Research Article

Arc Welding Process Selection through a Quality and Costs

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Abstract

This paper presents a methodology to compare three welding processes, namely SAW (submerged arc welding), SMAW (shield metal arc welding) and GMAW (gas metal arc welding) and to select the best one for a given application. Study is the selection of arc welding process for improving quality and welding cost case in MIE and proposes a method for determining the welding process by comparing time, quality and cost, against one over the other of the three types of Arc welding. The welds were carried out in MIE training center. The selection was based on double criteria: operational costs and non-quality costs. The former is related to the normal costs evaluated in such kind of decision, like consumable cost, labor cost, etc. The is the financial loss suffered by the client every time response variable drifts away from its target value or presents variability. The results indicated that the non-quality and operational costs for the SAW process are slightly lower in comparison to the GMAW and SMAW. SAW is selective among them for quality wise. Therefore, it is the best process for the given application. However; cost incurs little high for GMAW.

Keywords: Arc welding, St-52, quality analysis, cost analysis, process selection

1. Introduction

A welding case study is used in this research study. The welds were carried out in radiographic test, mechanical test and microstructure test for the three arc welding processes namely: SMAW SAW with flux shielding, and GMAW with CO_2 based shielding gases. For Quality analysis, geometrical aspects of the beads were considered and for cost analysis, welding parameters and consumable prices. Quantitative indices were proposed and evaluated. After that, evaluation of both quality and costs calculated, possible to select the most suitable welding process to a specific application, taking into account the market conditions of a company.

Overhead crane where welding was done is a material handling equipment made of carbon steel St-52 is used for lifting, loading, unloading and transportation of semi-finished and finished products mainly in workshops. They are two types namely: (a) single girder and (b) double girder type crane. Solid modeling of assembled overhead crane bridge and overhead crane during welding is shown in Figure 1and Figure 2 given below.
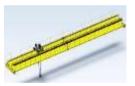

Fig.1. Solid modeling of Overhead Crane Bridge

Fig.2. Overhead crane during welding

1.1. Motivation

The main concern of dealing with Arc welding was because of continuous internal customers' claim in the company, lot of welding electrodes wastage, low quality product, unnecessary welding cost and unexpected additional consumable material request.

1.2. Problem statement

Currently, Mesfin Industrial Engineering (MIE) has been engaged in manufacturing of steel overhead crane bridge structure of different workshops of steel

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manufacturers and dam projects, such as MIE new shops, Ethiopian water construction works, Zarema mayday dam, Ribb dam, Kalema dam manufacture, supply and erection. However, the assembling of the structure is mainly done using three different welding processes(GMAW, SMAW and SAW) that incurred high cost elements like: consumable material cost (electrode, flux and shielding gas), labor cost and electric power cost when compared with estimated design cost. Therefore, the existing steel bridge welding process can be proposed by one welding process effectively and economically without compromising the strength and quality of the product.

1.3. Objective

The general objective of this work is to propose, apply and evaluate a methodical approach to select welding processes of overhead crane bridges, based on cost elements and market requirements of Quality and Cost.

1.4. Significance of the research

The key significance of the research is to reduce manufacturing cost, increase customer satisfaction, sustaining an affordable product and make the company more productive and profitable.

2. Literature review

The research on welding technology optimization of different types of welding for obtaining various responses in output have been done by a number of researchers using a wide range of materials. They make use of various types of methods, techniques and mathematical models for evaluating and obtaining results.

In this research the welding voltage, current, wire speed and gas flow rate are considered as input parameter. The experiment was designed by face centered composite design matrix. From the experiment they conclude that the optimum values of process parameter such as welding voltage 22.5 V, wire speed 2.4 m/min and gas flow rate 12 l/min for maximum yield strength both transverse and longitudinal are remain same but the current value is 190 A and 210 A respectively(Ajit. H. *et al*, 2012).

(Patel C. N. *et al,* 2013) Evaluated the parameters; welding current, wire diameter and wire feed rate to investigate their influence on weld bead hardness for MIG welding and TIG welding by Taguchi's method and Grey Relational Analysis (GRA). From the study it was concluded that the welding current was most significant parameter for MIG and TIG welding. By use of GRA optimization technique the optimal parameter combination was found to be welding current, 100 Amp; wire diameter 1.2 mm and wire feed rate, 3 m/min for MIG welding.

(Lakshminarayanan A.K. *et al,* 2009) Investigated the AA6061 Aluminum alloy joints mechanical properties welded by gas metal arc welding, gas tungsten arc welding and friction stir welding. Single V joint configuration, pure argon shielding gas and AA4043 filler wire were used for the gas metal arc welding and gas tungsten arc welding. Non consumable high carbon steel tool was used for the friction stir welding. Diamond compound was used for a final polishing. The friction stir weld joints produced the high strength values than GMAW and GTAW. The strength value 34% higher than the GMAW and 15% higher than the GTAW. The base metal and heat affected zone produced the high hardness values than the weld metal. FSW produced the high hardness value and GMAW produced low hardness value. Equiaxed uniformly distributed fine grains increased the high tensile properties in the weld region for FSW joints.

It is essential to know the cost of a weld to make manufacturing decisions. An understanding of welding economics / costs and the value added by technology allow a company to manage them and become more profitable. Total welding costs incurred should include: time spent preparing a joint, blasting, removing oils, assembly, preheating, tack-up, positioning, welding, slag removal, spatter removal, inspection, changing electrodes, transportation times, machine setup times, repair and rework. Material costs include: electrodes, shielding gas / gas mixtures, electric power, and gas for preheating (Chaudhuri S. *et al*).

There is no mystery in Welding-cost estimate: it is mainly a question of common sense. But it must be appreciated that correct accounting for total Welding-cost incurred in a welding operation is a preliminary requirement to the assessment of the best practices and a necessary tool for the economic management of any welding enterprise (Kumar S. *et al*, 2011).

A good cost estimation model has a direct bearing on the selection of material and the type of manufacturing process. A good cost model also has to deal with the problems of overestimation and underestimation. The break-down cost method requires detailed information about the production process to derive the relevant cost components. Labor, overhead, tooling, maintenance and repair, etc., are the commonly used cost components for developing cost models for any manufacturing process (Tipaji P.K. *et al,* 2007).

(Tewari S. P. *et al*, 2010) Analyzed the effect of various welding parameters on the weldability of Mild Steel specimens under the effect of heat input welding current, voltage and speed of wire etc. The welding current, arc voltage, welding speed, heat input rate are chosen as welding parameters. The depth of penetrations were measured for each specimen after the welding operation on closed butt joint and the effects of welding speed and heat input rate parameters on depth of penetration were investigated.

Author investigates the effects of welding process parameters of Gas Metal Arc Welding (GMAW) on

tensile strengths of SS 3Cr12 steel material specimen. In this research work, the welding voltage, wire feed rate, welding speed and gas flow rate were considered as inflating input parameter. Medium-carbon steels (below 0.25–0.55% carbon) are often heat-treated (quenched and tempered) to achieve yet higher strength, but it is mainly the compositions below 0.35% carbon that are relevant to this report. Carbon steel is one of the most widely used materials in the industry. This material is used not only in many of the water and steam-pressure containing systems in power plants but also in the supports for these systems. Although this report concentrates primarily on the pressure containing applications of carbon steels, it can also be a useful tool for structural carbon steel fabrication issues. As the description implies, the primary alloying element of these iron based materials is carbon. Because carbon is such a powerful alloying element in steel, there are significant differences in the strength, hardness, and ductility achievable with relatively small variations in the levels of carbon in the composition. However, other important factors such as material fabrication, heat treatment, component fabrication, and fabrication processes can result in significant changes to the properties of the carbon steel components. In some cases, requirements established by codes and standards must be supplemented to achieve results when working with carbon steels. It is important for the utility engineer to have access to metallurgical and properties information to aid in making decisions for projects involving carbon steels. Carbon steel is available in virtually all product forms, including both the forms needed for pressure containing applications and the shapes needed for structural applications (Pradip D. Chaudhari *et al,* 2014; Gupta J.K. *et al,* 2005).

The applied tensile load and extension are recorded during the test for the calculation of stress and strain. Each standard may contain a variety of test standards suitable for different materials dimensions and fabrication history. When a specimen was subjected to an external tensile loading, the metal would undergo elastic and plastic deformation (AWS *et al,* 2007; AWS D1.1 *et al,* 2008; ASTM *et al*).

This test method covers a guided bend test for the determination of soundness and ductility of welds in ferrous and nonferrous products. Defects, not shown by X-rays, may be appearing the surface of a specimen when it is subjected to progressive localized overstressing. This guided bend test has been developed primarily for plates and is not intended to be substituted for other methods of bend testing (AWS *et al,* 2007; AWS D1.1 *et al*, 2008; AWS D1.1 *et al*, 2008).

3. Material and Methods

3.1 Material

The specimen materials are prepared from St-52-3, is the engineering material for fabrication of steel crane bridge structures to conduct various tests and analysis required for the project.

3.2 Methods

A St-52-3 medium carbon steel plates, with chemical composition and the balance Iron as shown in Table 1, were selected as base metal for the experiments. The plates were machined into 200 mm ×250 mm×8 mm as weld blanks. The surface of the plates were grind and polished to remove the dust and other foreign particles. In order to obtain a strong bonded joint the properties of the base metal and the welding wire must comply with each other. The type of material of welding wire total depends upon the material that is required to be welded. So ER 70S-6 was selected as MIG welding wire, E7018 for SMAW and AWS A5.17E12 as SAW wire whose chemical composition are as shown in Table 1. The diameter of the welding wire or electrode depends upon the base metal thickness.

Fig.3. Types of welding machines

Fig. 4. Types of welding wires/electrodes

Types of welding machines are shown in Figure 3 given above. As the thickness of base metal was 8 mm, welding wire with a diameter of 1.2 mm for MIG, 4mm for SAW and 3.2mm for SMAW were selected as given in Figure 4 above.

Table 1: Chemical compositions of welding wires/electrodes

Percentage Chemical composition of welding wires/electrodes										
Weight%	C	Mn	Si	P	S	Ni	Cr	Mo	V	Cu
ER70S-6	0.6-0.15	1.40-1.85	0.80-1.15	0.025 max	0.035 max	0.15max	0.15max	0.15max	0.03max	0.50 max
E7018	0.15max	1.6max	0.75max	0.035 max	0.035 max	0.30max	0.20max	0.30max	0.08max	-
AWS A5.17:EL12	0.04-0.14	0.2-0.60	0.10 max	0.030max.	0.030max.	-	-	-	-	0.35max

3.2.1. Chemical composition testing

MIE's Belec compact port spectrometry machine used for chemical characterization is shown in Figure 5 given below.

Fig. 5. MIE's Belec compact port spectrometry machine

3.2.2. Visual Inspection (VI) and Radiographic Testing (RT) Visual Inspection (VI)

Dimensions of bevels and grooves, and values of misalignment and angular distortion which affect the quality of welds and the performance of joints are inspected visually.

Radiographic Testing (RT)

This method of weld testing makes use of X-rays, produced by an X-ray tube, or gamma rays, produced by a radioactive isotope. Penetrating radiation is passed through a solid object that is in a weld joint, onto a photographic film, resulting in an image of the object's internal structure being deposited on the film.All discontinuities are detected by viewing shape and variation in density of the processed film. This testing method is usually suited to having access to both sides of the welded joint. Test machine to conduct radiographic and X-ray is shown in Figure 6(a) Radiographic test machine (b) X-Ray viewer machine given below.
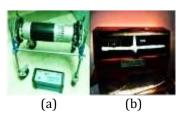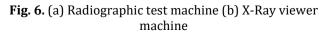
Radiographic procedures

Step 1: Welding the specimens
Step 2: Visual inspection the welding surface
Step 3: the film is immersed in standard developer and fixer solutions accordance with manufacturer's recommendation washing the film with water to remove all the processing chemicals
Step 4: drying the film to be suited for viewing
Step 5: after the film processed, washed and dried, radiographs are viewed by a qualified personnel using X-ray film viewer or a light box with high light intensity machine and interpreted it.

(a)   (b)

Fig. 6. (a) Radiographic test machine (b) X-Ray viewer machine

3.3. Mechanical testing

3.3.1. Tensile testing

The standard dimension of specimens subjected for tensile strength testing was prepared according to ASTM E8/E8M – 09. It was machined using milling machine to get the required shape and size. The tensile test specimens' specification is shown in Figure 7 given below. The Tensile testing machine used to conduct tensile tests is shown in Figure 8 (a), (b) and (c) given below.
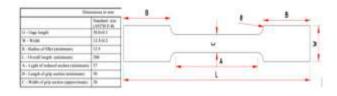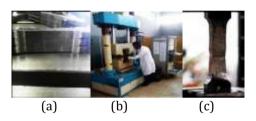

Fig 7. Tensile test specimen specification

(a)   (b)   (c)

Fig 8. (a) Machined tensile test specimen,(b) Tensile test machine during testing, and (c) Tensile test specimen during testing

3.3.2.   Metallography

Metallographic samples were produced from welds in accordance to ASTM E3-11(2017).The samples were polished and etched using 2% Nital solution (Nitric acid and methanol).Optical Microscope attached digital camera used for microstructural observation is shown in Figure 9 given below.

Fig. 9. Optical microscope attached digital camera used for microstructural observation

3.4. Analysis of Quality

In manufacturing industries, the general term quality refers into the two complementary categories of quality of design and quality of conformance. Whereas quality of design focuses on how the product design meets consumer requirements, quality of conformance is concerned with whether the quality produced and provided to the consumer meets the intended design. Improving produced quality of conformance via defect prevention and improving quality of conformance delivered to the customer via inspection.

3.5. Cost analysis

Costs determination can be used for composing sale price, helping take decisions about a product fabrication opportunity, determining the necessary investment volume for an operation, predicting modifications owing to fabrication scale changes, establishing the principles to implement a cutting cost program and providing assistance to a welding process selection. In the present case, costs will be used as a balancing parameter during selection of the most suitable welding process.

4. Results and Discussion

4.1 Results

4.1.1 Visual inspection of welding

During the observation at the welding training shop of Mesfin Industrial Engineering PLC, the defect of the weld St52-3 was seen on some surfaces of weld. All of the welded St52-3 plate was being observed visually. Visual inspections for welded specimen data are presented in Table 2 given below.

Table 2: Visual inspection examined welded joint

Process Type	Trails	Undercut	Overlap	Inconsistency	Spatter	concavity	convexity	Insufficient reinforcement	Excessive reinforcement
SAW	T1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	T2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	T3	√	Nil	Nil	Nil	Nil	√	Nil	Nil
	T4	Nil	√	Nil	√	Nil	Nil	Nil	Nil
	T5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
GMAW	T1	Nil	Nil	Nil	√	Nil	Nil	Nil	Nil
	T2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	T3	Nil	Nil	Nil	Nil	Nil	√	Nil	√
	T4	√	Nil	Nil	Nil	√	Nil	Nil	Nil
	T5	Nil	Nil	Nil	Nil	Nil	√	Nil	Nil
SMAW	T1	Nil	Nil	√	√	Nil	Nil	Nil	√
	T2	Nil	Nil	Nil	√	Nil	√	Nil	√
	T3	Nil	√	√	√	Nil	√	Nil	Nil
	T4	Nil	√	Nil	Nil	Nil	Nil	√	Nil
	T5	Nil	Nil	Nil	Nil	Nil	Nil	√	Nil

Where:
Nil -no defects
√ ... there is defects

From the visual inspection results of Table 2, it comprises that the overall welded specimen parameter of the level that have T3 and T4 in SAW, and T3, T4,and T5 in GMAW , and T1, T2, T3, T4, T5 in SMAW have defects.However, SMAW have more defect in comparison to GMAW and SAW.

4.1.2 Radiographic inspection of welding

Welding radiographic inspection reports are presented in Table 3 given below. Overall comparison of radiographic inspection, fewer defects are observed in SAW, GMAW and SMAW.

Table 3: Radiography test results report of the evaluator

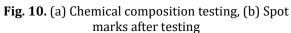| Process type	Trials	Porosity	slag inclusion	crack	lack of fusion	Molting
SAW	T1	N	N	N	N	N
	T2	N	N	N	N	N
	T3	N	N	N	N	N
	T4	N	Y	N	N	Y
	T5	N	N	N	N	N
GMAW	T1	Y	N	N	Y	N
	T2	N	N	N	N	N
	T3	N	N	N	N	N
	T4	N	N	N	N	N
	T5	N	N	N	N	N
SMAW	T1	N	N	N	N	N
	T2	Y	Y	N	Y	N
	T3	N	N	N	N	Y
	T4	N	N	N	N	N
	T5	N	N	N	N	N

Where:
N-no defects
Y ... there is defects

4.1.3 Chemical, Mechanical and Microstructure testing

4.1.3.1 Chemical composition analysis result of the welded St 52-3 steel

(a)   (b)

Fig. 10. (a) Chemical composition testing, (b) Spot marks after testing

Chemical composition tests to conduct for chemical composition is shown in Figure 10 (a) Chemical composition testing (b) Spot marks after testing given above. The obtained chemical composition results for the materials are given in the Table 4 below.

Table 4: Summarized value of the material chemical composition result of specimen

No.	Aver.	
C	0.185	
Si	0.039	
Mn.	1.017	
Cu	0.02	
Al	0.005	
Cr	0.014	
Mo	0.005	
Ni	0.016	
V	0.042	
Ti	0.008	
Nb	0.023	**Grade:1.0570, St 52-3**
Co	0.03	
W	0.111	

4.1.3.2. Tensile test

Tensile tested non-heat treated SMAW; MIG and SAWspecimens wereconducted at Mekelle University shown in Figure 11. Tensile test results of non-heat treated samples for SAW, GMAW and SMAW are shown in Table 5 below.

Fig. 11. Tensile tested non-heat treated welded specimen

Table 5: Tensile testing results of non-heat treated welded specimens

Welding type	Tensile strength in N/mm²	Yield strength N/mm²	Modulus of elasticity, GPa	%age of elongation	%age of reduction in area
SAW	521.7	412.4	187.8	26.934	33.06
GMAW	503.3	404.7	186	20.912	29.96
SMAW	496	399	186	20.514	28.17

4.1.4. Welding Quality Analysis

All manufacturing processes are imperfect and have an associated non-conformance rate. Manufacturers seeking to achieve higher quality of conformance have a wide range of options to choose from. These can be divided into two categories; improving produced quality of conformance via defect prevention and improving quality of conformance delivered to the customer via inspection. Formula for determination of welding quality index is shown in Table 6 given below. Welding defects were observed are shown in Figure 12 (a) and (b) given below. Quality index of three arcs welding were calculated and given in Table 7 below. Image analysis of weld penetration depth and observed quality defects after penetration are shown in Figure 13 and Figure 14 given below.

Fig. 12.(a) Submerged arc welding 4mm diameter preparation (b) Welding defects

Table 6: Formula for determination of welding quality

1	Penetration index	$PI = (p / t) \times 100$ [%]
2	Convexity index	$CI = (r / w) \times 100$ [%]
3	Spattering index	$SI = (S / Dr) \times 100$ [%]
4	Spattering rate	$S = (F_{elect}$ or $F_{wire}) - Dr$
5	Deposition rate	$Dr = 3.6 \times (M_{fcp} - M_{icp}) / t_{arc}$
6	Deposition efficiency	$De = Dr / (F_{elect}$ or $F_{wire}) \times 100$ [%]
7	Electrode feed rate	$f_{elect} = 3.6 \times (M_{iel} - M_{fel}) / t_{arc}$.
8	Wire feed rate	$f_{wire} = 60 \times (p \times \varnothing^2 \times f_{wire} \times \rho) / 4$

Where: p= the weld penetration [mm], t = joint thickness [mm],r=bead reinforcement [mm], w=bead width [mm], S=spattering rate [kg/h], D_r = deposition rate [kg/h],F_{elect} =covered electrode fusion rate [kg/h], f_{elect} =wire feed rate [m/min],M_{iel}= initial mass of the covered electrode, before welding [g], M_{fel}= final mass of the covered electrode, after welding [g], t_{arc}=arc duration time [s], F_{wire}= wire fusion rate [kg/h], $\varnothing$= wire diameter [mm],f_{wire} =wire feed rate [m/min], ρ=

steel density (7.85 x 10^{-3} g/mm³), M_{fcp} =final mass of the test plate, after welding [g], M_{icp}= initial mass of the test plate, before welding [g] and De=deposition efficiency [%].
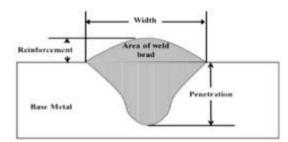

Fig. 13. Image of weld penetration depth

Fig. 14. Images of weld quality defects

Calculation for SAW

Deposition rate (Dr)

$$Dr = 3.6 \, X \, (Mfcp - Micp)/ \, tarc$$

$$Dr = 3.6 \, X \, \frac{(12.92 - 12.576)}{5}$$
$$Dr = 0.24768$$

$Dr = 0.24768 \, X \, 9.15$

$Dr = 2.266$ Kg/h

Deposition efficiency (De)

$$De = \left(\frac{Dr}{Fwire}\right) X \, 100\%$$

$$De = \left(\frac{2.266}{2.280}\right) X \, 100\% \qquad De = 99.38\%$$

Spattering rate (S)

$$S = (Fwire) - \, Dr$$

$$S = (2.280 - 2.266) \qquad S = 0.014 \, Kg/h$$

Spattering Index (SI)

$$SI = \left(\frac{S}{Dr}\right) X \, 100\%$$

$$SI = \left(\frac{0.014}{2.266}\right) X \, 100\% \qquad SI = 0.617\%$$

Calculation for GMAW

Deposition rate (Dr)

$$Dr = 3.6 \, X \, (Mfcp - Micp)/ \, tarc$$

$$Dr = 3.6 \, X \, \frac{(12.90 - 12.576)}{7}$$
$$Dr = 0.167$$

$Dr = 0.167 \, X \, 12.76$

$Dr = 2.130$ Kg/h

Deposition efficiency (De)

$$De = \left(\frac{Dr}{Fwire}\right) X \, 100\%$$

$$De = \left(\frac{2.130}{2.165}\right) X \, 100\% \qquad De = 98.3\%$$

Spattering rate (S)

$$S = (Fwire) - \, Dr$$

$$S = (2.165 - 2.130) \qquad S = 0.035 \, Kg/h$$

Spattering Index (SI)

$$SI = \left(\frac{S}{Dr}\right) X \, 100\%$$

$$SI = \left(\frac{0.035}{2.130}\right) X \, 100\% \qquad SI = 1.64\%$$

Calculation for SMAW

Deposition rate (Dr)

$$Dr = 3.6 \, X \, (Mfcp - Micp)/ \, tarc$$

$$Dr = 3.6 \, X \, \frac{(12.93 - 12.576)}{7}$$
$$Dr = 0.182$$

$Dr = 0.182kg \, X \, 12.0$

$Dr = 2.184$ Kg/h

Spattering rate (S)

$$S = (Felect) - \, Dr$$

$$S = (2.29 - 2.184) \qquad S = 0.106 \, Kg/h$$

Spattering Index (SI)

$$SI = \left(\frac{S}{Dr}\right) X \ 100\%$$

$$SI = \left(\frac{0.106}{2.184}\right) X \ 100\% \qquad SI = 4.853\%$$

Deposition efficiency (De)

$$De = \left(\frac{Dr}{Fwire}\right) X \ 100\%$$

$$De = \left(\frac{2.184}{2.29}\right) X \ 100\% \qquad De = 95.371\%$$

Table 7: Calculated quality index of three arc welding

S/No	Type of arc welding	Dr (Kg/h)	S (Kg/h)	SI %	De %	F_{wire} (m/min)
1	SAW	2.266	0.014	0.617	99.3	2.280
2	GMAW	2.130	0.035	1.64	98.3	2.165
3	SMAW	2.184	0.106	4.853	95.371	2.29

Quality index of three arc welding confirms that SAW is better among them in quality wise.

4.1.5. Welding Costs Calculation

Cost analysis is an important tool for product design and material selection. Efficient and effective cost estimation tool is necessary for early design evaluations. Each cost component has been closely analyzed and the major cost components have been included in the cost calculation. In the present case, Costs will be used as a balancing parameter during selection of the most suitable welding process.

The Costs can be based on estimate values (estimations of amount of weld to be deposited) and actual values (amount in fact reached in experimental tests). In this work, the actual deposited amount was used. The reason for that is that the used joint, a butt weld joint with no groove and gap for SAW, makes difficult to estimate the amount of weld to be deposited. It is important to point out that, even in case of grooved joints, each process may deposit different height of reinforcements, misconducting calculations. Therefore, to apply the approach for process selection, weldments of test plates became necessary, simulating real cases. The composition of Costs takes into account materials, electricity, labor and equipment. Indirect Costs will not be considered, since they are approximately the same in terms of comparison. Total welding cost (TWC) is a composition of equipment, materials, and labor and electricity costs. Indirect costs are approximately the same in terms of comparison.

$$\boxed{TWC= EC + MC + LC + EPC}$$

Where: EC is equipment cost, MC is material cost, LC is the labor cost and EPC is the electrical power cost.

Note: all costs are expressed in ETB/m, 1 ETB=27.79USD and material cost comprises the electrode and/ or wire, flux and the gas costs. The investment, depreciation and maintenance costs are the elements of equipment cost. Equations used for determining each term of the costs are represented in Table 8 given below. Specification used for welding electrodes is shown in Table 9 given below.

Table 8: Equations used for determining each term of the costs

1	Material cost(MC)	Cost determining Equations
1.1	SAW wire (CSw)	$Csw = P_w \ x \ (Dr \ x \ 100/De)/(t_{speed} \ x \ 60/100)$
1.2	MIG wire (CMw)	$Cmw = P_w \ x \ (Dr \ x \ 100/De)/(t_{speed} \ x \ 60/100)$
1.3	SMAW electrode (Ce)	$Ce = P_e \ x \ (Dr \ x \ 100/De)/(t_{speed} x \ 60/100)$
1.4	Flux (Cf)	$Cf = P_f x \ Rf \ x \ 100/t_{speed}$
1.5	Gas(Cg)	$Cg = P_g x \ R_g x \ 100/t_{speed}$
2	Labor cost(LC)	$LC = S_w/(t_{speed} \ x \ 60/100 \ x \ f_{op}/100)$
3	Investment (Ci)	$Ci = V_e \ x \ (Ir/100) \ x \ D_r/(\ P_m \ x \ t_{speed} \ x \ 60/100)$
4	Depreciation(Cd)	$Cd = V_e \ x \ D_r/(T_d \ x \ P_m \ x \ t_{speed} \ x \ 60/100)$
5	Maintenance (Cm)	$Cm = E_m \ x \ Dr/(\ P_m \ x \ t_{speed} \ x \ 60/100)$
6	Electrical power (EPC)	$EPC= (I_m \ x \ V_m \ x \ P_{el})/(\ 1000x(ee/100) \ x \ t_{speed} \ x \ 60/100)$

Where: P_w is wire price (birr/kg); P_e is electrode price (birr/kg); D_r is deposition rate (kg/h); D_e =deposition efficiency(%); t_{speed} is travel speed (cm/min); P_g is gas price(birr/kg); P_f is flux price (birr/kg); R_f is flux flow rate (kg/min); R_g is gas flow rate (l/min); S_w is welder/operator's salary including taxes and duties (birr/h); f_{op} is operating factor (%); Ve is equipment value(birr); p_m ismonthly weld production (kg/month); T_d is depreciation time (60 months); I_r is monthly interest rate; I_m is welding mean current(A); V_m is welding mean voltage (v); P_{el} is electricity price (birr/kwh); ee is electrical efficiency of the equipment (%); E_m is monthly maintenance expense (birr/month).

Table 9: Specification for used welding electrodes

S/N	Type of welding machine	Wire diameter (mm)	Electrode diameter (mm)	Shielding material	Length of specimen (m)	Time taken in minute
1	SAW	4	-	Flux	1	9.15
2	MIG	1.2	-	CO_2	1	12.76
3	SMAW	-	3.2	-	1	12.00

In this case welding steel plates were prepared using plates of plain carbon steel St-52-3, with a dimension of 150 mm x 250 mm x 8 mm to weld butt welding with 3mm, 2mm and no root opening for SMAW,MIG and SAW respectively, welding on the flat position. The welding procedures were as follows:

Submerged arc welding process (SAW): 4.0 mm diameter welding wire.

Shield Metal Arc Welding process (SMAW) 3.2 mm diameter stick electrode.

CO_2 Gas Metal arc Welding Process (GMAW): 1.2 mm diameter welding wire.

SAW welding: Material cost (MC)

Wire cost (Csw)

$$Csw = PwX(\frac{DrX100}{de})/(\frac{t_{speed}X60}{100})$$
$$Csw = 415.36 Birr/KgX(\frac{2.266\frac{Kg}{Hr}X100}{99.38})/(\frac{7cm/min\ X60}{100})$$
$$Csw = 375.80\ birr/meter$$

Flux cost (Cf)

$$Cf = PfXRfX100/t_{speed}$$
$$Cf = \frac{\{1.5birr/Kg\}x\ 0.21\ x\ 100}{7cm/min}$$
$$Cf = 450\ birr/meter$$

Labor cost (LC)

$$LC = Sw/(t_{speed}X60/100Xfop/\ 100)$$
$$LC = 45birr/hr/((\frac{7X60}{100})X(30/\ 100))$$
$$LC = 59.52\ birr/meter$$

Investment (Ci)

$$Ci = VeX\left(\frac{Ir}{100}\right)XDr/(PmXt_{speed}\ X\ 60/100)$$
$$Ci = 99150.03\ birr\ X\left(\frac{1\%/month}{100}\right)X\ 2.266kg/hr/(891.56\ kg/month\ X\ 7cm/minX\ 60/100)$$
$$Ci = 1$$

Depreciation (Cd)

$$Cd = VeXDr/(Td\ X\ Pm\ X\ t_{speed}X60/\ 100)$$
$$C_d = \frac{99150.03X2.266kg/60min}{60monthX891.56kg/monthX0.07cm/minX0.6}$$

$$Cd = 1.67\ Birr/m$$

GMAW welding: Material cost (MC)

MIG Wire cost (Cmw)

$$Cmw = 954.67\ birr/kg\ X\ (\frac{2.130kg/hrX100}{98.3})/(\frac{8.5\ cm/minX60}{100})$$
$$Cmw = 954.67\ X\ (\frac{DrX100}{60})/(\frac{t_{speed}X60}{100})$$
$$Cmw = 676.01\ Birr/meter$$

CO_2 Gas cost (Cg)

$$Cg = PgXRgX\ 100/t_{speed}$$
$$Cg = \left(\frac{0.41Birr}{kg}\right)X1kg/minX100/0.085\ m/min$$
$$Cg = 482.35\ Birr/meter$$

Labor cost (LC)

$$LC = Sw/(t_{speed}X60/100Xfop/\ 100)$$
$$LC = 45birr/h/((8.5cm/minX(\frac{60}{100})X(30/\ 100))$$
$$LC = 49.01Birr/meter$$

Investment (Ci)

$$Ci = VeX\left(\frac{Ir}{100}\right)X\ Dr/(Pm\ X\ t_{speed}\ X\ 60/100)$$
$$Ci = 99150.03\ birrX\left(\frac{1\%/month}{100}\right)X\ 2.130kg/hr/(690.156kg/month\ X\ 8.5cm/min\ X\ 60/100)$$
$$Ci = 1$$

Depreciation (Cd)

$$Cd = Ve\ X\ \frac{Dr}{(Td\ X\ PmX\ t_{speed}X60/100})$$
$$Cd = 99150.03birr\ X\ 2.130\ kg/hr/60monthX690.156\ kg/month\ X\ 0.085\ m/min\ X60/100)$$
$$Cd = 1.67\ Birr/m$$

SMAW welding: Material cost (MC)

Electrode cost (Ce)

$$Ce = PeX\ (\frac{Dr\ X\ 100}{de})/(\frac{t_{speed}X\ 60}{100})$$
$$Ce = 256.26\ Birr/kg\ X\ (\frac{2.184\ kg/hr\ X\ 100}{95.371})/(\frac{6\ cm/min\ X\ 60}{100})$$
$$Ce = 271.68\ Birr/m$$

Labor cost (LC)

$$LC = Sw/(t_{speed}X60X100\ Xfop/\ 100)$$
$$LC = 45\ Birr/hr/((0.06m/minX(\frac{60}{100})X(65/\ 100))$$
$$LC = 32.05\ Birr/meter$$

Investment (Ci)

$$Ci = VeX\left(\frac{Ir}{100}\right)\ X\ Dr/(Pm\ X\ t_{speed}\ X\ 60/100)$$
$$Ci = 99150.03birrX\left(\frac{1\%/month}{100}\right)X2.184\frac{kg}{hr}/(950.5\frac{kg}{month}X0.06m/min\ X\ 60/100)$$
$$Ci = 1.054$$

Depreciation (Cd)

$$Cd = Ve \ X \ \frac{Dr}{(Td \ X \ Pm \ X \ t_{speed} X \ 60/ \ 100)}$$
$$Cd$$
$$= 99150.03 \ BirrX \ 2.184 kg/hr$$
$$/60 months X 950.5 \ kg/month X \ 0.06 m/min \ X 60/ \ 100)$$
$$Cd = 1.7578 \ Birr/meter$$

SAW (Labor cost, Electrode cost and Electric power Cost)

$$\frac{Labor cost}{meter \ of \ weld}$$
$$= \left[\frac{\frac{Labor \ and \ Overhead \ Costs}{Hour} \ X \ \frac{Kilograms \ of \ weld \ deposite}{meter \ of \ weld}}{Deposition \ Rate \ X \ Operating \ Factor} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{(55x5)birr}{Hour} \ X \ \frac{0.325 \ KG}{meter of weld}}{2.266 \ X \ 0.6} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{275 birr}{Hour} \ X \ \frac{0.325 \ KG}{meter of weld}}{2.266 Kg/hr \ X \ 0.6} \right]$$

$$\frac{Labor cost}{meter of weld} = 65.736 Birr$$

$$\frac{wire \ cost}{meter \ of \ weld}$$
$$= \left[\frac{\frac{Kilograms \ of \ weld \ deposite}{meter \ of \ weld} \ X \ \frac{Cost \ of \ electrode}{Kilogram}}{Deposition \ Efficiency} \right]$$

$$\frac{wire \ cost}{meter \ of \ weld} = \left[\frac{\frac{0.325 KG}{meter of weld} \ X \ \frac{53.35}{Kilogram}}{0.993} \right]$$

$$\frac{wire \ cost}{meter \ of \ weld} = 17.460 \ Birr$$

$$\frac{Electric \ power \ cost}{meter \ of \ weld}$$
$$= \frac{Welding \ Current \ X \ Welding \ Voltage}{Power \ source \ efficiency} X \ power \ cost \ X \ welding \ time$$
$$\frac{Electric power cost}{meter \ of \ weld} = \frac{250 \ X \ 28}{50} X \ 0.0035 \ X \ 9.15$$
$$\frac{Electric \ power \ cost}{meter \ of \ weld} = 4.4835 \ birr$$

GMAW (Labor cost, Electrode cost and Electric power Cost)

$$\left[\frac{\frac{Labor \ and \ Overhead \ Costs}{Hour} \ X \ \frac{Kilograms \ of \ weld \ deposite}{meter \ of \ weld}}{Deposition Rate X Operating Factor} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{(55x5)birr}{Hour} \ X \ \frac{0.325 \ KG}{meter of weld}}{2.130 \ Kg/hr \ X \ 0.6} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{275 birr}{Hour} \ X \ \frac{0.325 \ KG}{meter of weld}}{2.130 X \ 0.6} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = 69.933 Birr$$

$$\frac{wire \ cost}{meter \ of \ weld}$$
$$= \left[\frac{\frac{Kilograms \ of \ weld \ deposite}{meter \ of \ weld} \ X \ \frac{Cost \ of \ electrode}{Kilogram}}{Deposition \ Efficiency} \right]$$

$$\frac{wire \ cost}{meter \ of \ weld} = \left[\frac{\frac{0.325 KG}{meter of weld} \ X \ \frac{63.65}{Kilogram}}{0.983} \right]$$

$$\frac{wire cost}{meter of weld} = 21.043 \ Birr$$

$$\frac{Electric \ power \ cost}{meter \ of \ weld}$$
$$= \frac{Welding \ Current \ X \ Welding \ Voltage}{Power \ source \ efficiency} X \ power \ cost \ X \ welding \ ti$$
$$\frac{Electric \ power \ cost}{meter \ of \ weld} = \frac{185 \ X \ 23}{50} X \ 0.0035 \ X \ 12.76$$
$$\frac{Electric \ power \ cost}{meter \ of \ weld} = 3.80 \ birr$$

SMAW (Labor cost, Electrode cost and Electric power Cost)

$$\frac{Labor \ cost}{meter \ of \ weld}$$
$$= \left[\frac{\frac{Labor and Overhead Costs}{Hour} \ X \ \frac{Kilograms of weld deposite}{meter of weld}}{Deposition \ Rate \ X \ Operating \ Factor} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{(55x5)birr}{Hour} \ X \ \frac{0.325 \ KG}{meter \ of \ weld}}{2.184 \ X \ 0.35} \right]$$

$$\frac{Labor \ cost}{meter \ of \ weld} = \left[\frac{\frac{275 birr}{Hour} \ X \ \frac{0.325 \ KG}{meter of weld}}{2.184 Kg/hr X \ 0.35} \right]$$

$$\frac{Labor cost}{meter of weld} = 116.92 Birr$$

$$\frac{Electrode \ cost}{meter \ of \ weld}$$
$$= \left[\frac{\frac{Kilograms \ of \ weld \ deposite}{meter \ of \ weld} \ X \ \frac{Cost \ of \ electrode}{Kilogram}}{Deposition \ Efficiency} \right]$$

$$\frac{Electrode \ cost}{meter \ of \ weld} = \left[\frac{\frac{0.325 KG}{meter \ of \ weld} \ X \ \frac{156.26}{Kilogram}}{0.95371} \right]$$

$$\frac{Electrode \ cost}{meter \ of \ weld} = 53.249 Birr$$

$$\frac{Electric\ power\ cost}{meter\ of\ weld}$$

$$= \frac{Welding\ Current\ X\ Welding\ Voltage}{Power\ source\ efficiency}\ X\ power\ cost\ X\ welding\ time$$

$$\frac{Electric\ power\ cost}{meter\ of\ weld} = \frac{90\ X\ 25}{50}\ X\ 0.0035\ X\ 12.0$$

$$\frac{Electric\ power\ cost}{meter\ of\ weld} = 1.89\ Birr$$

Table 10: Total cost/m for three different electrode diameters in respect of deposition rate, operating factor, labor cost, depreciation, power efficiency etc.

Electrode/wire type	H08MnA SAW wire dia. 4mm	ER70S-6 copper wire dia. 1.2mm	E7018 Dia. 3.2mm
Weight of deposit per meter (Kg/m)	0.325	0.325	0.325
Deposition efficiency (%)	99.3	98.3	95.371
Deposition rate (Kg/hr)	2.266	2.130	2.184
Welding current (amps)	250	185	90
Welding voltage (volts)	28	23	25
Operating factor (%)	60	60	35
Labor + Overhead cost (ETB/hr)	55	55	55
Electrode cost per Kilogram (ETB/Kg)	53.35	63.65	156.26
Power source efficiency (%)	50	50	50
Depreciation(C_d)[ETB/m]	1.67	1.67	1.7578
Labor + Overhead Cost/meter of weld (ETB/m)	65.736	69.933	116.92
Electrode cost/ Meter of weld (ETB/m)	17.640	21.065	53.249
Electric power cost/Meter of weld (ETB/m)	4.4835	3.80	1.89
Total [ETB/m]	87.8592	94.798	172.059

Total cost/m for three different electrode diameters in respect of welding time, deposition rate, operating factor, labor cost, power efficiency etc. are shown in Table 10 given above. Welding time, deposition rate, deposition efficiency, welding current, welding voltage, operating factor and power source efficiency observed data are presented in Table 11 given below. Results of man power, material, electrical and total costs-(Birr/m) are presented in Table 12 given below. Comparison of welding parameters and cost are shown in Figure 15 given below. Comparison of welding consumables and cost are shown separately in Figure 16 given below.

Table 11: Welding time, deposition rate, deposition efficiency, welding current, welding voltage, operating factor and power source efficiency required values for three welding process

Process type	SAW	GMAW	SMAW
Welding time (min)	9.15	12.76	12.0
Weight of deposit per meter (Kg/m)	0.325	0.325	0.325
Deposition efficiency (%)	99.3	98.3	95.371
Deposition rate (Kg/hr)	2.266	2.130	2.184
Welding current (amps)	250	185	90
Welding voltage (volts)	28	23	25
Operating factor (%)	60	60	35
Power source efficiency (%)	50	50	50

Table 12: Results of man power, material, electrical and total costs-(Birr/m)

Process type	SAW	GMAW	SMAW
Labor + Overhead cost (Birr/hr)	55	55	55
Electrode cost per Kilogram (Birr/Kg)	53.35	63.65	156.26
Electric power cost per kilowatt (Birr/Kw-hr)	0.4993	0.4993	0.4993
Labor + Overhead Cost/meter of weld (Birr/m)	65.736	69.933	116.92
Electrode + consumable cost/ meter of weld (Birr/m)	41.57	45.5	52.5
Electric power cost/meter of weld (Birr/m)	4.4835	3.80	1.89
Total (Birr/m)	220.6388	238.3823	383.0693

Fig. 15. Comparison of welding parameters and cost

Fig. 16. Comparison of welding consumables and cost

4.2. Discussion

As a result, from the quality and cost analysis of the samples taken, the product was directed to be expensive because of the material, labor and electricity. To achieve the mechanical property and cost target of welding was trail analysis was done by experimentation the three welding on St- 52-3 plate with material thickness of8mm.

By analyzing data, it can be discussed for the SAW to be selective in term of saving welding time, high deposition efficiency, and by deposition rate. However,

in respect of welding current, welding voltage, and eclectic power cost per weld meter SAW has slight than GMAW.

It is possible to reduce total welding cost of fabrications by judicious choice of all the factors that goes into the cost and simultaneously achieve improved assured quality as specifically required for the application.

Conclusion

The objective of this work is to analyses how to select the best arc welding process of the products based on quality and low welding cost. Based on the best performance of quality and cost analyses, it is possible to conclude that:

The selection of the best welding process is possible to a certain industrial activity, considering the performance of quality and costs, according to market requirements of the company.

Radiographic test results and Visual inspection examined welded joint indicates that SAW have possess better quality among three arc weld process. However, fewer defects are attendant in all of them.
Mechanical test results in non-treated condition confirm the SAW is chosen better in comparison to the GMAW and SMAW.

Analysis by quality index of three arc welding confirms that SAW is better among them in quality.

It is possible to achieve required consistent quality welding for an application with adaptability to advanced applications with simultaneous reduction in overall cost by using SAW process. It is also possible to save cost by adopting total quality concept in using other processes like GMAW also compared to other arc process.

Overall, SAW is selective among them for quality wise. However, cost incurs little high for GMAW.

Acknowledgements

References

An American National Standard AWS B4.0 (May 2, 2007), Standard Methods for Mechanical Testing of Welds, 7th Edition, Supersedes *ANSI/AWSB4.0-98*.

AWS D1.1/D1.1M (July 2, 2008),An American National Standard, Structural welding code-steel, 21st Edition, under the direction of the *AWS technical committee*.

Ajit. H,Ashwani. D, and Satpal. S(October 2012), Optimization of MIG welding process parameter to predict maximum yield strength in AISI 1040, *International journal of Mechanical engineering and Robotics research*, 1(3),203-213.

Designation of E190– 92(2008),Standard Test Method for Guided Bend Test for Ductility of Welds, *ASTM, international*.(Reapproved).

Patel C. N. and ChaudharyS.(2013), Parametric Optimization of Weld Strength of MetalInert Gas Welding and Tungsten Inert Gas Welding by using Analysis of Variance and Grey Relational Analysis, *International Journal of Research in Modern Engineering and Emerging Technology*, *1(3)*.

Lakshminarayanan A.K., Balasubramanian V. and Elangovan K.(2009), Effect of welding processes on tensile properties of AA6061 Aluminium alloy joints,*International Journal of Advanced Manufacturing Technology*, 40,286-296.

Chaudhuri S., Welding Cost, Economics- GMAW & MMAW Process& Quality, Indian Institute of Welding lecture tutorial.

KumarS., and Nand S. (January2011),Estimation and Comparison of Welding Cost of MIG & MAG Process on Mild Steel, *Proceedings of the National Conference on Recent Advances In Manufacturing Engineering & Technology*, 10-11.

TipajiP.K., AlladaV., and MistraR.(2007), A Cost Model For The Metal Inert Gas (Mig) Welding PROCESS, *Proceedings of the ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2007 September*, 4-7, Las Vegas, Nevada, USA.

TewariS. P., Gupta AnkurandJyotiPrakash(2010) ,effect of welding parameters on the weldability of material, *International Journal of Engineering Science and Technology*, 2(4), 512-516.

Designation E8/E8M–13a,Standard Test Methods for Tension Testing of MetallicMaterials1, *ASTM, international, American Association State Highway and Transportation Officials Standard, AASHTO No. T68, an American National Standard.*

Pradip D. Chaudhari and NitinN.More (2014), Effect of welding process parameters on tensile strength, *IOSR journal of engineering,* 04(05),01-05.

Gupta J.K. and Khurmi R.S,(2005), A text book of machine design (multicolor) Eurasian, publishing house (Pvt Ltd) ram Nagra New Delhi India.