RESEARCHERID
THOMSON REUTERS

[Pal* *et al.*, 6(5): May, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A COMPARATIVE STUDY OF GROOVE DESIGN AND WELDING PROCESS ON SHRINKAGE STRESS, RESIDUAL STRESS AND TENSILE PROPERTIES OF P91 STEEL

Vinay Kumar Pal*, Dr. L. P. Singh, C.Pandey

* M. Tech, SHUATS, ALLAHABAD Department of Mechanical Engineering Sam Higginbottom University of Agriculture, Technology And Sciences (U.P State Act No. 35of 2016, as passed by the Uttar Pradesh Legislature) Allahabad, India

Assistant Professor, SHUATS, ALLAHABAD Department of Mechanical Engineering Sam Higginbottom University of Agriculture, Technology And Sciences (U.P State Act No. 35of 2016, as passed by the Uttar Pradesh Legislature) Allahabad, India

DOI: 10.5281/zenodo.571600

ABSTRACT

Present research work deals with the selection of appropriate range of welding parameters and procedure that is used for conventional and narrow groove welding of thick sections at different welding process.The development of narrow gap welding procedure by P-GMAW process is carried out for joining of thick sections by appropriate reduction in number of weld passes and amount of weld metal. Study of the effect of variation in groove design and welding processes was performed by summarizing the mechanical properties of transverse shrinkage, tensile strength, and residual stress of weld joint.

KEYWORDS: Conventional; V-groove, Narrow groove, Shrinkage, residual stress, Tensile properties.

INTRODUCTION

A333 grade3 pipe was generally used for low temperature application. A considerable change in the mechanical properties was observed during the manufacturing processes such as welding. The change in mechanical properties was observed because of microstructure transformation. Joining of P91 pipe in industry is generally carried out by gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW) with GTAW root pass [1]. During the multi-pass welding, the weld metal undergoes localized solidification shrinkage [2]. The repetitive influence of thermal cycle from subsequent weld passes affect stresses developed in weld groove upto certain extent and finally cause continuous change in groove design and groove area with every weld passes[3]. Due to change in grove size with subsequent pass, groove angle will also change and it will not be uniform at all location in each quadrant of pipe. It is observed that the change in groove size and groove area is more in case of V-groove welding than narrow-groove welding. This occurred because of less area present at the narrow-groove (less weld metal deposition) than V-groove.

In view of the above the present investigation on welding of thick wall A333 garde3 steel pipe has been carried out using pulse current gas metal arc welding in narrow weld groove. The studies have been systematically planned in order to minimize the transverse shrinkage and stress using different welding process and weld groove design.

EXPERIMENTAL DETAILS

Base material

The investigation has been carried out using 22mm thick A333 grade3 pipe. The chemical composition of the base material has been given in **Table 1.**

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Table 1Chemical composition of base metal.

Material (A333 grade3)	Source	Chemical analysis (wt. %)								
		C	Si	Mn	p	S	Cr	Ni	Al	Cu
	*Laboratory test	0.2047	.1964	.5981	.0122	0.0070	0.0635	0.1668	0.0392	0.018

Groove design and Experimental setup

To prepare the butt weld joint, pulsed gas metal arc welding with copper coatedcontinuous solid state AWS/SFA 5.18 ER: 70S-6was used. The shielding gas of composition 80% argon and 20% CO_2 was used. The filler wire/electrode was selected by generally matching the physical and chemical characteristics of base metal.Thechemical composition of filler metal used in welding process is given in Table 2.

Table 2 Chemical composition of filler metal

Filler metal	Chemical composition					
	C	Mn	Si	S	P	Cu
	0.15	1.40	.80	.035	0.025	0.50

A modern transistorized power source, ARISTO 2000-LUD 450 UW model was used to carry out welding. The power was capable to operate for different welding processes such as GTAW, SMAW, GMAW and P-GMAW with DC straight and reverse polarity in both the synergic and non-synergic modes at a given command on selection of material and diameter of electrode/filler wire as well as shielding gas.A suitable fixture for welding of pipes in 1GR position is utilized for making the butt joint. The system has manipulator for rotation of pipe supported by a flexible torch holding and positioning facility fitted to a modern torch carriage trolley required for GMA and P-GMA welding of pipes. The welding speed for said dimension of pipe can be controlled in the range of 1.0 – 19 cm/min by an electronically controlled mechanism (AC drive). The welding set-up consists of mechanized GMA welding gun travelling equipment and a "KAT" travel carriage capable to hold the welding torch rigidly in the rack and pinion arms and clamping pivots to adjust it at any desired position. The travelling equipment was having facility to vary the travel speed in the range of 2.6 -83.8 cm/min with a digital display. The torch carriage trolley which could also be locked at desired location helped further in positioning of torch especially inside the weld groove at a precisely maintained contact tip to work piece distance during welding operation. The manipulator having a three-jaw chuck for firm holding and centering of pipes was used for its welding in 1GR position.

The conventional V-groove used for preparation of weld confirms the ASME section ix of boiler and pressure code. For narrow groove design following parameters should be kept in mind: 1. groove width - minimum groove width is selected based on nozzle design so that it insures the GTAW pass at root, 2. angle of attack – 5 ° - 15° for desired groove wall fusion, 3. depth of fusion – 0.5 – 1.0 mm for sound weld joint, 4. cathode to work distance is 13mm. Initial groove opening and groove area are presented in **Table 3.**

Table 3 Groove area for conventional and narrow grooves

Groove Design	Groove area (mm^2)
Conventional (groove width 26)	338.12
Narrow 1(groove width 15)	217.50
Narrow 2(groove width 13.4)	202.34

Welding process and parameters

The welding was carried out in 1GR position by holding the pipes in a rotating table with the help of three jaw self-centering chuck. For making the root pass in pipes a clamping attachment was prepared as shown in fig.4.6. After making the holding device, the weld joints were prepared by autogenous GTAW root pass. The GTAW pass

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

was carried out using water cooled torch with 7mm diameter gas nozzle and 3.2 mm diameter tungsten electrode under the shielding of commercial argon at a flow rate of 12 L/min in conventional as well as narrow groove weld. The parameter used for root pass in weld is shown in **Table 4.**

Table 4 parameter used for root pass

Voltage (V)	Current(A)	Welding speed (cm/min)
12	110	6-7

The P-GMA weld joints were initially prepared with conventional V-groove having Ø=0.15 at9.5± 0.35 kJ/cm heat input. Having same parameter, the narrow gap 15 and 13.6 P-GMA welding of pipes was carried out at a same heat input of 9.5± 0.5 kJ/cm. At four equally divided quadrants of circumferential locations, the transverse axial shrinkage after each pass of multi-pass weld deposition was estimated by measuring the difference of distance between two axially located points at a known distance apart across the joint marked by centre punching prior to welding.The record sheet of each weld giving parameter details, overall transverse shrinkage and thermal profile has been presented in the result. Heat input per pass was calculated by assuming a process efficiency or thermal heat transfer efficiency (η_a) of the arc as 0.7[4].

$$\text{Heat input (KJ/cm)} = \eta \times \frac{\text{Welding current (A)} \times \text{Arc Voltage (V)}}{1000 \times \text{welding speed (cm/s)}} \quad \ldots..(1)$$

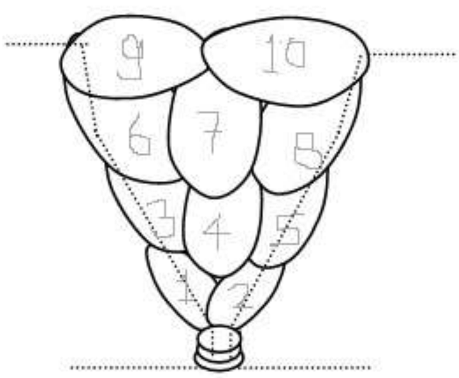
The GMA welding of pipes was carried out only in conventional groove with spray mode of metal transfer using developed narrow GMA welding torch nozzle. The GMA weld deposition was primarily carried out by using 1.2 mm diameter solid mild steel filler wire under argon gas shielding at a flow rate of 18L/min with direct current electrode positive (DCEP) polarity at an electrode extension of 12-14 mm. The welding parameters and transverse shrinkage for multi-pass weld deposition were measured has been mentioned in the results. Heat input was calculated also as per eq. (1) by considering process efficiency on an average as 0.7.

The welding process parameter for GMAW and pulse-GMAW process are tabulated in **Table 5.**

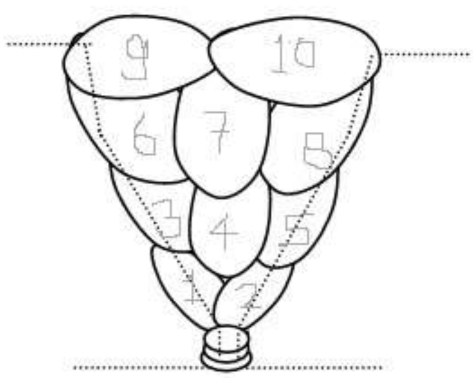
Table 5 welding parameters

Welding Process	Welding Parameter								
	Voltage (V)	Heat input	Travel speed S (Cm/min)	I/I_m (A)	Pulse Parameters I_p (A)	I_b (A)	f (Hz)	t_b (ms)	t_p (ms)
GMAW	24 ± 1	11.6 ± .5	20	230 ± 4	_	_	_	_	_
P-GMAW	24± 1	9.5 ± .5	16	160	324	160	50	13	7

Welding sequence followed in P-GMA and GMA conventional V-groove weld joints is as schematically shown in figure below.



P-GMAW



GMAW

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Fig. 1 Schematic representation of passes in Conventional grooves (a) P-GMAW, (b) GMAW

Transverse shrinkage, shrinkage stress, residual stress, and tensile test

The residual stresses at the top and root of the pipe weld joints were measured by placing three-element strain gauge rosette system in the desired locations and using hole drilling technique. The measurement of residual stresses has been carried out at different locations of the weld and HAZ adjacent to the fusion line (FL). The surface area of selected region for the measurement of residual stresses was mechanically smoothened and cleaned by acetone prior to fixing the strain gauge.

Cumulative transverse shrinkage was measured after each pass at four circumferential segments during multi-pass deposition as schematically as shown in Fig. 2.

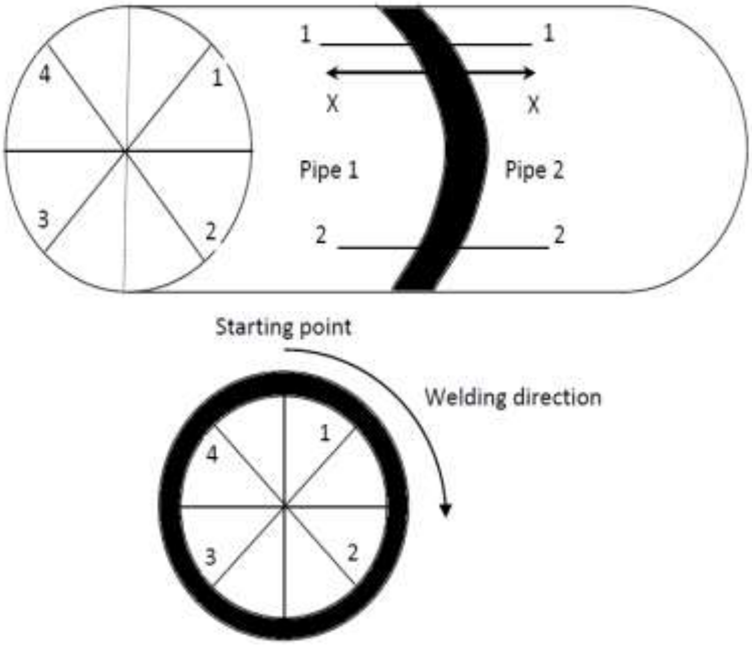


Fig. 2 Schematic diagram of measurement of transverse shrinkage at different locations of pipe weld

It is calculated through the evaluation of transverse shrinkage, number of passes and average thickness of weld metal deposited per layer. It is given by [5];

$$\sigma_{tr(i-i)} = \frac{\Delta_{tr(msd)}}{N} \times \frac{a}{h} \times \frac{E}{L_s} \tag{2}$$

where,

$\Delta_{tr(msd)}$ = transverse shrinkage (mm), N = number of weld layer, E = modulus of elasticity (GPa) L_s = straining length (55 mm) (Fig.3), h = wall thickness of pipe, a = average thickness of weld metal deposited per layer

After calculating the transverse shrinkage stress ($\sigma_{tr(i-j)}$) at each location of the pipe weld, the average transverse shrinkage stress (σ_{avg}) generated in entire pipe weld weredivided into the four quadrants along with its standard deviation which has been estimated as follows,

$$(\sigma_{avg}) = \sum_{i=0}^{4} \frac{\sigma_{tr(i-j)}}{4} \tag{3}$$

Standard deviation = $\sqrt{\left(\frac{1}{4} \times \sum_{i=0}^{4} (\sigma_{(i-j)} - \sigma_{avg})^2\right)}$ (4)

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Based on the estimation of transverse shrinkage stress at different location of pipe weld, the transverse shrinkage stress in each quadrant has been estimated by considering the average transverse shrinkage stress at the end point of any quadrant.

$$\sigma_{(i-j)} = \frac{\sigma_{i-i} + \sigma_{j-j}}{2} \quad (5)$$

The residual stress measurement was performed by using the hole drilling method as per ASTM E837-13 standard. TML make FRS-2-1, three elements strain gauge rosettes was pasted to measure the residual stress in weld fusion zone, HAZ and root face. At the center of strain gauge rosette, hole of 2 mm diameter was created by using the end mill cutter. Residual longitudinal and axial stress at the top and root face of P91 plate weld was estimated by using the ASTM E837-13 standard. To overcome the effect of stress concentration and plasticity during the residual stress measurement, the induced error has been estimated for the strain gauge FRS-2-11 having drilled hole of 2 mm diameter [6].

The tensile testing was carried out using round tensile specimen confirming to ASTM E8M specification and the properties are reported as an average of test results of at two specimens. The tests were carried out at a speed of 1mm/min at universal testing machine. The tensile specimens of the base metal and weld joints of pipes were machined in transverse direction only. The transverse tensile specimens of the base metal and weld jointwere having 50mm gauge length and 10 mm diameters.

RESULTS AND DISCUSSION

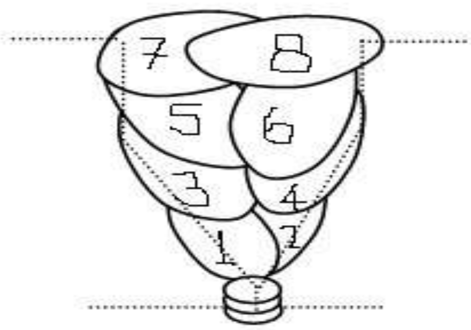
Transverse shrinkage distribution

Theoveralltransverseshrinkageinfourcircumferentialsegmentsofmulti-passP-GMAandGMA welds ofpipe are asshown in Table 5. In GMA welding the mode of metal transfer is short circuit but in P-GMA welding mode of metal transfer is pulsed thus it imparts high heat input than P-GMA welding process. In P-GMA welding, due to pulsed mode of current, the mean current value for P-GMA welding process is much less than conventional GMA welding. Cumulative shrinkage in GMA weld is higher than P-GMA weld.

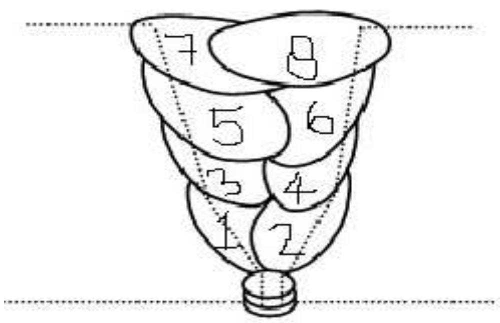
Table 5 Cumulative shrinkage for conventional groove

PROCESS	Ω (KJ/Cm)	Cumulative shrinkage at different locations on pipe,(mm)					Average Shrinkage (mm)
		1-1	2-2	3-3	4-4		
P-GMAW	9.5	1.52	1.41	1.45	1.14		1.36
GMAW	11.6	2.54	2.01	2.95	2.05		2.07

Welding sequence followed in narrow groove P-GMA weld joints is as schematically shown in **Fig. 3.**



Groove width-15



Groove width-13.4

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Fig. 3 Schematic representation of passes in narrow welds having (a). Groove width-15 (b) Groove width-13.4

Table 6 Cumulative shrinkage for narrow groove

Process	Ω (KJ/Cm)	Cumulative shrinkage at different locations on pipe,(mm)				Average Shrinkage (mm)
		1-1	2-2 3-3	4-4		
P-GMAW Weld width-15	9.5	1.46	1.22 .89	1.03		1.15
P-GMAW Weld width13.6	9.5	1.14	1.10 1.11	1.12		1.06

Parameter used for narrow groove welding is same for both groove but difference only in their weld deposition area. The weld deposition area is higher in narrow groove 15 than narrow groove 13. When higher the weld metal deposition, higher will be the shrinkage therefore shrinkage in narrow groove 15 is higher than narrow groove 13.6. Results of transverse shrinkage for narrow grooves are given in **Table 6.** Thecomparisonof transverse shrinkageinall grooves is shown in **Fig. 4.**

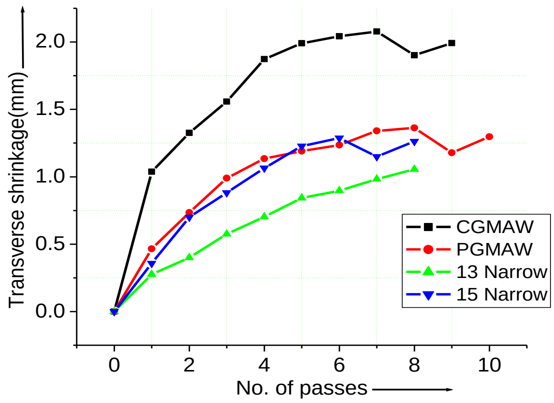


Fig 4 Cumulative shrinkage for all welds

Thermal profile

Formeasuringthermalprofile, thermocouplewasattachedtothepipeat20mm awayfrom the edgeof groove. Thetemperaturehasbeenrecordedat specified particular interval for each pass. Inter pass temperature was maintained about 40 ºC during the filling passes. Thermal profile is drawn for those pass which have maximum temperature above at all passes. Temperature in GMA weld is higher than P-GMA weld because parameter used for GMA welding has high heat input comparison to P-GMA weld in conventional groove.Thermalprofile for conventionalP-GMAandGMAweldisshown in**Fig. 5.** Parameters used for narrow groove welding are at same heat input. Therefore maximum temperature in narrow groove 15 is closely same to narrow groove 13.6. Thermal profile for narrow weld is shown in **Fig. 6.**Comparison of all thermal profile is shown in **Fig. 7.**

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

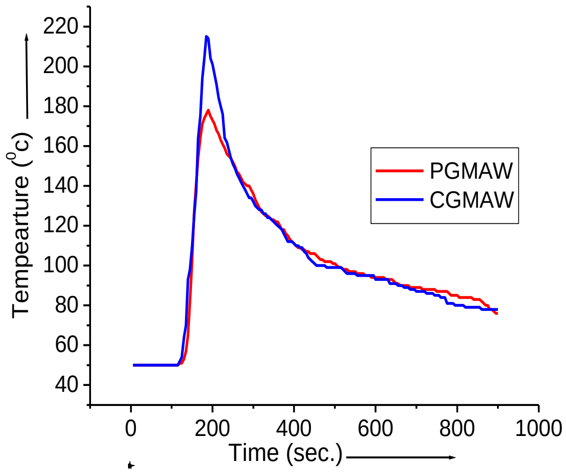


Fig 5 Thermal profile for Conventional Welds

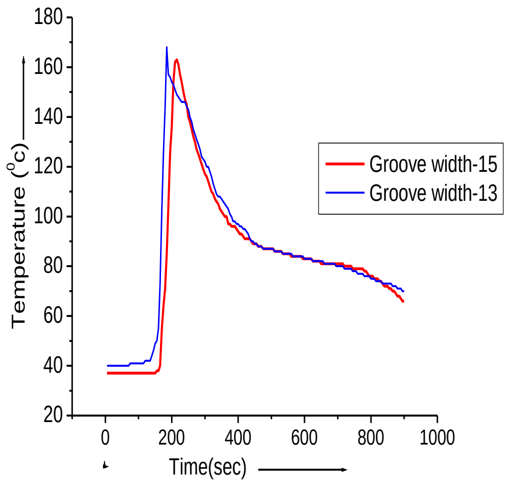


Fig 6Thermal profile for Narrow Welds

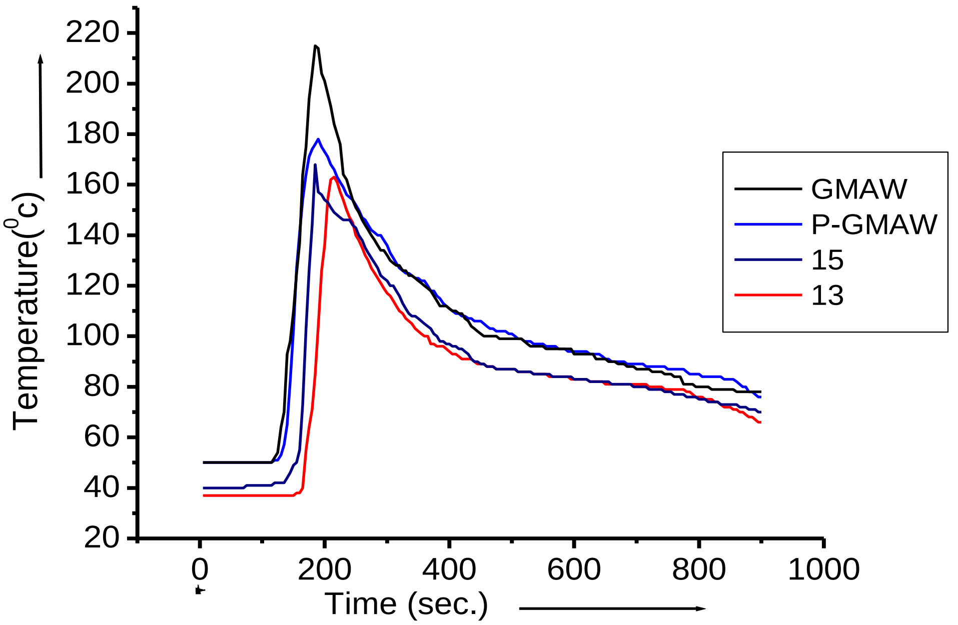


Fig 7 Thermal profile for all welds

Residual stress

The longitudinal and transverse residual stresses present at different locations on the top of the weld, as compared to the centre and fusion lines of the P-GMA and GMA weld joints in conventional grooves are shown in **Fig. 8(a-b).**P-GMAW process is found to be advantageous in respect of reduction in residual stress distribution in A333 grade 3 pipe joint than GMAW for similar groove design.The figures show that at the top and root of weld, longitudinal residual stress reduces by 35-45% and 15-20% respectively for P-GMA in comparison to GMA welds. The transverse residual stress also follows a similar trend but having a magnitude comparatively lower than the longitudinal residual stress of the weld joint as it is commonly observed in earlier works.

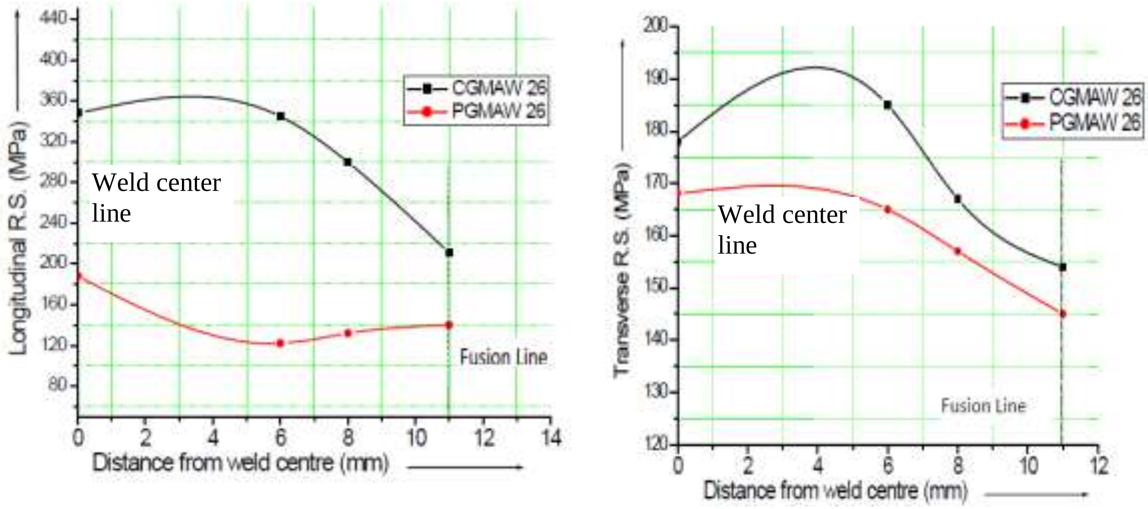


Fig. 8 Distribution of (a) longitudinal and (b) transverse residual stresses at the top in the P-GMA and GMAweld joints in conventional groove.

The longitudinal and transverse residual stresses present at different locations on top of the weld to the centre and fusion lines of the two narrow groove having groove width 15 and 13.4 P-GMA weld joints are shown in Fig. 9(a) and (b), respectively. The figures show that for different groove width at the top and the root of the weld, longitudinal residual stress reduces by 10-12% with reducing groove width by use of P-GMAW process. A considerable difference in the development of residual stresses in the conventional and narrow gap welds may be attributed primarily to the severity of thermo mechanical characteristics arising out of differential expansion and contraction stresses resulting from multi-pass deposition, which becomes comparatively milder in case of the narrow gap weld holding appreciably lower amount of weld deposit.

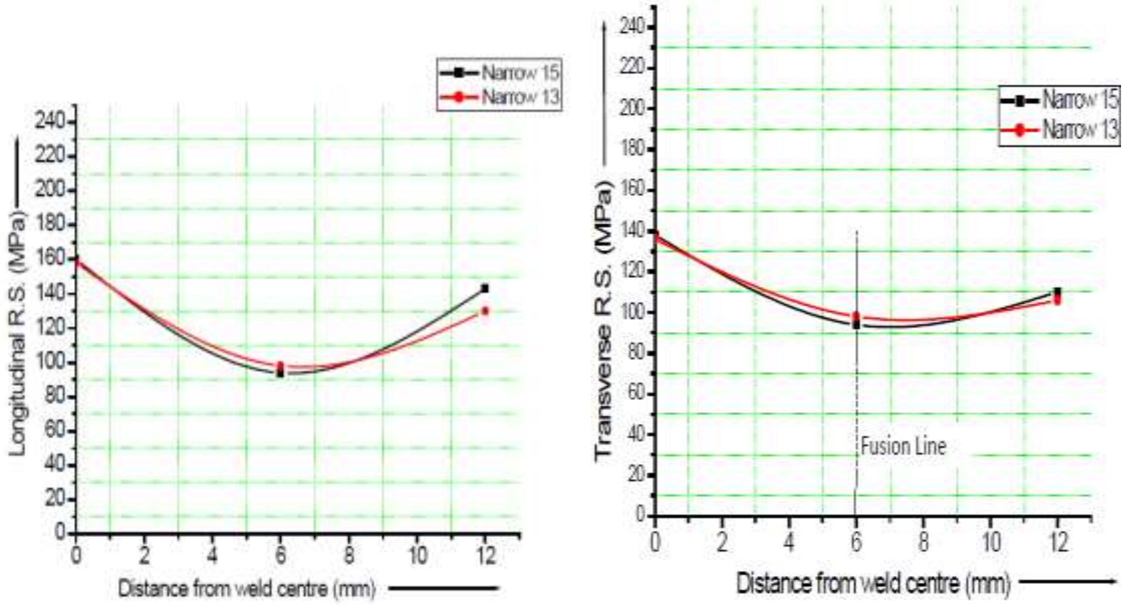


Fig. 9Distribution of (a) longitudinal and (b) transverse residual stresses at the top in the P-GMA welds joints in narrow grooves

Tensile properties
The tensile properties of P-GMA and GMA weld joints of the pipes along their transverse directions are shown in **Table 7.Tables 7** reveals that, P-GMA welds have significantly higher tensile properties than GMA weld joints

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

in conventional as well as narrow groove. One important point can also be depicted by results that Narrow gap P-GMA welds have higher strength than conventional P-GMA weld joints.

Table 7Tensile properties in GMA and P-GMA weld joints in different grooves in transverse direction

Process	Groove width (mm)	H.I. kJ/cm	TENSILE PROPERTIES			
			UTS (MPa)		YS (MPa)	
P-GMAW	26	9.5	560	557	418	426
			554		428	
	15	9.5	575	578	447	438
			580		443	
	13.4	9.5	572	570	435	442
			568		442	
GMAW	26	11.6	532	533	418	424
			534		425	

Transverse shrinkage stress

Calculation used for conventional GMA welds for transverse shrinkage stress is shown in **Table 8.Table 9** shows the nature of stress in the location of Conventional GMA welds similarly nature of transverse stress for P-GMAW weld for conventional, narrow groove 15 and narrow groove 13 are shown in **Table 10, Table 11 and Table 12**, respectively.

Nature of transverse shrinkage stress depends upon the heat input, number of passes and straining length used for making welds. Average shrinkage stress is higher in conventional GMA than any other P-GMA welds. It is due to high heat input used for GMA welds.

Table 8 Estimation of the $\sigma_{(i-i)}$ and $\sigma_{(i-j)}$ for the conventional groove pipe weld prepared by GMAW process

Estimation of the $\sigma_{(i-i)}$	Estimation of the $\sigma_{(i-j)}$
$\sigma_{(1-1)} = \frac{2.54}{10} \times \frac{4.13}{22} \times \frac{240\times10^3}{85} = 148.09$	$\sigma_{(1-2)} = \frac{\sigma_{(1-1)} + \sigma_{(2-2)}}{2} = \frac{148.09+108.34}{2} = 128.215$
$\sigma_{(2-2)} = \frac{2.01}{10} \times \frac{4.2}{22} \times \frac{240\times10^3}{85} = 108.34$	$\sigma_{(2-3)} = \frac{\sigma_{(2-2)} + \sigma_{(3-3)}}{2} = \frac{108.34+166.58}{2} = 137.46$
$\sigma_{(3-3)} = \frac{2.95}{10} \times \frac{4.4}{22} \times \frac{240\times10^3}{85} = 166.58$	$\sigma_{(3-4)} = \frac{\sigma_{(3-3)} + \sigma_{(4-4)}}{2} = \frac{166.58+114.18}{2} = 140.38$
$\sigma_{(4-4)} = \frac{2.05}{10} \times \frac{4.34}{22} \times \frac{240\times10^3}{85} = 114.18$	$\sigma_{(4-1)} = \frac{\sigma_{(4-4)} + \sigma_{(1-1)}}{2} = \frac{114.18+148.09}{2} = 131.135$
Estimation of the σ_{avg}= $(\frac{128.215+137.46+140.38+131.135}{4}) = 134.29$	
Estimation of S.D.= $\sqrt{(\frac{1}{4}\times((134.29-128.215)^2+(134.29-137.46)^2+(134.29-140.38)^2+(134.29-131.135)^2)} = \pm 4.73$	

Table 9 Nature of Transverse stress at different location of conventional GMA pipe weld

Weld location	Transverse shrinkage stress(MPa)	Nature	Avg. Transverse Shrinkage Stress ± Std.Dev.
1-2	128.215	Compressive	

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

2-3	137.46	Tensile	134.29±4.73
3-4	140.38	Tensile	
4-1	131.135	Compressive	

Table 10 Nature of Transverse stress at different location of conventional P-GMA pipe weld

Weld location	Transverse shrinkage stress(MPa)	Nature	Avg. Transverse Shrinkage Stress ±Std.Dev.
1-2	77.645	Tensile	75.165±2.8
2-3	78.305	Tensile	
3-4	72.685	Compressive	
4-1	72.025	Compressive	

Table 11 Nature of Transverse stress at different location of Narrow P-GMA pipe weld having groove width 15

Weld location	Transverse shrinkage stress(MPa)	Nature	Avg. Transverse Shrinkage Stress ±Std.Dev.
1-2	101	Tensile	88.6±9.9
2-3	82.1	Compressive	
3-4	76.2	Compressive	
4-1	95.1	Tensile	

Table 12 Nature of Transverse stress at different location of narrow P-GMA pipe weld having groove width 13.6

Weld location	Transverse shrinkage stress(MPa)	Nature	Avg. Transverse Shrinkage Stress ±Std.Dev.
1-2	84.8	Compressive	86.69±1.35
2-3	86.4	Compressive	
3-4	88.585	Tensile	
4-1	86.985	Tensile	

CONCLUSIONS

1. In comparison to conventional groove GMA, P-GMA welding can produce sound weld at a comparatively lower heat input of 9.5 $\pm$ 0.3 kJ/cm. Thus, the use of P-GMA welding reduces transverse shrinkage and residual stress of weld than GMA weld.
2. Narrow groove welding procedure using P-GMAW process reduces number of passes and area of weld deposit by about 35-40 % by volume.
3. The use of P-GMAW process reduces residual stresses in narrow groove design at almost constant heat input.
4. The use of P-GMA welding increases tensile properties of the weld by almost 5-10% than GMA weld.
5. The advantages of narrow groove design is having low deposit area so number of passes to joint for 22mm thick pipe also reduces, which also reduces shrinkages and residual stresses of about 20-30% as compared to conventional groove design.

REFERENCES

[1] B.Y.H.H. Sun, Development of Welding Wire for High-Purity Austenitic Stainless Steels, (1999) 38–45.
[2] D. Deng, H. Murakawa, W. Liang, Numerical and experimental investigations on welding residual stress in multi-pass butt-welded austenitic stainless steel pipe, Comput. Mater. Sci. 42 (2008) 234–244. doi:10.1016/j.commatsci.2007.07.009.
[3] P. Dong, Residual Stress Analyses Of A Multi-Pass Girth Weld: 3-D Special Shell Versus Axisymmetric Models, J. Press. Vessel Technol. 123 (2001) 207–213. doi:10.1115/1.1359527.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

[4] C. Pandey, A. Giri, M.M. Mahapatra, On the prediction of effect of direction of welding on bead geometry and residual deformation of double-sided fillet welds, Int. J. Steel Struct. 16 (2016) 333–345. doi:10.1007/s13296-016-6007-z.

[5] B.P.K. GHOSH, K. Devakumaran, A.K. Pramanick, Effect of Pulse Current on Shrinkage Stress and Distortion in Multipass GMA Welds of Different Groove Sizes, Aws. 89 (2010) 43–53

[6] A. Giri, C. Pandey, M.M. Mahapatra, K. Sharma, P.K. Singh, On the estimation of error in measuring the residual stress by strain gauge rosette, Meas. J. Int. Meas. Confed. 65 (2015) 41–49. doi:10.1016/j.measurement.2014.12.047.

CITE AN ARTICLE:

Pal, V. K., Singh, L. P., Dr, & Pandey, C. (2017). A COMPARATIVE STUDY OF GROOVE DESIGN AND WELDING PROCESS ON SHRINKAGE STRESS, RESIDUAL STRESS AND TENSILE PROPERTIES OF P91 STEEL. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *6*(5), 65-75. doi:10.5281/zenodo.571600