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Identification of Chemical Properties of ER307 Electrode in GMAW Welding for Physical and Mechanical Characteristics of Armor Steel

[1] **Maura Indah Puspita,** [2] **Imastuti**

[1, 2] Department of Physics, Faculty Military of Science and Mathematics, Defense of University, Bogor, Indonesia

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Corresponding Author: **Maura Indah Puspita, Imastuti**

Abstract

Gas Metal Arc Welding (GMAW) is a welding technique widely used in industry due to its efficiency and ability to produce high-quality weld joints. In this process, the selection of filler metal is an important factor that affects the mechanical properties and microstructure of the weld. One type of filler used is ER307, which is a high manganese stainless steel-based austenitic welding wire designed to join dissimilar metals or steels with high carbon content. The use of ER307 in the GMAW process provides advantages in increasing crack resistance and toughness of the weld, especially in joints that experience high stress or extreme environmental conditions. This study aims to identify the ER307 electrode in the Gas Metal Arc Welding (GMAW) process against the physical and mechanical properties of MIL-DTL-46100E armor steel. Characterization is carried out through EDS tests for microstructure observation, and Vickers hardness tests. The results show that the highest hardness value is in the HAZ zone (523 HV), while the weld metal reaches 324–328 HV, according to Defense Standard 03-34. The content of Mn and Ni in ER307 increases the combination of strength and ductility, while Zn plays a role in corrosion resistance. Thus, ER307 is proven to meet the requirements for welding armor steel for defense applications. The results show differences between the weld metal areas with higher hardness values. The influence of the welding process causes microstructural changes, especially in the HAZ area where the phase is dominated by the ferrite phase. Evidence of material strength in ER 307 electrodes has unique chemical properties by containing elements Manganese (Mn) and nickel which help improve the combination of strength and ductility of the material, and Zinc which has the property of protecting the material from corrosion to strengthen the properties of the joint material in accordance with the steel strength guidelines.

Keywords: Steel, Electrodes, Welding, EDS, Chemical Properties

Introduction

In the advancement of modern technology and industry, especially in the field of metal manufacturing, the welding process plays a crucial role in the manufacture or repair of metal structures [1]. To ensure performance and structure, the selection of welding methods and materials is an aspect that must meet established technical standards. One important application is the manufacture of military vehicles such as battle tanks, which use high-standard materials such as Armor Steel. This material is chosen because it has high hardness and toughness properties against ballistic attacks. Therefore, what is important in combat vehicles is the choice of materials used. The selection of this material as the main security is from the vehicle body. Including the selection of electrodes that match the characteristics of the hardness and toughness of the material for joining armor steel.

The technique used for assembly into a certain shape for joining. The technology that can join these materials in the manufacturing industry is called Welding. This welding technology is used for repairs, cutting and also the joining process, especially in this joining process, which is the process of joining two or more materials to be joined by melting the electrode together with the weld lip through heat energy derived from electrical energy. This process consists of partially melting the two materials to form a single material, by providing heat or pressure, or both [2]. The welding technique commonly used in industry is Gas Metal Arc Welding (GMAW). The GMAW welding technique is a metal joining method that utilizes a continuously supplied electrode wire and external shielding gas to protect the weld area from the influence of the surrounding air or contaminants. Gas Metal Arc Welding (GMAW), because it has advantages such as the speed of the welding process, good joint quality, and the ability to weld materials with high levels of hardness.

This study aims to analyze the characteristics of the microstructure and hardness of welded joints in MIL-DTL-46100E steel using ER307 filler, and evaluate its suitability to defense material welding standards. By referring to the Steel standard guidelines in accordance with the MIL-DTL-46100E Armor Steel reference. To produce medium carbon steel that has high hardness and strength so that medium carbon steel can be given heat (heat treatment) to change the mechanical properties [3]. The formation of these properties is very necessary to obtain industrial materials that are appropriate to the needs and functions. The focus of this research is to identify the suitability of mechanical properties based on the chemical composition of the resulting steel joints. This research will provide an in-depth microstructural analysis and enhance understanding of the appropriate filler selection for weld quality in high-hardness steel, thus providing more accurate recommendations for armor steel welding materials.

Methode

In this study, the welding technique chosen is Gas Metal Arc Welding (GMAW) using a t-joint specimen. This welding process aims to connect two or more metals and generally produces 3 important areas, base metal, fusion line, and Heat Affected Zone (HAZ). The chemical composition of the metal was analyzed using Energy Dispersive Spectroscopy (EDS), while the hardness was tested using the Micro Vickers Hardness method. Observations of macro and micro structures were carried out on all joint zones, with parameter control in the form of a current of 236 A, a voltage of 26.2 V, and a Down-to-Hand welding position. In making the Vickers test specimen, the GMAW welding method was used with a variable control dimension of the Armor Steel MIL-DTL-46100E specimen.

Results and Discussion

This research analysis identifies the material content of the ER307 electrode in relation to previous theories and research to strengthen the validity of the findings. It also evaluates suitable materials in terms of composition and interference with hardness data.

Tabel 1: Tabel properties kawat ER307

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	24.633	7.908
8	O	Oxygen	17.554	7.508
13	Al	Aluminum	0.694	0.501
14	Si	Silicon	1.067	0.801
15	P	Phosphorus	0.121	0.100
16	S	Sulfur	0.234	0.200
24	Cr	Chromium	5.329	7.407
25	Mn	Manganese	1.431	2.102
26	Fe	Iron	46.132	68.869
28	Ni	Nickel	1.659	2.603
30	Zn	Zinc	1.146	2.002

Table 1 shows that the Oxygen content has a tendency to form cracks and can weaken metal bonds. The mixture of carbon and iron provides a texture with appropriate heating making the material behave like steel with the composition of other materials having the same composition approach as Armor Steel. Data shows that the EDS results show the dominant content of Fe (68.8%), C (24.6%), Cr (5.3%), Mn (1.43%), and other elements such as Ni and Zn in ER307 wire. The Manganese (Mn) content plays a role in increasing the combination of strength and ductility of the material. This theory is consistent with the research of Lei Xia *et al*. (2022) which states that high manganese austenitic steel has a good combination of mechanical properties, especially in applications with high shock loads [5]. Nickel (Ni) plays a role in the formation of a stable austenite phase and increases toughness. This is reinforced by Bajželj *et al*. (2022) which shows that the presence of Ni in stainless steel improves carbide formation and crack resistance [6]. Zinc (Zn) functions as a corrosion protection layer. Chavan *et al*. (2013) reported that Zn coating on steel increases resistance to oxidation and corrosion [7]. The composition of ER307 wire supports the formation of welded joints with good mechanical properties and high environmental resistance, making it suitable for armor steel supporting the formation of strong, ductile, and corrosion-resistant welded joints. This is in accordance with the standard requirements that are desired to have the same durability and mechanical properties as armor steel.

Hardness

In this study, the welding process of armor steel with ER 307 was carried out. The current and voltage used during the welding process were fixed at 236 A and 26.2 Volts. From the welding results, hardness testing was carried out for each parameter in the base metal (BM), heat affected zone (HAZ), and weld metal (WM) areas. The results of the test data processing can be seen in Figure 1 for the hardness test data on ER 307 filler welding.

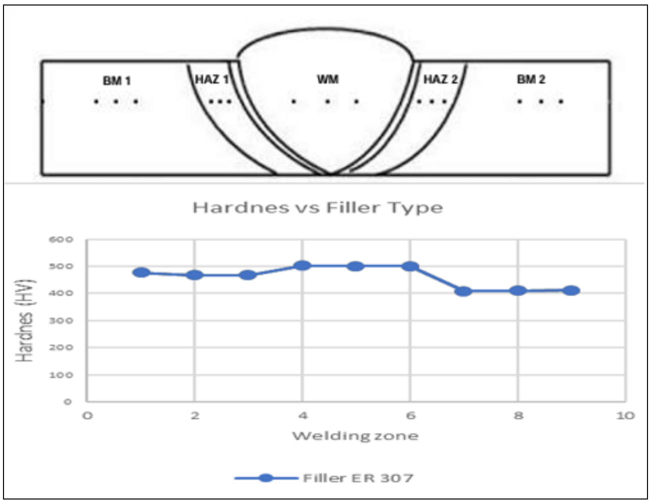

Fig 1: Plotting hardness values on specimens

Observations show microstructural changes in the HAZ region with a predominance of the ferrite phase and the possible formation of martensite due to rapid cooling. Theory supports this result: in medium-high carbon steel, rapid cooling in the HAZ causes the transformation of austenite into martensite, which increases hardness. The highest hardness of the weld joint is located in the HAZ due to the intense heat influence during the welding process. The welding process involves heating the base metal material to melt it, and rapid cooling after welding can cause significant microstructural changes around the heat-affected zone [8]. The microstructural stability of the weld metal is relatively more homogeneous because it comes from the ER307 filler metal, which is more resistant to deformation than the base metal. The GMAW welding process with ER307 produces a transition zone (HAZ) that is harder than the weld metal due to differences in cooling speed and alloying element content.

The highest hardness value is found in the HAZ (523 HV), while the weld metal is lower (324–328 HV) but still meets the Defense Standard 03-34 standard (≤550 HV). This pattern is in accordance with welding theory: the HAZ area experiences intense heating and rapid cooling resulting in a martensite structure with high hardness so that the filler material matches or improves the mechanical properties of the base metal, such as strength, corrosion resistance, etc. which causes the final hardness of the weld zone (WM) to be lower than the harder base metal (BM) [9]. The hardness distribution obtained in this study supports the welding standards for armor steel: the value in the weld metal is high enough for strength, and the HAZ is still within safe limits (not excessively brittle).

Armor steel demands a combination of high hardness to resist ballistic penetration and ductility to absorb impact energy. The results of this study indicate that ER307 produces joints with stable mechanical properties and meets defense standards, so it can be recommended as a filler for combat vehicle applications. thus maintaining consistent mechanical properties. This good dimensional stability shows a similar trend that joint quality is determined in welded joints referring to the ability to avoid unwanted dimensional changes during the welding and cooling processes, which affect the hardness and strength of the joint [10].

The heat affected zone (HAZ) of this wire has high hardness. This is because the high cooling rate in the HAZ after welding can increase the possibility of phase transformations that produce high hardness, such as the formation of martensite in high carbon steel [11]. The content of Mn, Ni, Zn in ER307 contributes to strength, ductility, and corrosion resistance. The highest hardness in the HAZ is in line with the theory of phase transformation due to rapid cooling. The hardness value is within the international standard range, supporting armor steel applications.

Conclusion

The use of ER307 welding wire in welding MIL-DTL-46100E steel with the GMAW method shows hardness and microstructure results that comply with defense industry standards. The combination of mechanical properties and filler chemical composition is able to produce a strong, stable, and deformation-resistant weld joint, making ER307 the right material of choice in armor steel welding applications.

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