specimens (DIN 50215) having weld at its centre as shown in Fig. 3. Tensile properties of the base material were also determined by using similar tensile specimen. The tensile test was carried out at a cross head speed of 1 mm/s. Yield strength was determined at 0.2% offset strain on the load vs. strain diagram obtained with an extensometer fixed on the gauge length (50 mm) portion of the specimen. Elongation of the joint was also estimated over the same gauge length.



ALL DIMENSIONS IN mm

**Fig. 3 :** Schematic diagram of the tensile test specimen.

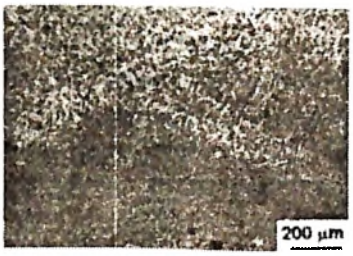


**Fig. 4 :** Typical microstructure of the continuous current GMA weld consists of comparatively fine (F) and coarse (C) dendritic regions

**TABLE - II : Chemical Composition of Base Metal and Filler Metal**

| Material | Zn | Mg | Mn | Fe | Si | Cu | Cr | Al |
|---|---|---|---|---|---|---|---|---|
| Base Metal (Wt.%) | 4.5 | 1.20 | 0.47 | 0.32 | 0.30 | 0.02 | 0.15 | Rest |
| Filler Metal (Wt.%) | – | 4.5 | 0.65 | – | – | – | – | Rest |

## RESULTS AND DISCUSSION

### Chemical analysis

Chemical composition of the base material and filler wire has been shown in Table - II. The table shows that the filler wire does not contain zinc but the base material is having considerable amount of zinc in it. The selection of Al-Mg filler wire containing no zinc in it was made as per recommended practice (16], where the weld deposit gives good mechanical properties and corrosion resistance. However, the weld deposit has been found to pick-up zinc from the base material (Table-III) due to dilution. During the change in pulse frequency or duration, the variation in dilution affecting the zinc pick-up primarily resulted from different weld thermal cycle caused by the change in $I_p$ and $I_b$ as shown in Table-I. The presence of zinc in weld deposit has caused precipitation of $Mg_3Zn_3Al_2$ in the matrix, as it is identified (Table-IV) by the existence of $(Al,Zn)_{49}Mg_{32}$ under the X-ray diffraction studies. The presence of $(Al,Zn)_{49}Mg_{32}$, which is in close approximation by nature [17] to the $Mg_3Zn_3Al_2$, has been confirmed by the inter-planar spacing (d-value), where no other interfering d-value is observed. The stoichiometric amount of precipitate has been found to increase with the increase of zinc pick-up, as it is given in Table-III.

### Microstructure

Microstructure of the weld has been found to consist of a mixture of coarse columnar dendritic and relatively finer dendritic regions. These two regions are largely defined by their different dendrite arm spacing and the aspect ratio of dendrite arms, measured under scanning electron microscope (SEM). It is observed that the dendrite arm spacing of the coarse columnar dendrite is of the order of 4.78 ± 1.27μm with an aspect ratio of 0.22 ± 0.024 whereas, the dendrite arm spacing of the relatively finer dendrite is of the order of 1.54 ± 0.69μm with an aspect ratio of 0.144 ± 0.02. Microstructure of the weld deposit produced by continuous current welding is presented in Fig. 4. The variation in pulse parameters has been found to affect the fine dendrite content of the matrix (Table-III), which may influence mechanical properties of the weld. Typical micrographs of the pulse current weld deposit having a comparatively low and high finer dendrite content are shown in Fig. 5 (a and b) respectively. The Table - III shows that at a given pulse duration the change in pulse frequency from 25 to 50 Hz enhances the finer dendrite fraction of the weld followed by a decrease with a further increase in pulse frequency to 100 Hz. It is also observed that at a given pulse frequency the increase in pulse duration from 4.5 to 6.5 ms enhances the finer dendrite fraction of the weld followed by a decrease

**TABLE - III**

**Characteristics of Weld Deposit at Different Welding Parameters**

| Specimen Designation | Dilution [%] | Zinc Pick-up [Wt.%] | Amount of $(Al,Zn)_{49}Mg_{32}$ Precipitate [Wt.%] | Finer Dendrite Fraction [Area %] | Porosity Content [Vol.%] |
|---|---|---|---|---|---|
| A | 17.5 | 0.64 | 1.0539 | 39 | 2.4 |
| B | 15.5 | 0.60 | 0.9880 | 51 | 3.4 |
| C | 13 | 0.53 | 0.8563 | 59 | 2.9 |
| D | 14.5 | 0.56 | 0.9180 | 49 | 2.3 |
| E | 17.5 | 0.67 | 1.1033 | 60 | 3.0 |
| F | 15.5 | 0.58 | 0.9551 | 65 | 2.7 |
| G | 18 | 0.69 | 1.1362 | 56 | 2.1 |
| H | 19.5 | 0.72 | 1.1856 | 55 | 2.25 |
| I | 17.5 | 0.68 | 1.1198 | 61 | 1.80 |
| J | 21 | 0.78 | 1.2845 | 52 | 1.40 |

**TABLE - IV**

**X-ray diffraction analysis of the weld**

| Sin $\theta$ | d A$^0$ | (hkl) |
|---|---|---|
| 0.761 | 1.0124 | (400) Al |
| 0.659 | 1.169 | (222) Al |
| 0.631 | 1.221 | (311) Al |
| 0.538 | 1.431 | (220) Al |
| 0.536 | 1.437 | (941, 853) $(Al, Zn)_{49}Mg_{32}$ |
| 0.383 | 2.012 | (710, 550) $(Al, Zn)_{49}Mg_{32}$ |
| 0.380 | 2.024 | (200) Al |
| 0.333 | 2.310 | (611, 532) $(Al, Zn)_{49}Mg_{32}$ |
| 0.330 | 2.338 | (111) Al |

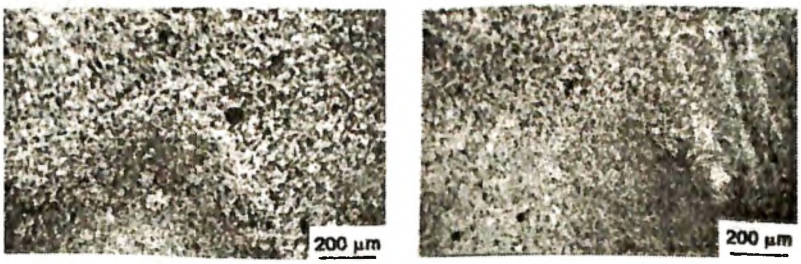


**Fig. 5** : Typical microstructures of the pulse current GMA welds having comparatively (a) low and (b) high finer dendrite content.

in it with a further increase of pulse duration to 8.5 ms. However, it is observed that the pulse current weld contains more finer dendrite in comparison to that present in the conventional continuous current weld.

## Porosity content of weld deposit

The micrographs presented in Figs. 4 and 5 also typically show the presence of some porosity in the weld prepared by both the continuous and pulsed current processes, which may have influence on mechanical properties of the weld up to certain extent. Qualitatively the pores are mostly found to be of fine round in shape within close size range maintaining a practically homogeneous distribution in the matrix . Amount of porosity in the weld has been found to vary with the change in welding parameters as depicted in Table-III. The table shows that at a given pulse frequency the increase in pulse duration and at a given pulse duration the increase in pulse frequency reduces porosity content of the weld. It may be further noted that a proper selection of pulse parameters, such as a higher pulse frequency and duration of 100 Hz and 8.5 ms respectively, reduces porosity content of the weld significantly in comparison to that of continuous current weld. However, the porosity content of the weld has been found to lie within the acceptable range as per BS 8118, part 2, satisfying many applications criteria [18].

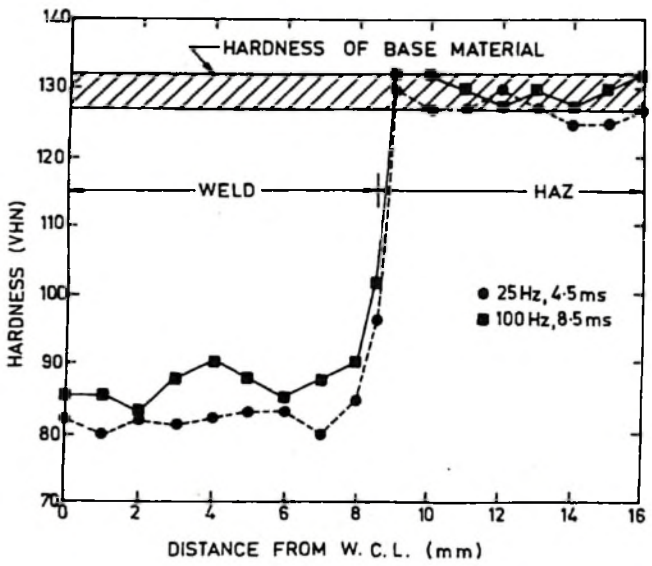


**Fig. 6 :** Hardness distribution across the weld centre line.

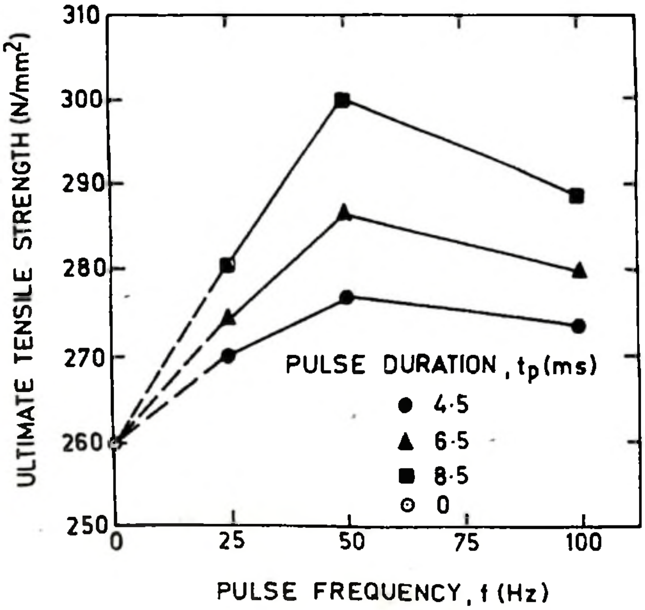


**Fig. 7 :** At a given pulse duration the effect of pulse frequency on ultimate tensile strength of the weld.

### Hardness distribution in weld

In order to understand qualitatively the homogeneity in properties of the weld primarily in reference to distribution of its chemistry, microstructure and porosity the variation in hardness across the weld has been studied. The typical hardness distribution along centre line across the weld to HAZ of the weldments, prepared at the low and high pulse frequency and duration of (25Hz and 4.5ms) and (100Hz and 8.5ms) respectively, shows (Fig. 6) no significant variation confirming the weld as a practically homogeneous one with respect to its characteristics as mentioned above. The homogeneity in hardness of the weld largely governed by a uniform distribution of zinc in the matrix is primarily attributed to turbulence in weld pool during deposition as well as diffusion by reheating under multipass deposition. The variation in welding parameters has been found to marginally affect the hardness of the weld primarily due to a change in its zinc pick-up and finer dendrite fraction in the range of 47 and 67% respectively. In spite of this much variation in zinc pick-up the marginal change in hardness is primarily attributed to a low amount of precipitate (Table-III). However, the observed variation in weld characteristics has been found to have a markable influence on tensile properties of the weld.

### Tensile properties

At a given pulse duration the influence of pulse frequency and at a given pulse frequency the influence of pulse duration on ultimate tensile strength (UTS) of the weld has been shown in Figs. 7 and 8 respectively. Similarly the influence of pulse frequency and pulse duration on yield strength (YS) and reduction in cross sectional area (RA) of the weld are shown in Figs. 9 and 10 and Figs. 11 and 12 respectively. During tensile testing of the weld joints the specimens were

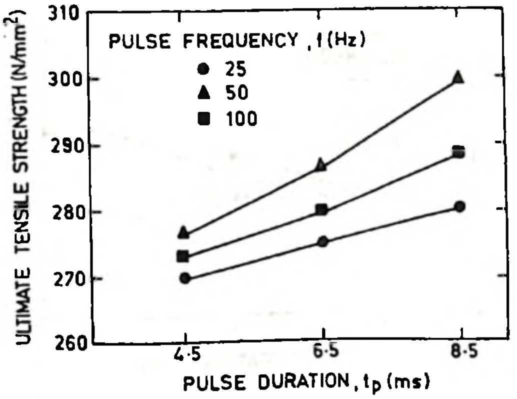


**Fig. 8 :** At a given pulse frequency the effect of pulse duration on ultimate tensile strength of the weld.

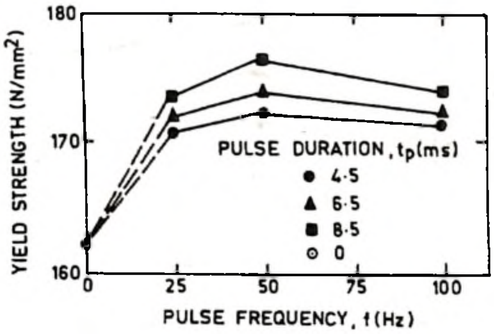


**Fig. 9 :** At a given pulse duration the effect of pulse frequency on yield strength of the weld.

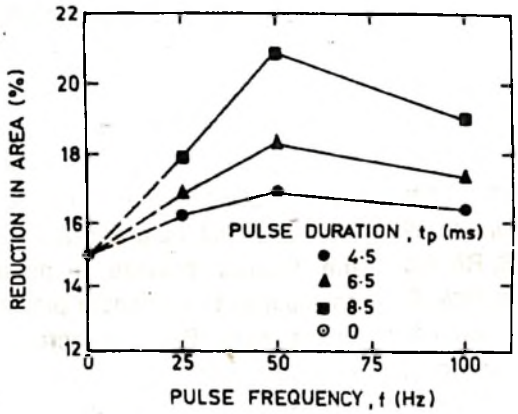


**Fig. 10 :** At a given pulse duration the effect of pulse frequency on reduction in cross sectional area of the weld.

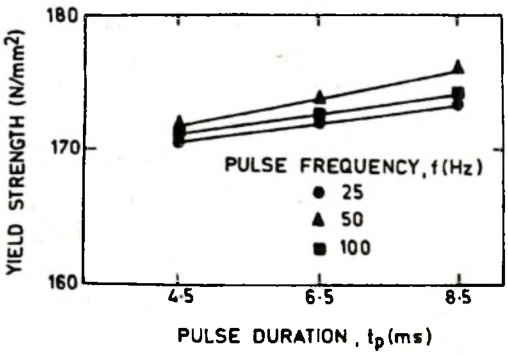


**Fig. 11 :** At a given pulse frequency the effect of pulse duration on yield strength of the weld.

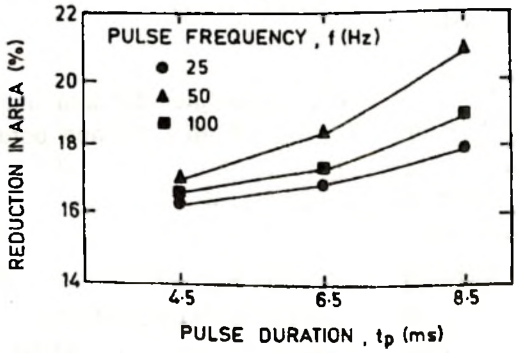


**Fig. 12 :** At a given pulse frequency the effect of pulse duration on reduction in cross sectional area of the weld.

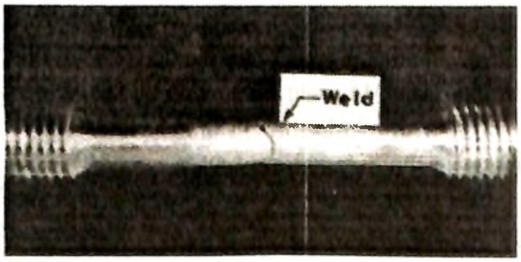


**Fig. 13 :** Typical photograph of the tensile specimen fractured from the weld zone.

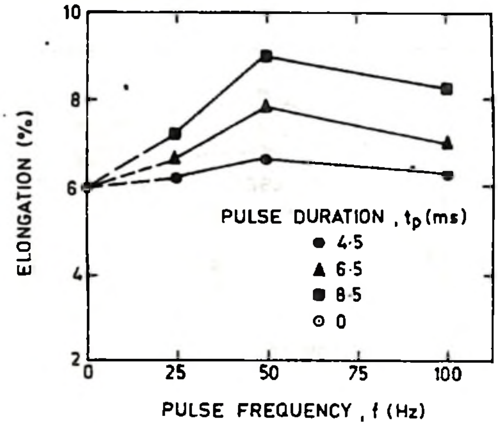


**Fig. 14 :** At a given pulse duration the effect of pulse frequency on elongation of the weld.

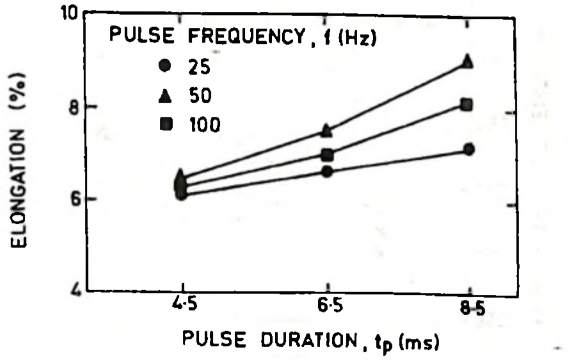


**Fig. 15 :** At a given pulse frequency the effect of pulse duration on elongation of the weld.

found to fracture from the weld region as typically shown in Fig. 13. Thus, it may be assumed that the tensile properties depicted in Figs. 7-12 primarily represent the properties of the weld. During tensile test the specimens were also found to show maximum deformation (necking before fracture) in the weld region. So, it may also be assumed that the influence of pulse frequency and pulse duration on the elongation (El) of the weld joint, as depicted in Figs. 14 and 15 respectively, primarily reveals the ductility of the weld. The Figs. 7, 9, 10 and 14 show that the use of pulse current GMA welding improves the tensile properties of the weld over those of the continuous current (0 Hz) GMA weld. But, It is also observed that the tensile properties of the pulse current GMA weld varies critically with the change in pulse frequency and pulse duration. At a given pulse duration the increase in pulse frequency from 25 to 50 Hz has been found to enhance the UTS, YS, RA and El of the weld followed by a decrease in them with a further increase in pulse frequency to 100 Hz as shown in Figs. 7, 9, 10 and 14 respectively whereas, at a given pulse frequency the increase in pulse duration from 4.5 to 8.5 ms has been found to all along increase the UTS, YS, RA and El of the weld as shown in Figs. 8, 11,12 and 15 respectively. However, it is marked that the influence of pulse parameters on yield strength of the weld is comparatively less significant than that observed on other tensile properties of the weld.

The tensile properties of a weld is primarily governed by its chemical composition, microstructure and porosity content. In the present investigation the variation in pulse parameters has been found to influence the zinc pick-up, finer dendrite fraction and porosity content (Table III) of the weld significantly. Thus they simultaneously affect the tensile properties of the weld prepared at different welding parameters. The increase in zinc pick-up strengthens the weld by enhancing the amount of precipitate (Table III) in the weld. The refinement of microstructure modifies the tensile properties of the weld by affecting the morphology of the matrix and the precipitates. Both the factors provide a positive contribution to the tensile properties of the weld. But, the increase in porosity content of the weld adversely affects the tensile properties of the weld by reducing its effective cross sectional area. To analyse their influence on tensile properties of the weld a systematic effort has been made.

At a given finer dendrite fraction (54.5 ± 3.8 area %) and porosity content (2.4 ± 0.62 vol.%) the influence of zinc pick-up on the UTS, YS, RA and El of the weld has been shown in Figs. 16 (a, b, c, and d) respectively. Similarly at a given zinc pick-up (0.625 ± 0.04 wt.%) and porosity content (2.86 ± 0.36 vol.%) the influence of finer dendrite fraction and at a given finer dendrite

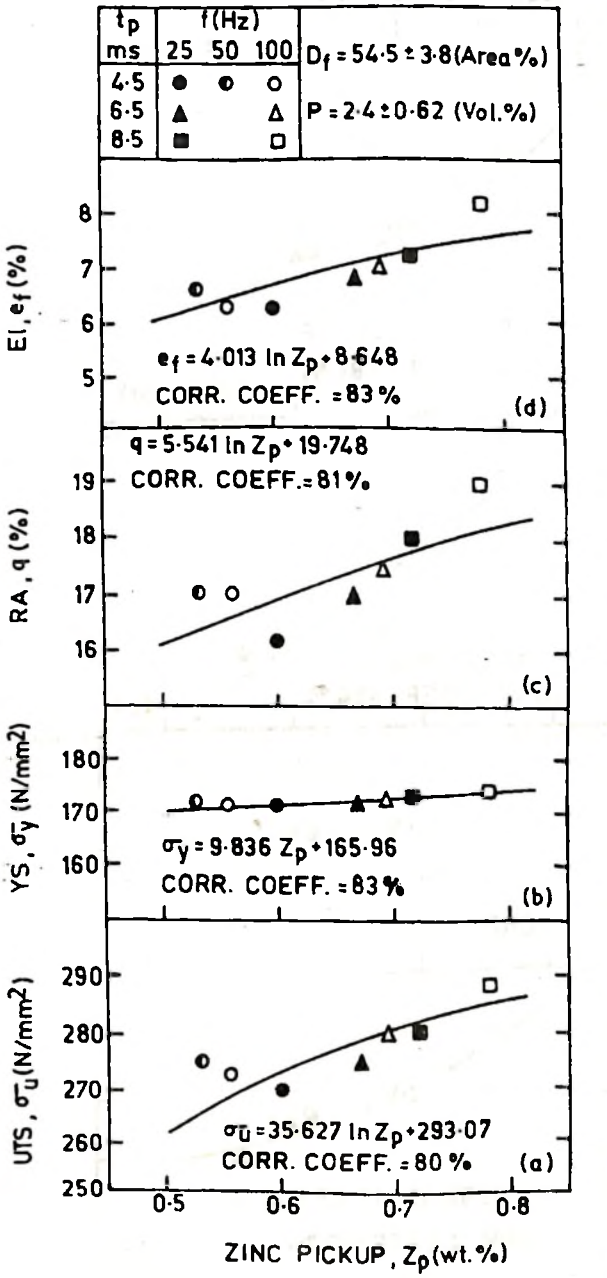


**Fig. 16 :** At a given finer dendrite fraction and porosity content the influence of zinc pick-up on the (a) UTS, (b) YS, (c) RA and (d) El. of the weld.

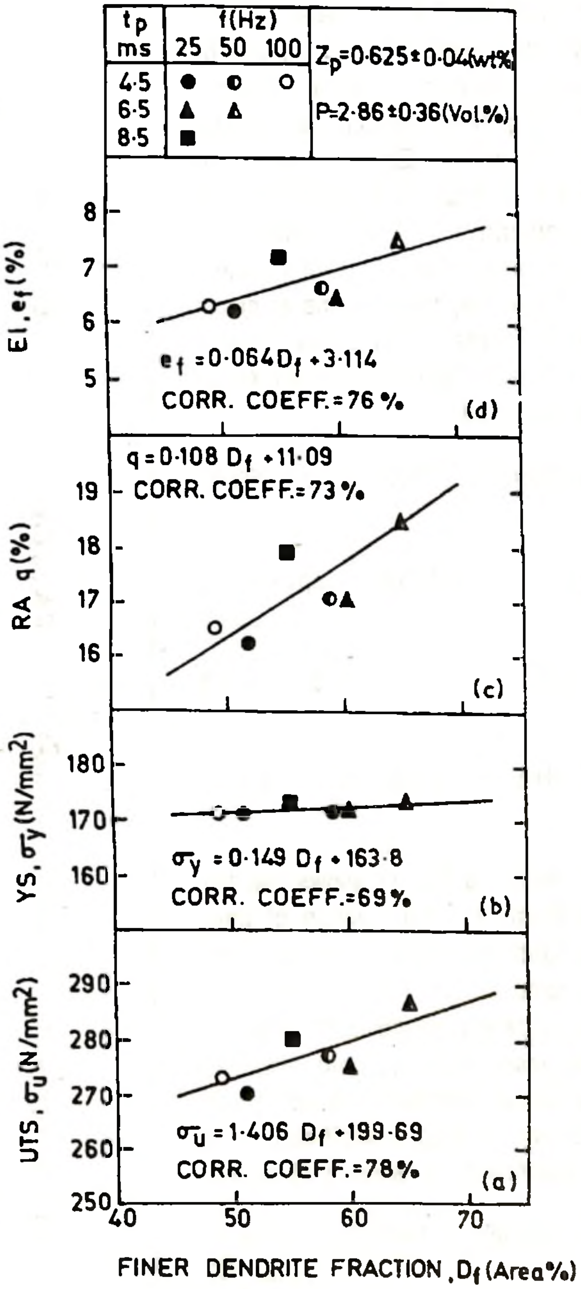


**Fig. 17 :** At a given zinc pick-up and porosity content the influence of finer dendrite fraction on the (a) UTS, (b) YS, (c) RA and (d) El. of the weld.

fraction (54.5 ± 3.8 area %) and zinc pick-up (0.655 ± 0.089 wt%) the influence of porosity content of the weld on its UTS, YS, RA and El are shown in Figs. 17 (a, b, c, and d) and 18 (a, b, c, and d) respectively. The Fig. 16 shows that the increase in zinc pick-up (Zp wt.%) enhances the UTS ($\sigma u$), El (ef) and RA (q) significantly along with a comparatively insignificant increase in YS ($\sigma_Y$) by following the empirical expressions given below having coefficient of correlation in the range of 80 to 83%.

$\sigma_U$(N/mm$^2$) = 35.627 ln Zp + 293.07 ...........(i)

$e_f$ (%) = 4.0131 ln Zp + 8.648 ..........(ii)

q (%) = 5.541 ln Zp + 19.748 ...........(iii)

$\sigma_Y$ (N/mm$^2$) = 9.836 Zp + 165.96 ..........(iv)

Similarly the Fig. 17 shows that the increase in area fraction of finer dendrite (Df area%) of the weld enhances its $\sigma_U$, ef and q significantly along with a minor increase in $\sigma_Y$ by following the empirical expressions as given below having coefficient of correlation in the range of 69 to 78%.

$\sigma_U$ (N/mm$^2$) = 1.406 $D_f$ + 199.69 ..........(v)

$e_f$ (%) = 0.064 $D_f$ + 3.114 ..........(vi)

q (%) = 0.108 $D_f$ + 11.09 ..........(vii)

$\sigma_Y$ (N/mm$^2$) = 0.149 $D_f$ + 163.8 ..........(viii)

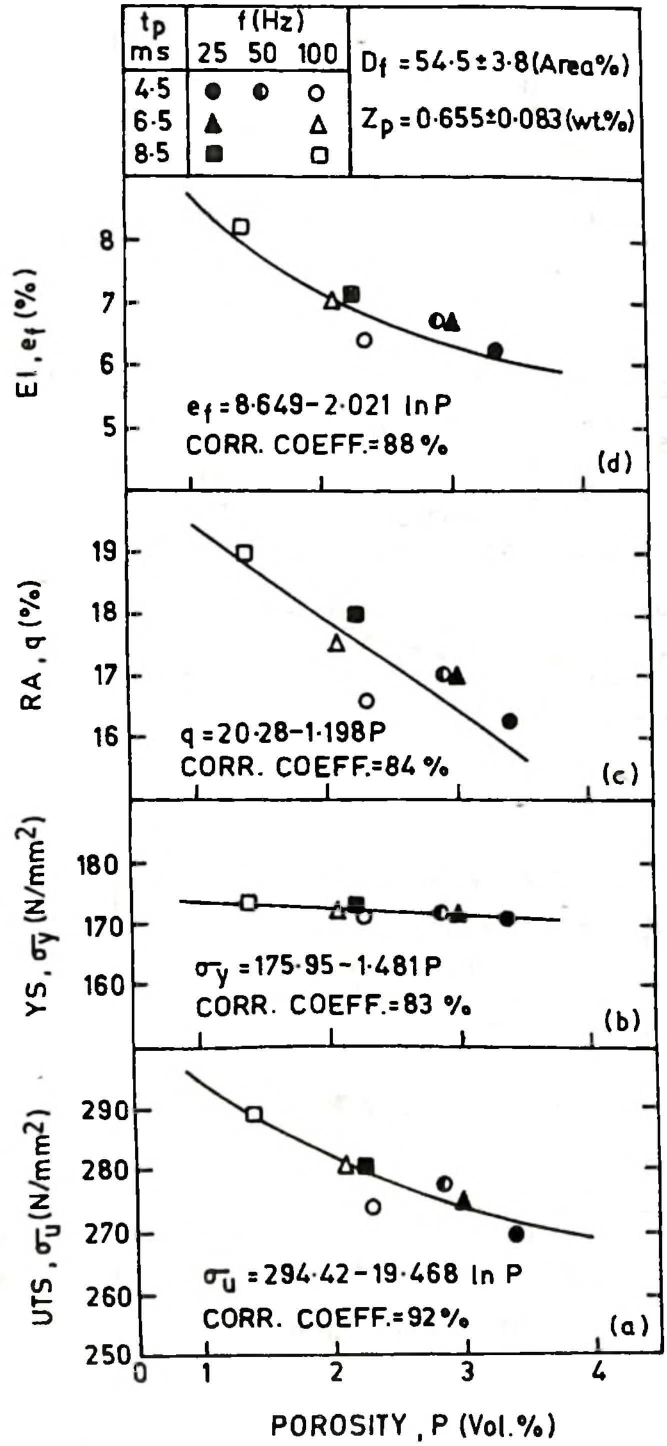


**Fig. 18 :** At a given zinc pick-up and finer dendrite fraction the influence of porosity content on the (a) UTS, (b) YS, (c) RA and (d) El. of the weld.

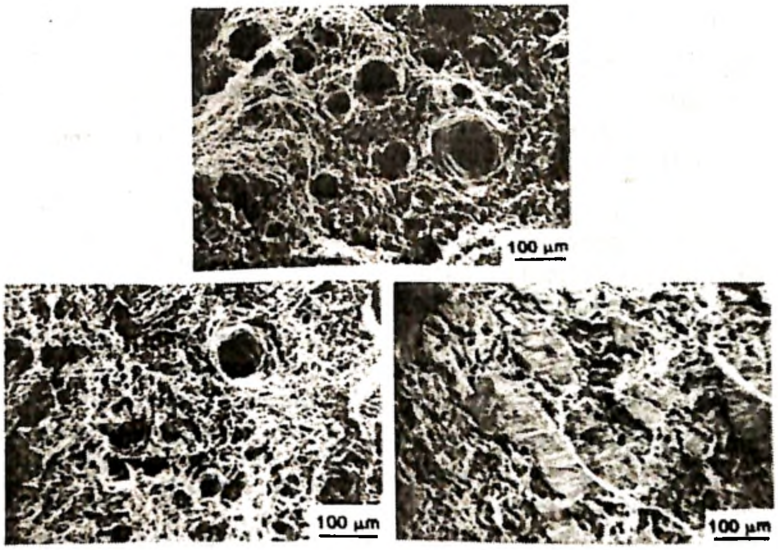


**Fig. 19 :** Typical fractographs of the (a) conventional weld and pulsed current welds showing comparatively (b) low and (c) high tensile strength.

The influence of porosity content on tensile properties of the weld, depicted in Fig. 18, shows that the porosity is having significant adverse effect on its $\sigma$u, ef and q. However, the adverse effect of porosity on $\sigma_Y$ of the weld has been found (Fig. 18) relatively lower. The correlation of porosity content (P vol.%) with the $\sigma$u, $e_f$, q and $\sigma_Y$ of the weld, having coefficient of correction in the range of 83 to 92% are as follows.

$$\sigma_U(\text{N/mm}^2) = 294.42 - 19.468 \text{ In } P \qquad \text{..........(ix)}$$

$$e_f\ (\%) = 8.649 - 2.021 \text{ in } P \qquad \text{..........(x)}$$

$$q\ (\%) = 20.28 - 1.198\, P \qquad \text{..........(xi)}$$

$$\sigma_Y\ (\text{N/mm}^2) = 175.95 - 1.481\, P \qquad \text{..........(xii)}$$

The typical SEM fractographs of the conventional continuous current weld showing comparatively low tensile strength has been shown in Fig. 19(a). Similarly the typical fractographs of pulsed current welds having comparatively low and high tensile strength are depicted in Fig. 19 (b and c) respectively. The fractographs reveal that the welds having lower tensile strength (Fig. 19 (a and b)) are fractured predominantly in ductile mode containing dimples throughout the matrix whereas, the weld showing comparatively higher tensile strength is fractured in mixed mode (Fig. 19(c)) with considerable amount of cleavage in the matrix. The cleavage may have formed due to micro-segregation of zinc in these regions making them comparatively hard due to formation of comparatively larger amount of precipitates at these locations. The presence of cleavage further supports the observed enhancement of strength of the weld. However, the presence of a significant amount of dimpled region along with the cleavage in the matrix of the comparatively high strength weld may have restored the ductility in it up to certain extent.

## CONCLUSIONS

During pulsed current GMAW the variation in pulse parameters namely the pulse frequency and duration has been found to affect tensile properties of the weld significantly, primarily due to their considerable influence on the weld characteristics such as zinc pick-up, amount of precipitate, porosity content and finer dendrite fraction of a multipass Al-Zn-Mg alloy weld. The increase in zinc pick-up has been found to enhance the precipitate content as well as the tensile strength of the weld. The increase in finer dendrite fraction has also been found to improve the tensile properties whereas the porosity content of the weld is found to adversely affect the tensile properties of the weld. The use of pulse current GMA welding at suitable pulse parameters has been found to result in far superior tensile properties of the weld as compared to those observed in case of conventional continuous current GMA welding.

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