Effect of Multi-pass SMAW Welding on the Surface Hardness and Microstructure of Carbon Steel AISI 1050

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Abstract. The objective of this work is to investigate the chemical composition, mechanical, and metallurgical properties of welded the carbon steel plates by electrode E7Cr utilize a shielded metal arc welding (SMAW) to weld three cases include one, two, and three passes. The material of the carbon steel plate was of type AISI 1050 with a thickness of 18mm, the diameter of the electrode was 3.2mm. A surface welding was used as a deposit on the surface of base metal with welding parameters of welding current = 90-140A, voltage = 21V. The welded workpiece was tested by a chemical composition analysis, Vickers hardness test, and microstructure test. The results refer that the chemical composition analysis of deposited weld metal achieved an increase in the alloying element of C, Cr, and Mn. The microstructure test of welding zone gives the microstructure different of the base metal, which it consists of a mixture of fine-grain Ferrite, dendrite, coarse dendrites, and Cr-carbide, especially in the third pass. The Vickers hardness test of the third layer had an estimate much higher than of the other layers.

Keywords. Shielded metal arc welding (SMAW), Carbon steel, E7Cr, Multi-pass welding, Surface hardness.

1. Introduction
Welding is a typical and compelling approach of join various pieces of any structure. The processes welding are various kinds, some rely upon the electrical arc and others don't utilize the electrical arc during welding. During the process of arc welding, the shielded metal arc welding (SMAW) is the most widely recognized, otherwise called stick welding and is regularly utilized in little industries. In this process, the choice of the electrode is very significant. SMAW take up the position of most significant in the fusion welding processes combination, and on account of its flexibility and cost-availability, it is an irreplaceable technology for steel-outlined structures, motor vehicle manufacture, shipbuilding, and different industries. Since the SMAW technique is pliable, it's the most proper approach to many works. If the input of welding variables, for example, voltage, current, welding angle, feed, and speed of welding, etc are multiple the optimum estimation of the output of welding variables like tensile strength, hardness, and impact strength, etc can be regulated. Welding properties can likewise be influenced by the accession of required elements in the electrode covering. Welding cooling rate additionally influences hardness. Joining of metal is a generally controlled process utilized for the combine similar/dissimilar metals. Among the many techniques of metal joining, welding is one of the most generally utilized procedures for an assortment of applications. Physical, metallurgical, and chemical changes because of the welding processes that seriously influence the
welding corrosion resistance [1-4]. To know the quality of welding, the most significant thing is to examine the microstructure and variant mechanical properties, for example, impact toughness, microhardness, and weld strength of welded samples in different zones such as HAZ, less HAZ, and the fusion zone. In the microstructure, pearlite and ferrite grains were generally observed. The fundamental objective is to increase the weld quality, impact toughness, strength with better microstructure and more sturdy welded joints. The mild steel is the most normally utilized steel for welding because of its low and good relatively mechanical properties, which are suitable for plentiful applications, particularly in cruel conditions, such as the greenhouse effect, extreme weather, corrosive marine environment, and external massive loads [5-7]. The alloy of steel is a combination comprising of the major elements of iron (Fe) and carbon (C), likewise to other components such as Mn, Cr, Ni, Si, etc., that are organized in exceptional little percentages. Other than, these components will influence the quality of steel. The welding process mostly includes the parts of melting and subsequent cooling, and the consequence of this thermal cycle may be distortion if the items of welded are free to residual stress or move if the component is securely held [8,9]. There’s a point where the magnitude of residual stress can lead to potential issues, either promptly or amid the life of the welded structure, and it must be diminished or removed. Post weld heat treatment (PWHT) is the foremost commonly utilized form of stress-relieving when the welded structures are completion of fabrication. High-level residual stresses can happen in weldment consequent to restraint by the principle metal amid weld solidification [10,11]. The stresses might be as loudly as the material yield strength itself. When combined with typical load stresses these may surpass design stresses. These stresses competence be relieved by PWHT. Understandably, PWHT can incorporate many various prospect treatments; nevertheless, within the steel industry, the two widely popular methods utilized are stress relieving and post-heating. The heat treatment comprises of the annealing, stress-relief, or solution annealing-based treatment as required. For illustration, the annealing and tempering are used to essentially progressed the mechanical properties of welded steel [12,13]. As well, to reliably produce high-quality welds, arc welding requires the welding personnel to have experienced. One cause for this is typically the got to appropriately recognize welding parameters for a specific task to supply good welding quality which is decided by its microstructure and the spatter amount, and depending on the proper geometric estimate of the beads. Therefore, the utilize of the control system in electric arc welding can dispose of much of the regularly utilized by welders’ specialists to decide welding parameters for a specific assignment [14,15]. This paper exhibits the investigation of the effect of using the electrode E7Cr with the base metal of carbon steel AISI 1050 in terms of the microstructure, mechanical behaviour (hardness), and the chemical composition of the welding metal. By employing the SMAW processes to welding the electrode E7Cr on the surface of the base metal or rather, it is called deposited the electrode E7Cr by multi-pass welding (one, two, and three pass) on the surface to obtain the hardfacing surface.

2. Experimental Work

2.1. Metals Properties
In this investigation, the metal of carbon steel metal AISI 1050 was used with 18 mm sheet thickness also the electrode E7Cr was that used in the welding process, which the chemical composition analysis was performed for carbon steel and the electrode as appeared in tables 1 and 2 respectively.

| Table 1. Chemical composition of carbon steel AISI 1050 |
|-------------------------------------------------------|
| Elements | C% | Si% | Mn% | P% | S% | Cr% | Mo% | Ni% | Al% | Cu% | Ti% | Fe% |
|---------|----|-----|-----|----|----|-----|-----|-----|-----|-----|-----|-----|
| Actual  | 0.492 | 0.23 | 0.72 | 0.011 | 0.023 | 0.08 | 0.015 | 0.043 | 0.025 | 0.02 | 0.028 | Bal. |
Table 2. Chemical composition of the electrodes E7Cr

| Elements | C% | Cr% | Mn% | Mo% | Nb% | Si% | Fe     |
|----------|----|-----|-----|-----|-----|-----|--------|
| Actual   | 0.5| 7.2 | 0.92| 0.52| 0.05| 0.8 | Bal.   |

Also, the mechanical properties analysis (Vickers hardness test) was the procedure for each of the carbon steel and the electrode, the estimate of Rockwell hardness was 275 HV0.2.

2.2. Welding Procedures:
In this study, the process of SMAW was performed to weld the carbon steel AISI 1050 base metal by utilized electrode E7Cr, the steps of this procedure has consisted of three stages; 1) welding or deposit only one pass, 2) welding or deposit only two passes, 3) welding or deposit only three passes, the welding parameters that were used shown in table 3.

Table 3. The welding parameters

| Electrode Length (mm) | Welding current (A) | Arc voltage (v) | Electrode Diameter (mm) |
|-----------------------|---------------------|----------------|-------------------------|
| 450                   | 90-140              | 21             | 3.2                     |

2.3 Experimental Examination
The specimens were prepared and a chemical composition analysis was performed in the weld zone for the three welding cases (one, two, and three passes). The microstructure examination was achieved for the metallographic of three cases, where the specimens prepared as follows; 1) the specimens cutting, 2) grinding by using emery Paper (180, 320, 500,800,1200), 3) polishing by using Alumina powder, 4) etching by using (98% Alcohol +2% Nitric acid). The Vickers hardness test was achieved on the three welding cases by applying the load 200g for 15s dwell time, where this test was performed at points weld line as shown in the figure 1.

![Figure 1. Hardness test specimen; a) welding one pass specimen, b) welding two-pass specimen, c) welding three-pass specimen](image)

3. Results and Discussion
3.1. Chemical composition analysis
Table 4 shows the analysis of the chemical composition of the welding zone after welding of carbon steel metal by the SMAW process and using electrode E7Cr, for each welding cases (one, two, and three passes). Where an increase in the deposited layer or welding passes led to variety and enrichment of proportion elements of chemical composition within the surface, particularly, C, Cr and Mn, and subsequently microstructure and hardness are various with each pass.
### Table 4. Chemical composition of weldment

| Elements  | C %  | Si %  | Mn %  | P %  | S %  | Cr %  | Mo %  | Ni %  | Al %  | Cu %  | Ti %  | Fe %  |
|-----------|------|-------|-------|------|------|-------|-------|-------|-------|-------|-------|-------|
| One pass  | 0.86 | 0.93  | 0.523 | 0.024| 0.094| 4.75  | 0.499 | 0.079 | 0.04  | 0.025 | 0.06  | Bal.  |
| Two passes| 0.74 | 1.17  | 0.492 | 0.012| 0.016| 7.38  | 1.07  | 0.075 | 0.009 | 0.069 | 0.023 | Bal.  |
| Three passes| 0.73 | 1.23  | 0.486 | 0.011| 0.021| 7.86  | 1.18  | 0.066 | 0.008 | 0.072 | 0.027 | Bal.  |

3.2. Microstructure examination

The examination of microstructure was performed on the cross-section zone of the base metal and welding layer after deposit electrode E7Cr on the surface of the workpiece, wherever the procedure of examination was performed on the specimens as shown in figure 1 from below the base metal towards the top of welding layer, where it has been observed that the microstructure of base metal comprises of fine-grain the Ferrite and Pearlite and this formation continues with no changes from the bottom edge of base metal until the 16 mm in the cases of one and two passes, and to 15 mm in case of three passes. This is refer to no heat effect of welding (one and two passes) on the base metal in this distance, however, a case of three passes appeared grain growth because of additional heat in this case.

As it has been observed that changes occasion in the microstructure when going nearer to the welding zone due to the influence of temperature, wherever it was noticed the dendrites began to appear. At welding one and two passes, the microstructure of weld metal was consisting of fine grain Ferrite and dendrite and Cr-carbide, however, the microstructure of welding three pass was comprised of fine-grain Ferrite, dendrite, coarse dendrites, and Cr-carbide, as shown in figures 2, 3 & 4. The dendrites appeared in the weld metal structure due to mismatch composition.

![Figure 2. Microstructure of one pass welding](image1)

![Figure 3. Microstructure of two pass welding](image2)
3.3. Vickers hardness Result

Figure 5 exhibited the result of the Vickers hardness test, where it found the hardness estimate of the third layer was much higher than of the substance other layers, it was estimated 745 HV and the rate of increment 2.7 times compared to the base metal. Wherein increment the hardness of third pass layers is relative to the dilution effect, when more layers are deposited, the dilution diminishes, and thus the hardness increase. Also, the HAZ of the third layer was much higher than other passes due to additional heat with third pass layers. That is the reason it’s called surface hardness or hardfacing.

4. Conclusions

The carbon steel AISI1050 was welded by the SMAW process utilizing the electrode E7Cr. From the chemical composition analysis, it found that an increase in the alloying elements was obtained. The microstructure examination demonstrates the microstructure of weld metal when it deposits the electrode E7Cr, it has a significant influence on the microstructure due to high temperature, as it has given large changes in the microstructure, where it found the welding multi-pass appear to involve of Cr-carbide, Ferrite, dendrite, and coarse dendrites. The Vickers hardness test shows the welding zone of the third pass having highest values and the surface hardness improved by 2.7 times contrasted with
the base metal, which it is the best process can use it for diminishing the cost of replacement, it decreases downtime, it tends to be utilized on any steel material.

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