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Research Article

Selection of Joint Preparation Procedure based on Cost-effectiveness and Defects analysis of Double-V SMAW Joint

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***Abstract* –** Double sided shielded metal arc welded joint has wide applications in fabrication sector for production of critical joints but the root pass in those joint leads to many defects, mainly due to the sudden cooling because the adjacent base material is at room temperature in the start of welding and compromises the quality of the weldments. In the fabrication industry, root pass removal is a routine practice for producing quality joints using grinding and air carbon arc gouging. In this research, comparative study of cost-effectiveness and defects analysis of the above root pass removal procedures have applied to the double-v mild steel shielded metal arc welded joint for the selection of better procedure. For cost calculation of joints, labor cost (LC), energy cost (EC), material cost (MC) and overhead cost taken into account and defects examined by the visual inspection, liquid penetrant test, radiographic test and optical microscope. The results showed overall 4.7% lower cost and enhanced quality in terms of macro/micro-defects for ground joint. The major contribution to the lower cost of ground joint has given by the consumables and energy but in defects analysis, only width difference in both sides' reinforcement i.e., front and back have observed for gouged joint and relatively more numbers of micro-defects.

Keywords – Shielded Metal Arc Welding, Double-V Joint, Root Pass, Grinding, Air Carbon Arc Gouging, Cost-Effectiveness, Defects

I. INTRODUCTION

Shielded metal arc welding (SMAW) have wide applications in engineering, from structures to the high-pressure vessels, since it produces weldments that are highly efficient, affordable, and flexible. In this technique electrode holder attached to the power supply (DC or AC) is used to clamp the flux covered electrode bare metal end (next to the welding tip) during operation. The electrode holder has an insulated grip that allows a human welder to hold and move it. In a welded joint, properties are typically sensitive to welding conditions such as welding process, heat input, preheat or inter-pass temperature, electrode composition, and plate thickness because the grain sizes changes. A material's mechanical properties largely depends on its grain size [1]. The weldment excellence depends on the quality of joints design and welding i.e., controlling of defects (surface and internal) is sought for accomplishing the best quality. Porosity, cracks and inclusions leads to the poor performance of the welded joint [2] [3]. Low quality welded joints can produce multiple problems in products both at the time of installation and during the service, which costs a lot to the customers. The surface defects can be controlled by visual inspection, liquid like circular, parallelogram and semicircular etc. with size up-to 1 μm have observed by many researchers in the deposited weld metals [4] [5] [6]. Choong and his colleague [7] studied the effect of different heat inputs on the API-65 grade alloy welded by high frequency electric resistance welding and examined the chemical composition of welded area and concluded that oxides could not be squeeze out, resulting in the defects. Additionally, it has been discovered that the amount of these flaws can be significantly decreased by raising the V-shaped angle and optimizing the heat input range. Numerous types of micro-defects, including vacancies, porosities, and micro-cracks, are invariably present in the material and have a substantial impact on its functionality. Around micro-defects, material crack frequently begins and progresses, which finally leads to the failure of the weldment [8]. P O Maruschak et al. [9] investigated the reason for cracking in the natural gas main pipeline of diameter 1420 mm and 1160 km long, working at 7.4 MPa fabricated almost 33 years ago by cutting small pieces. The metallic pieces investigated by the optical microscope and concluded that the cracks nucleated in the service due to the coalescence of micro-defects which were induced in the pipes during welding. ZK60 alloy friction stir welded joint tested under fatigue load and crack initiated between thermos-mechanical affected zone and heat affected zone at lower stress level due to the micro porosity [10].

Cost optimization is crucial in industrial sectors to increase product profitability without sacrificing quality. At the time of product design, a variety of permanent joining and temporary joining techniques are always taken into account. Joint preparation, material, labor, energy, and overhead costs, all are incorporated in the cost of welding joints. J. tusek with his colleagues [11] welded long L sections of steel by submerged arc welding with single, twin and triple wire and concluded that costs for welding with single wire was 20 % and 30 % higher than twin and triple-wire electrode respectively. Friction stir welding is cost effective for larger annual penetrant examination, magnetic particle inspection and internal macro-defects can be examined by radiographic and ultrasonic testing techniques but the issue of the micro-defects persists. However due to affinity of the molten metal for the oxygen, the porosities in the welded joint cannot be eliminate completely [4]. The porosities of various shapes production; however, metal inter gas and tungsten inert gas for small-volume production in case of pipes welding [12].

The previous research has shown that the micro-defects exist in the joints and leads to failure during service. The defects controlling at the time of welding is most economical because repair in service leads to the huge cost. Peng Yin with his team applied the ultrasonic waves to the base metal during the Gas metal arc welding of 7A52 aluminum plate and observed, greatly reduced welding porosity defects. Additionally, hot cracks are decreased and defects like undercut and partial penetration brought due to uneven arc energy were removed. The ultrasonic gas metal arc welded joint significantly improved both tensile strength and impact strength by more than 80%, when compared to traditional welded joints [13].

Boilers, pressure vessels, hydropower plant penstocks, nuclear power plants, oil and gas separators, kiln shells, and other critical products require 100% efficient welded joints. In these products double-sided welding is necessary, for the cost reduction and complete penetration through thick shells. Due to the fast cooling of the welding pool, the root pass in shielded metal arc welding joint is the most defective region. Various techniques are using in the fabrication industry to remove the root pass from the back side before application of the welding from that side. In this study the air carbon arc gouging and grinding procedure is applied to remove the root pass of the double-v SMAW welded joint and their effect on cost and quality of the joint have been investigated for the selection of the best procedure for industrial selector.

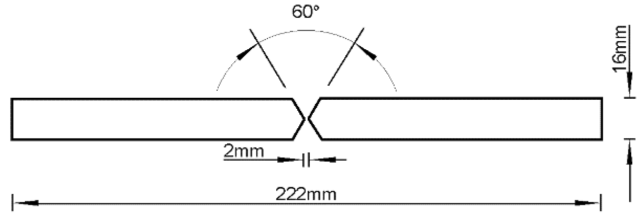

Fig. 1 Joint design

II. Materials and Method

Four plates of mild steel, boiler and pressure vessels grade (ASTM A516 grade 70) of dimensions 16 x 110 x 300 mm prepared by milling machine with chamfered angle 30º, fitted and tack welded on level fixture according to the joint design shown in Fig 1 (bevel angle 60º, Root face 1 mm and Root gape 2 mm). From the four plates of width 110 mm two joints of length 300 mm prepared and welded through shielded metal arc welding by the direct current electrode positive with all-positions low hydrogen electrode E7018-H4R through joint back-side preparation by air carbon arc gouging and grinding procedures according to the guidelines of American standard of mechanical engineer's sec IX [14]. In ground joint the root pass removed by the angle grinder of 1700W with 5" grinding disc and in gouged joint by the gouging electrode of diameter 6 mm with current 290 Amp, voltage 39 ~ 42V and gouging speed of 270 mm/min. The electrical energy consumption, time of each step and the amount of filler material consumed noted with great care. The chemical composition of the base metal and electrodes and welding parameters have shown in Table 1 and 2 respectively. The joints prepared by many welding passes and more passes made on the gouged joint due to the enlarged groove created by the air carbon arc gouging process. The detailed schematic of the welded joints preparation procedure has shown in Fig 2. Once the welding successfully finished, the joints cleaned by wire brush and visually inspected for all types of defects like undercut, surface porosity, weld crack, excess reinforcement etc. and then liquid penetrant test were applied for thorough surface defects examination. After satisfaction from all the surface defects, both the plates passed to radiographic testing for internal macro-defects and images of joints recorded. Finally, the welded plates moved to the electric discharge machine (EDM) and 3 samples of dimensions 16 x 20 x 55 mm extracted in normal section to the weld from each plate for the internal micro defects' analysis as shown in Fig 3. The joint center marked from thickness side on each sample and then polished by the emery papers of various grit numbers, followed by the diamond's paste papers according to the ASTM standard E3-11 [15] and examined by the optical microscope.

Table 1. Chemical composition (mass %) of base mmetal and electrode

Material	C	Mn	S	P	Si	Ni	Cr	Mo
ASTM A516 Grade 70	0.21	1.50	-	0.02	0.27	0.04	0.05	-
E7018-H4R	0.12	0.90	0.04	0.03	0.80	0.20	0.30	0.40

Table 2. SMAW parameters

Electrode diameter (mm)	Current nature	Current (A)	Voltage (V)	Welding speed (mm/min)
2.5	DC (RP)	85	20-24	138
3.2	DC (RP)	130	20-24	216

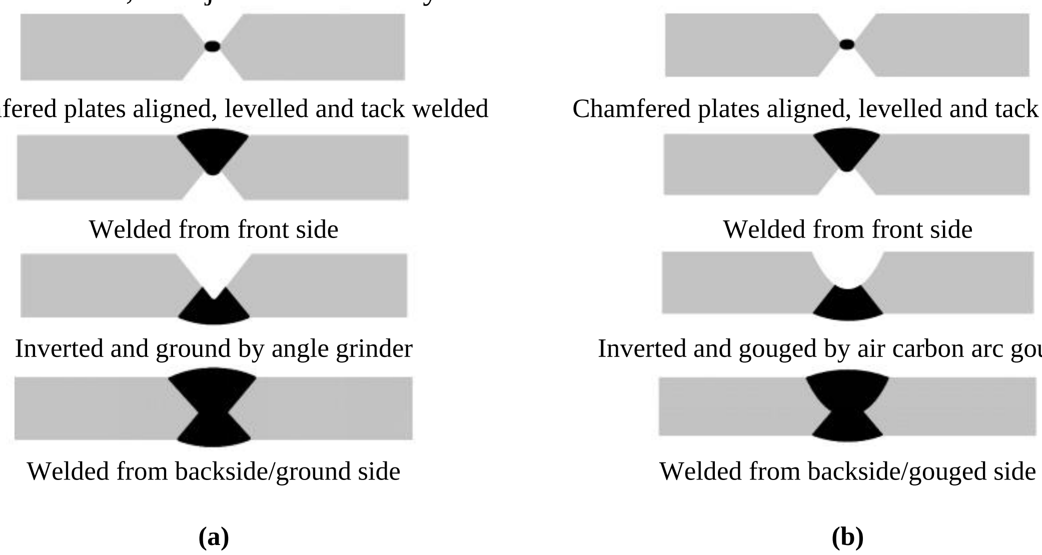

Fig. 2 Schematic of welded joint production (a) grinding (b) air carbon arc gouging

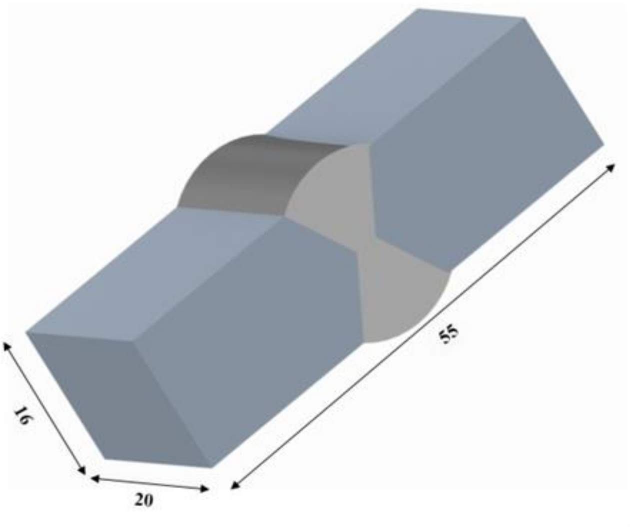

Fig. 3 Schematic of microscopic sample

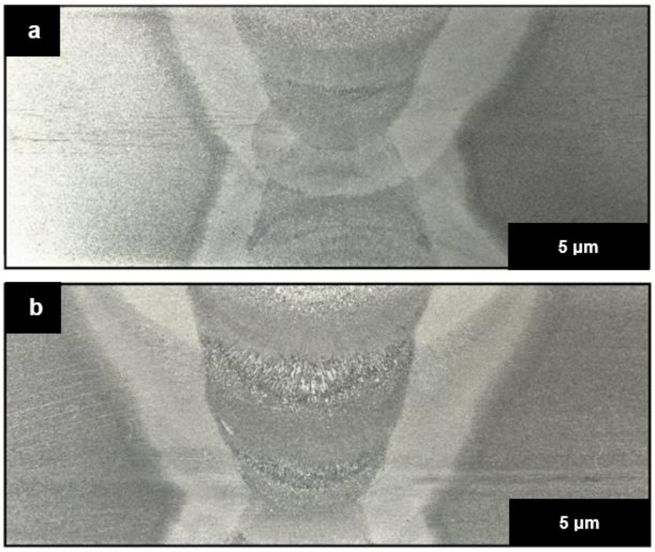

Fig. 4 Cross sectional macrographs of joints (a) ground (b) gouged

III. RESULTS AND DISCUSSION

A. *Defects Analysis*

Welded joints visually inspected and DP tested. In the examination it was observed that both the joints have no defects, which compromises the mechanical and metallographic properties of the weldments. On the other hand, air carbon arc gouged joint has front and back side weld reinforcement width difference, which affects the esthetic of the weld deposition as shown in Fig 4.

The radiographic testing films of the joints have shown in Fig 5, this technique works on the principle of local difference in thickness at the points of location, however the exact depth of defects can't be measure [16]. The films revealed that the deposited metal is completely free from macro-defects. The visual inspection, PT and RT have not shown any major macro-defect, despite the high affinity of molten metal for oxidation and fusion welding of plates in normal environment.

For micro-defects investigation, the optical microscopic images of weld metal joints taken at different magnification in various regions have shown in Fig 6. It illustrates that the scattered porosities exist throughout the weld metal but at some points clusters of porosities have found. Compared to the concentrated porosities, distributed porosities are not significantly worse. Lower number of micro-defects noted in the ground joint, this can be attributed to the comparatively lower number of welding passes for completion of the joint. The image (Fig 6c) 1st pass from back side in gouged joint have shown almost linear distribution of porosities which is transition zone of front and back groove. The reason for the highly populated porosities in this region may be due to the sudden cooling of welding 1st pass, which is generated by the relatively larger surface area at bottom due to curved shape as evident from Fig 2.The mechanical properties of weld deposits is inversely related to the amount of micro-defects [17] [18] [19] and for the above joints already higher

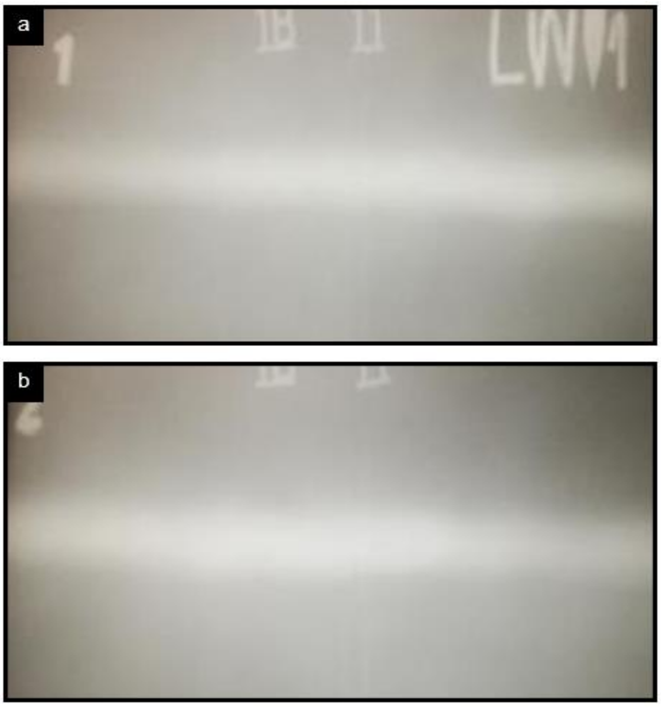

Fig. 5 X-ray film images (a) ground joint (b) gouged joint

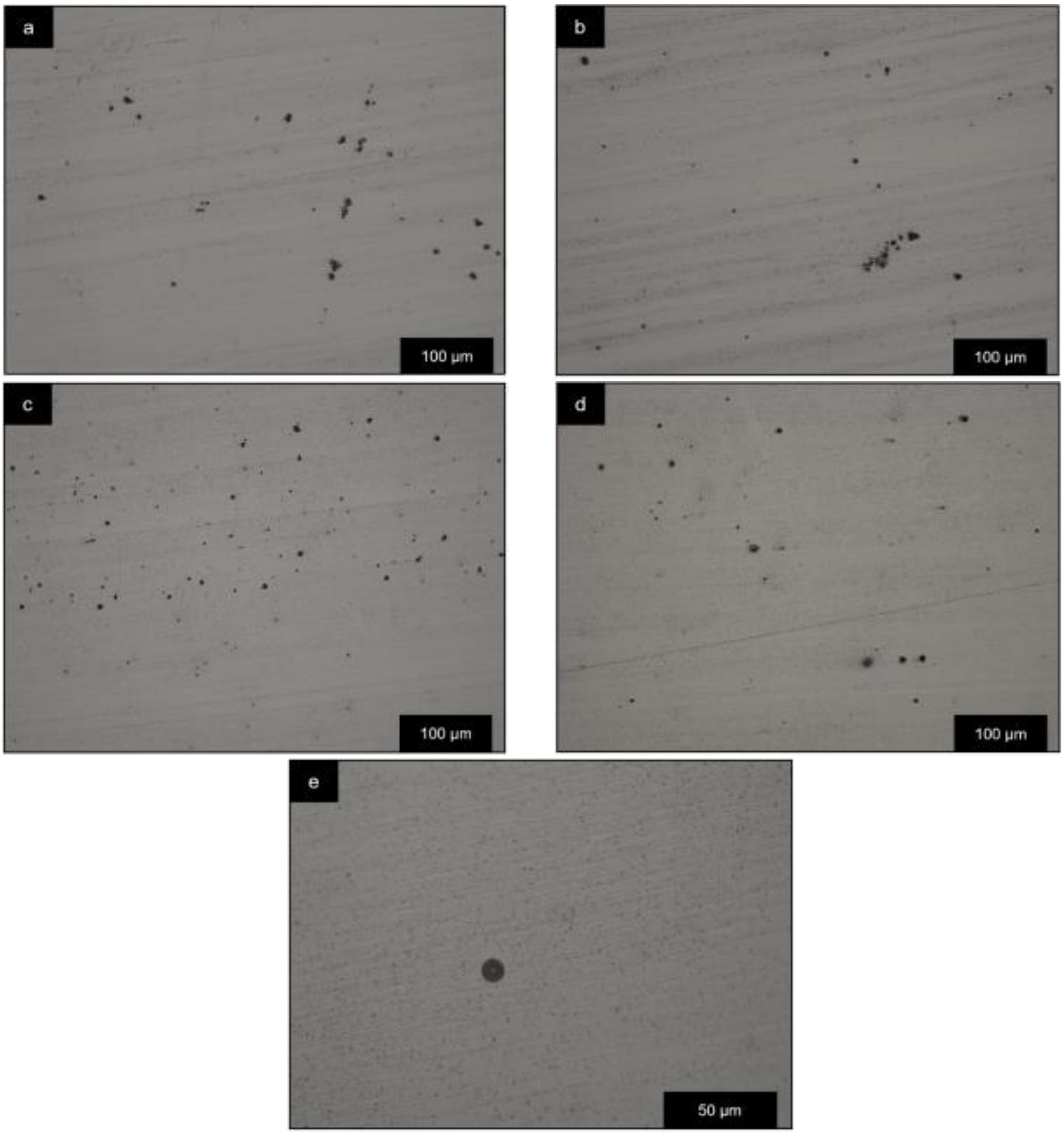

Fig. 6 Micro-defects in fusion zones: (a) back gouged joint; front v center, (b) back ground joint; front v center, (c) back gouged joint; 1^{st} pass from backside, (d) back ground joint; 1^{st} pass from backside, (e) circular porosity

mechanical properties (tensile, impact and hardness) have obtained for the ground joint by the authors of this article, which are in accordance with the micro-defects analysis. The above figure illustrates, that the joints is populated by porosities of different shapes, majorly by circular but free from micro cracks. One of very small circular porosity have shown in Fig 6e at high magnification.

B. Cost Calculations

Both predicted and actual manufacturing costs concepts can be used to compute the welding cost. However, concept of estimating costs is frequently utilized for quotes and expected project completion time frame work. In this study, the actual production cost calculation idea was applied for getting the most accurate comparison analysis because electrode wastage in molten metal evaporation, spatter production, stub end loss of electrode, leakage of energy and irregular groove preparation, after the root pass removal can disturb the accurate comparative analysis. In cost comparison, labor, electrical energy, consumables/ materials and overhead costs may be incorporated in the calculation of welding cost. The overall cost

Table 3. Cost details of the joints

Joint type	Power = 41.65 Rs/Kwh	Consumables		Time (mints)		Labor = Rs 237.5/h	Overh-eads	Total cost
	Rs/m	Electrodes	GD/GR GD =170/Pc GR= 26/Pc	JPP	WP	Rs/m	Rs/m	Rs/m
		Rs/m	Rs/m					
Ground	87.9	1088	114	10.7	117.6	508.02	101.95	1900
Gouged	124.3	1212	42	3.7	125.0	509.29	101.94	1989

Note: JPP means Joint preparation process (gouging or grinding process), WP means welding process, GD means grinding disc and GR means gouging rod, Pc means Piece.

contains indirect labor expenses such as management and supervision, lighting, cleaning, maintenance, and depreciation of equipment [20]. Equipment depreciation cost varies for the two processes although the other elements of overhead may be considered approximately same. The total cost of welded joint can be calculated by the below equation [21].

$$TWC = LC + EC + MC + OC \quad (1)$$

Where TWC is total welding cost, LC labor cost, EC energy cost, MC material /consumables cost, and OC is overhead cost. The total welding cost per meter along with its components have shown in Table 3 and Fig 7. It depicts total welding cost is 4.7 % higher for gouged joint. The major contribution in increased cost for gouged joint has given by the power 41.3% and Material cost 4.30% but no significant difference has noted in the labor (0.24% higher) and overhead cost (0.009 % lower), and time of production (0.25% higher). The main factor contributing to the increased cost is the wider and deep backside groove, which was produced by the gouging process and ultimately required more welding passes. The more passes demanded increased material and power for the joint.

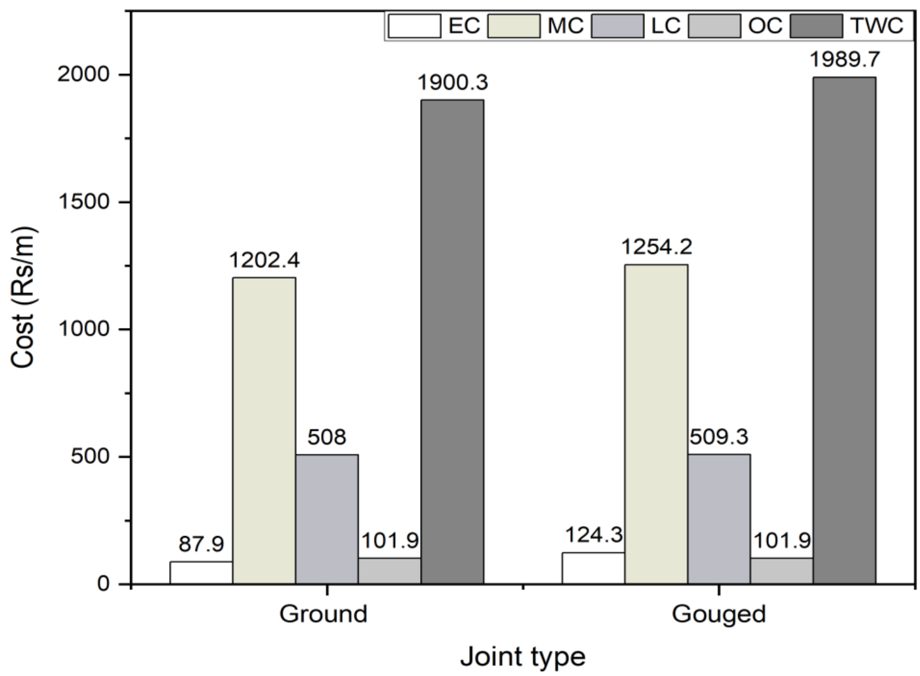

Fig. 7 Cost details of the joints

IV. CONCLUSIONS

In this study, an effort was made for the selection of better root pass removal procedure for fabrication sector in terms of quality/defects and cost-effectiveness for the double-v SMAW joint and obtained the following main points.

- Both ground and gouged joints were free from critical macro-defects, which compromises the mechanical properties of the joint. Only the difference in reinforcement width was noted in both sides of gouged joint that affects the esthetics of the joint.
- The micro-porosities have observed in the regions of both the joints but relatively higher percentage through area and numbers was noted in the gouged joint, which can result in the lower mechanical properties of the joint.
- Ground joint offered 4.7% lower cost than gouged joint, due to the smaller backside groove generated by the grinding in root pass removal process. The main difference in the total welded joint cost was created by the consumables and energy.

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