Optimization of shielded metal arc welding process parameters to minimize distortion in low carbon steel plates: A comprehensive review

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Abstract - *Shielded Metal Arc Welding (SMAW) is one of the most widely adopted welding processes in industrial fabrication due to its simplicity, cost-effectiveness, and adaptability. However, welding-induced distortion remains a significant challenge, particularly in mild steel plates, where non-uniform heating and cooling cycles generate residual stresses and dimensional inaccuracies. Excessive distortion adversely affects structural integrity, assembly precision, and overall manufacturing efficiency. This review paper presents a comprehensive analysis of existing research on SMAW parameter optimization aimed at minimizing distortion. Key process parameters such as welding current, arc voltage, travel speed, electrode diameter, root gap, groove angle, and welding position are examined. Various optimization techniques including Taguchi method, ANOVA, Grey Relational Analysis (GRA), Response Surface Methodology (RSM), and Finite Element Analysis (FEA) are critically reviewed. The study identifies dominant parameters influencing distortion and highlights the importance of systematic parameter selection over conventional trial-and-error methods. The findings provide a strong foundation for further experimental investigation and regression model development for distortion control in mild steel SMAW applications.*

Keywords: **SMAW, Welding Distortion, Mild Steel, Taguchi Method, ANOVA, Heat Input, Optimization Techniques**.

1. INTRODUCTION

Welding is a permanent metal joining process widely used in manufacturing, construction, and heavy engineering industries. Among various welding processes, Shielded Metal Arc Welding (SMAW) remains highly popular due to its operational flexibility and low equipment cost. Despite its advantages, SMAW frequently results in welding distortion due to uneven thermal expansion and contraction during heating and cooling cycles. This thermal imbalance produces Transverse shrinkage, Longitudinal shrinkage, Angular distortion, Rotational distortion, Bending, Buckling. Distortion leads to misalignment, increased rework cost, and reduced dimensional accuracy. Therefore, optimizing welding parameters to minimize distortion has become a critical research focus.

1.1.Welding distortion in SMAW

Distortion primarily occurs due to the following reasons

- Non-uniform heat distribution
- Excessive heat input
- Improper clamping
- Large groove angle
- High welding current
- Low welding speed
- Heat input

2.LITERATURE REVIEW

Sanjay et al (2023) optimized of stick welding parameters for joining dissimilar materials, specifically AISI 304 stainless steel and mild steel. They focused on evaluating mechanical properties, particularly tensile strength, while considering distortion and residual stresses developed during welding. V-groove butt joints of 5 mm thickness were welded using E6013 electrodes, with welding current varied from 90 A to 120 A. Tensile strength increased with increasing welding current, with maximum tensile strength observed at 120 A. All specimens fractured in the weld region, indicating the weld zone as the critical area. They found that proper selection and optimization of welding current significantly improve weld quality and joint performance in dissimilar SMAW welds [1]. Muhammad Saad Afzal et.al (2025) investigated the influence of SMAW parameters on weld quality and mechanical properties of mild steel joints. Five SMAW process parameters were selected, with each parameter set at four evenly divided levels. Those sections were made using a combination of screening experiments, machine specifications, guidance from the American Welding Specification handbook, and input from welding experts. The parameter names, units, and levels were depicted in Table-1. They focused on optimizing welding current, voltage, and travel speed to enhance tensile strength while minimizing welding defects and distortion. Their results indicate that welding current plays a dominant role in affecting joint strength and heat input, while improper parameter selection leads to excessive distortion and reduced weld integrity.

Table -1: SMAW variables and levels

Variables	Units	Symbol	L-1	L-2	L-3	L-4
Welding current	A	WC	100	130	160	200
Groove Angle	°	GA	50	60	70	80
Electrode diameter	mm	ED	2.5	3.25	4	5
Root Gap	mm	RG	1.5	2	2.5	3
Root Face	mm	RF	1	2	3	4

Their study reveals that systematic parameter optimization significantly improves weld quality, mechanical properties, and overall fabrication efficiency. The optimized setting was welding current of 160A, groove angle of 60°electrode diameter of 3.25mm, root gap of 3mm and root face of 3mm [2]. L S. Sisira et al (2019) conducted experimental and analytical study on the effect of SMAW parameters on distortion and mechanical properties of mild steel welded joints. They focused on key process variables such as welding current, voltage, travel speed, and electrode diameter, and evaluates their influence on heat input, angular distortion, and tensile strength. Experimental trials were conducted using butt welded mild steel plates, and distortion measurements were taken after welding to assess deformation behavior. Statistical techniques such as Taguchi method and ANOVA were employed to identify the most significant parameters affecting distortion. The results indicated that welding current and travel speed are the dominant factors influencing heat input and subsequent distortion, with higher heat input leading to increased angular deformation. Their study reveal that systematic optimization of welding parameters significantly reduces distortion while maintaining acceptable mechanical performance, thereby improving overall weld quality and dimensional accuracy [3]. Okwudili Simeon Ogbonna et al (2022) optimized of TIG welding parameters for dissimilar butt joints of AISI 1008 mild steel and AISI 316 austenitic stainless steel using a grey based Taguchi method. AISI 316 austenitic stainless steel and AISI 1008 mild steel plates having dimension (100 × 40 × 6) mm have been selected as the base materials for TIG welding in butt joint configuration with 2.5mm gap between the two plates. A 1.6mm thick austenitic stainless steel welding wire, ER309L, was used as the filler material. The results revealed that welding current was the most significant parameter with a 78.15% contribution based on ANOVA analysis [4]. Devendra Singh et al (2020) investigated the effect of plate thickness and current on the longitudinal shrinkage in mild steel butt joints. Studies reveal that as the thickness of mild steel plate increases, the longitudinal shrinkage in distortion also increases. As the Welding current of the mild steel increases, the longitudinal shrinkage also increases means the longitudinal shrinkage is proportional to the welding current. Bar graph was plotted as shown in chart-1,2 and 3. Longitudinal shrinkage is minimum when current and plate thickness is less.

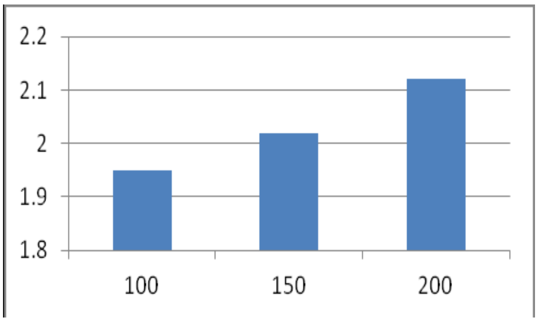

Chart -1: Longitudinal shrinkage at y axis and current at x axis of 6 mm thickness MS plate.

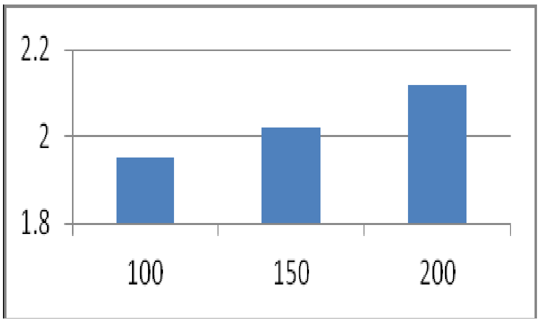

Chart -2: Longitudinal shrinkage at Y axis and current at x axis of 7 mm thickness of MS plate.

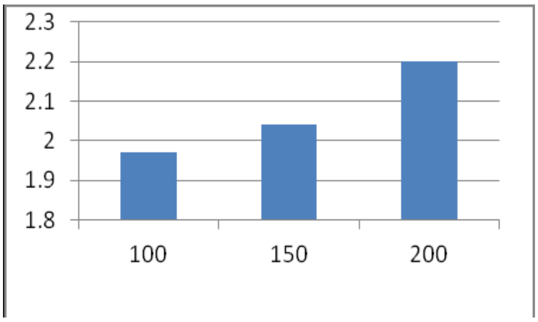

Chart -3: Longitudinal shrinkage at Y axis and current at x axis of 8 mm thickness of MS plate [5].

Harshal K Chavan et al (2012) simulated the complex arc welding process by using the finite element method (ANSYS) and studied the effects of varying the welding process parameters on the thermos mechanical responses also found a relationship between them. Their study reveal that the welding speed increases by, the responses such as displacement, strain decreases. An increase of 33% of welding speed results in a significant decrease in Y-displacement (11%), Z displacement (12%), and X-elastic strain (35%) [6]. P. Bharatha (2014) determined the influence of various welding parameters on the weld bead of

AISI 316 welded joint. In their work the ANOVA technique is used to identify the influence of the welding speed, current, electrode, root gap on the strength of the material. It was found that welding speed (46.51% contribution) has greater influence on bend strength and current (96.75%) has highest influence on tensile strength. Further it has found that root gaps have some influence on both tensile and bend strengths [7]. Balaram Naik et al (2018) optimized of shielded metal arc welding process on Duplex Stainless Steel (DSS 2205). They found that the influence of filler wire material is minimum and welding position is maximum for the maximum ultimate tensile strength. The influence of filler wire material on the hardness is minimum and welding current is maximum. Similarly welding current on the impact energy is minimum and welding position is maximum [8].M S Satish (2025) investigated the effect of hard facing on AISI 1020 mild steel using SMAW and MIG welding techniques with chromium-rich electrodes. findings showed that MIG welding, under controlled parameters, offers better performance in applications requiring high surface durability and wear resistance, while SMAW remains advantageous for deeper fusion and structural bonding [9]. Ade Nurfauziah et al (2023) used ASTM A36 carbon steel that material was welded by many variables that have been determined and the limitations of the problem during the study. It was found that the polarity and root gap distance used affected the welding results, where the DCEN polarity at 2 mm root gap showed better welding translucency results. As for the results of welding with DCEP polarity at 3 mm Root gap the results of better welding penetration. Their studies reveal that the use of different polarities and root gaps results in different welding qualities [10]. Abhishek Singh Gangwar et al (2017) their studies focused on how much distortion occur in low carbon steel (MS) plates and high carbon steel (EN-31) Plates of various cross-sections and thickness. They studied experimentally rather than by using any software, so that we can get more effective data. The amount of distortion can be controlled or minimize if pre-setting techniques are applied through welding fixtures. Studies reveal that it can't be suggested that what will happen if different types of weld cross section, different types of plate thickness, and different types of plate material are used in butt welding joints. Hence further study is necessary. If the other parameters of welding like speed of welding, voltage of welding, time of welding etc. which were kept constant in this study work. Hence scope of further work is still left wide open [11]. Ade Nurfauziah et al (2023) Studied the effect of root gap distance and polarity on defects in SMAW welding procedure The study revealed that the welding translucency is affected by polarity and root gap distance, where the DCEN polarity showed better translucent welding results than welding with DCEP polarity, even though it was still not in accordance with the standard [12]. Shivani Pant et al (2024) Evaluated Welding Electrode Angle and Root Gap Effects on Joint Quality. MS1018 and SS 304 metallic plates were connected together using the arc welding process. Two identically sized plates (110*50*6mm) are welded together to create a butt joint as shown in fig-1. The three most crucial process elements that affect bead shape are the welding. The results showed that while the heat input increased, the tensile strength increased. The hardness was predicted to increase as the current range increased, with the ideal parameters being high hardness, high tensile strength for weld at current of 110A, Electrode angle of 45 degree, and Root gap of 2mm [13].

Fig -1: welded MS1018 and SS 304 metallic plates

Rajeev Ranjan (2014) Optimized SMAW processes by using factorial design approach. The studies reveal that a strong joint of mild steel is found to be produced in this work by using the SMAW technique. If amperage is increased, welding deposition area generally increases. If travel speed is increased welding deposition area generally decreases [14]. S. H. Zoalfakar et al (2017) studies focused on the effect of welding parameters on mechanical and microstructural properties of St.37/2, St.44/2 and St.52/3 joints produced by shielded metal arc welding (SMAW) was analyzed in the present study. Different heat inputs (H) were applied to butt-welding joints by controlling current. To study the effect of groove angles on mechanical properties, the specimens were machined with different groove angles 40°, 60°, 80° and 100°. In order to determine the effect of welding process on the local heat affected zone (HAZ) thermal cycle during welding, three different conditions were chosen, where temperatures were recorded by using K-type thermocouples and a data acquisition system card of USB 6008, National Instrument type. Taguchi approach was applied to determine the most influential control factors which will yield better mechanical properties of the joints, where Taguchi's tools such as signal-to- noise ratio (S/N) have been used to observe the significant parameters and the optimal combination level of SMAW parameters [15]. Abhishek Singh Gangwar et al (2017) focused on, one of the welding defects known as Distortion. Distortion is the change in shape and difference between the positions of the two plates before welding and after welding. Distortion occurs due to good amount of temperature difference at various points along the joint and thus at any instant certain area of base metal expands and other including weld bead contract. It was studied down by experimentally rather than by using any software, so that to get more effective data. It has been found out the limit of angular distortion for three types of design for different thickness of plates i.e. 6 mm, 5 mm and 4 mm. with 1200, 900, and 600 Vee. These values of distortion will help the welder before welding to the present job and hence minimize distortion. But, still there is lack of information of this study. It can't be suggested that what will happen if different types of weld cross section, different types of plate thickness, and different types of plate material are used in butt welding joints. Hence further study is necessary. Extensive research has been conducted to study distortion behaviors and process optimization in SMAW. The following findings are discussed below.

2.1 Effect of welding current and heat input

Literature studies reveal that distortion increases with higher welding current and heat input. Increase in plate thickness and current significantly increases longitudinal shrinkage. Higher welding speeds reduce distortion due to lower heat input.

2.2 Taguchi based optimization

Taguchi orthogonal array methods (L9, L16, L27) have been widely applied to determine optimal parameter combinations. Studies reveal the following:

- Welding speed significantly influences distortion.
- Current strongly affects tensile strength.
- Groove angle impacts angular distortion.
- Electrode diameter affects impact strength.
- Taguchi methods improve robustness and reduce experimental trials.

2.3 ANOVA analysis

ANOVA has been used to determine percentage contribution of each parameter. Research findings indicate the following Welding current often has the highest contribution toward distortion. Voltage significantly influences weld deposition area. Welding speed plays a major role in angular distortion control.

2.4 Grey relational and multi objective optimization

Grey-based Taguchi methods have been used for multi-response optimization including:

- ❖ Tensile strength
- ❖ Hardness
- ❖ Impact strengths
- ❖ Distortion

These techniques help achieve balanced optimization rather than single-response improvement.

2.5 Finite Element Analysis (FEA)

FEA tools such as ANSYS are used to simulate thermal distribution and predict distortion.12% increase in heat input may cause up to 65% increase in displacement. Increased welding speed reduces strain and deformation. Narrow groove preparation reduces cumulative distortion.

Table -2: Comparative analysis of key findings

Parameter	Influence on Distortion	Research Consensus
Welding Current	High Impact	Major contributor
Welding Speed	Inversely Proportional	Critical factor
Groove Angle	Affects angular distortion	Moderate influence
Root Gap	Influences penetration & shrinkage	Moderate
Electrode Diameter	Affects heat input	Moderate
Welding Position	Affects angular distortion	Significant

3. RESEARCH GAPS IDENTIFIED

From the literature review, the following gaps are identified limited regression models specifically for distortion prediction in mild steel SMAW. Most studies focus on mechanical strength rather than distortion. Few studies integrate experimental validation with statistical modelling. Multi thickness mild steel plate optimization requires further study.

4.PROPOSED RESEARCH DIRECTION

Based on literature survey, the present study proposes:

- ❖ Application of Taguchi method for parameter optimization. Design of Experiments based OA.
- ❖ Evaluation of distortion for different mild steel plate thicknesses.
- ❖ Identification of optimal current, root gap & electrode angle combinations for minimum deformation.
- ❖ ANOVA for contribution analysis.
- ❖ Development of regression models for distortion prediction

5. CONCLUSION

This review shows that distortion in SMAW welded mild steel plates is strongly influenced by welding current, heat input, and welding speed. Higher heat input increases angular and longitudinal distortion, whereas optimized travel speed significantly reduces thermal gradients. Optimization techniques such as Taguchi method, ANOVA, Grey relational analysis, and FEA have proven effective in minimizing distortion while maintaining mechanical performance. Systematic parameter selection ensures repeatability and cost efficiency compared to conventional trial and error approaches. The literature strongly supports the need for integrated statistical modelling and experimental validation for reliable distortion control in SMAW processes.

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