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Effect of Porosity on the Mechanical Properties of Medium Carbon Steel Welded Using E7018 Electrode

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Abstract— *This study aims to evaluate the effect of porosity caused by moisture and hydrogen on the mechanical properties of medium carbon steel welded using E7018 electrode. Three welding conditions were carried out at a constant current of 120 A: the first without any preheating and with undried electrode; the second with preheating of the workpiece at 250°C; and the third combining preheating with electrode drying at 200°C. The tests included hardness measurement using Rockwell (150 kg), Charpy impact test, and visual inspection to determine porosity and cracks. The results showed that the absence of preheating and the use of a moist electrode led to significant porosity and hydrogen-induced cracks in the heat-affected zone, low hardness (10 HRC), and poor impact energy (13 J). Preheating alone reduced cracking but porosity persisted, with limited improvement in hardness (13 HRC) and absorbed energy (16 J). In contrast, combining preheating with electrode drying resulted in a remarkable improvement in weld quality, almost eliminating porosity, increasing hardness to 24 HRC, and significantly raising impact energy to 130 J. The findings confirm that porosity associated with moisture and hydrogen is a governing factor in the deterioration of mechanical properties, and that controlling drying and preheating conditions is an effective strategy to improve the performance of welded joints in medium carbon steel.*

Keywords— *E7018 Electrode, Electrode Drying, Hardness, Hydrogen, Induced Cracking, Impact Toughness, Medium Carbon Steel, Mechanical Properties, Porosity, Preheating.*

I. INTRODUCTION

Welding medium carbon steel is a common industrial process in engineering and construction applications due to its suitable mechanical strength and ease of forming and welding. However, engineers and researchers face challenges related to defects during welding, most notably porosity and hydrogen-induced cracking, which directly affect the mechanical properties of welded joints.

Porosity forms as a result of trapped gases such as hydrogen or water vapor inside the weld metal during solidification, while hydrogen-induced cracks often occur due to the presence of hydrogen in the heat-affected zone (HAZ) combined with rapid cooling or brittle microstructures. These phenomena reduce hardness, impact resistance, and tensile strength, and may lead to weld failure under mechanical loads or shocks.

Previous studies have shown that preheating the workpiece reduces the local cooling rate in the HAZ, preventing the formation of brittle structures and decreasing the likelihood of cracking. Drying electrodes before welding eliminates the hydrogen source from moisture in the electrode coating, significantly reducing porosity and thereby improving the mechanical properties of the weld.

This study aims to evaluate the effect of preheating and electrode drying on weld porosity and mechanical properties of medium carbon steel by comparing three different welding scenarios:
(1) without preheating and with moist electrode,
(2) preheating only.
(3) preheating combined with electrode drying.
The evaluation includes Rockwell hardness (150 kg), Charpy impact test, and visual inspection for porosity and cracks, with analysis of the relationship between mechanical defects and welding conditions.

II. MATERIALS AND METHODS

1. Base Material:

The material used in this experiment is medium carbon steel according to [specification number], with the chemical composition as shown in Table1 and Fig.1 with dimensions of 10 mm × 20 mm × 150 mm.

TABLE 1. The chemical composition of the Sample

Element	C	Mn	Si	P	S	Fe
(wt%)	0.45	0.65	0.25	0.03	0.03	Balance

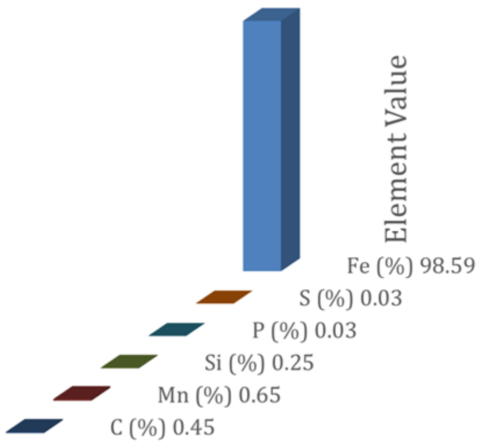

Fig. 1. Chemical composition of the Sample

2. Electrode Type

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The electrode used in this experiment is E7018 electrode, with the chemical composition as shown in Table 2, welding current 120 A.
Three conditions:
1. No preheating, moist electrode
2. Preheating at 250°C, moist electrode
3. Preheating at 250°C, electrode dried at 200°C

TABLE 2. Chemical composition of E7018 electrode.

E7018	C	Si	Mn	p	s	Cr	Ni
(wt%)	0.08	0.68	1.55	0.02	0.01	0.07	0.06

3. Preheating and Electrode Drying

- Preheating: Electric furnace at 250°C for 30 minutes
- Electrode drying: Electric furnace at 200°C for 1 hour, stored dry

4. Welding Process

SMAW, 120 A, flat position
Welding speed: 5 mm/s
Surface cleaned of oil and rust

5. Porosity and Crack Measurements

Visual and optical micrographic inspection.
Quantitative analysis using ImageJ software.

TABLE 3.

Condition	*Porosity (%)*	*Hydrogen Cracks*
1	≈ 3.5	YES
2	≈ 1.2	NO
3	≈ 0.1	NO

Fig. 2. Morphology of welding results at Porosity 3.5%

6. Statistical Analysis

In order to see if there is a statistically significant difference in the porosity between the three different conditions, the data from three different welding conditions were subject to a one-way ANOVA. Besides, five (5) measurements taken for each welding condition were considered to ensure statistical reliability. After that, Tukey's post-hoc test was used to analyze pairwise the statistical significance between the three welding conditions and their respective porosity values. The statistical computer programs Python with SciPy and Stats models libraries were used to perform the statistical analysis.

Fig. 3. Morphology of welding results at Porosity 1.2%

Fig. 4. Morphology of welding results at Porosity 0.1 %

7. Mechanical Testing

-Hardness: Rockwell HRC 150 kg

-Impact test: Charpy V-notch, sample dimensions 10 mm × 10 mm×55 mm, three trials per condition, average taken.

TABLE 4. Distribution of porosity ratios in three cases

Groupe1	3.5	3.2	3.8	3.6	3.4
Groupe2	1.2	1.0	1.3	1.1	1.4
Groupe3	0.1	0.2	0.15	0.0	0.1

III. RESULTS

TABLE 5. Comparing data at varying conditions.

Condition	Preheating	Electrode Drying	Porosity (%)	Cracks	Hardness (HRC)	Charpy Energy (J)
1	NO	NO	3.5	YES	10	13
2	250°C	NO	1.2	NO	13	16
3	250°C	200°C	0.1	NO	24	130

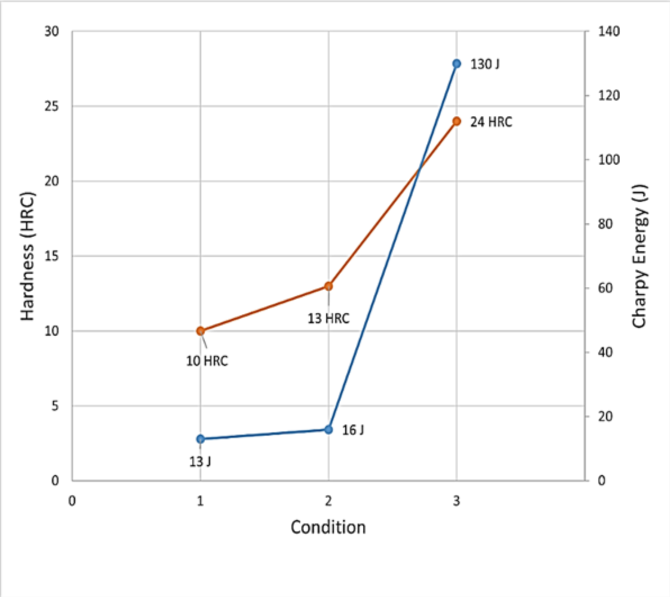

Fig. 5. Graph comparing data at varying conditions.

Analysis:
-Condition 1 showed the highest porosity and brittleness.
-Condition 2 eliminated cracks but porosity remained, with limited improvement.
-Condition 3 showed minimal porosity, no cracks, and significant improvement in hardness and impact energy.
The ANOVA yielded that there was a significant statistical difference, $F - statistic = 571.27$
$p - value = \sim 1.26 \, x \, 10^{-12}$ between the three different welding conditions.

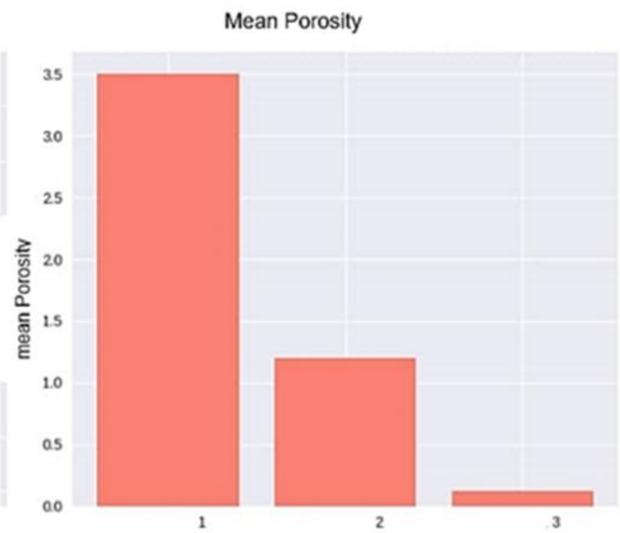

Fig. 6. Mean values of porosity for the welding conditions.

In addition, according to Tukey's post-hoc test, all three welding conditions (3) had a moderate and significant statistical difference, $p - value < 0.05$, when compared to one another. The Mean Porosity of each condition was;
$Condition\ 1: \approx 3.5\%,$
$Condition\ 2: \approx 1.2\%,$
$Condition\ 3: \approx 0.1\%.$
Boxplots and bar charts were also created to visually compare the distribution and mean values of porosity for all three welding conditions.as shown in Fig.6 and 7

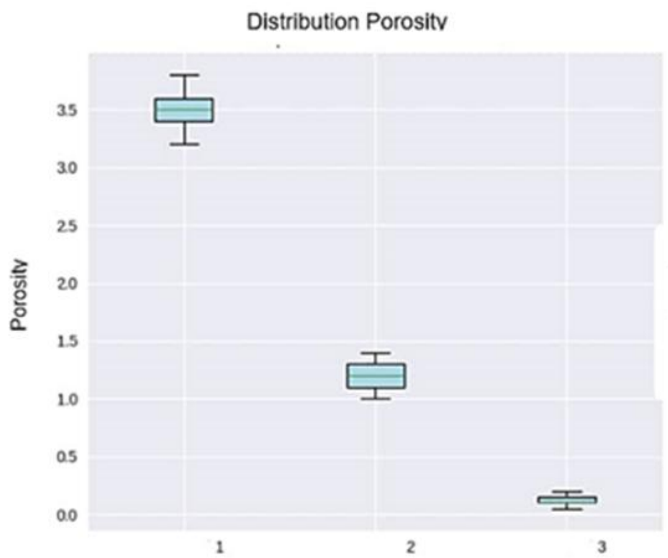

Fig. 7. Distribution porosity for the welding conditions

IV. Discussion

1. Effect of Moisture: Moist electrodes are a source of hydrogen and porosity, increasing weld brittleness.
2. Preheating: Reduces cooling rate, prevents brittle structures, and eliminates hydrogen-induced cracks.
3. Electrode Drying: Minimizes hydrogen entry, reduces porosity to ~0.1%, improves hardness and absorbed energy.
4. Porosity–Property Relationship: Lower porosity enhances hardness and impact toughness; higher porosity increases brittleness.
5. Comparison with Literature: Results align with previous studies on moisture and hydrogen effects in welding.
6. Practical Considerations: Applying preheating and electrode drying significantly improves weld quality.
7. Since the questionnaire data collection methods were validated using statistical analyses, the conclusions of the study are valid

V. Conclusions

1. Electrode moisture causes porosity, hydrogen cracking, and reduced hardness and toughness.
2. Preheating reduces cracking and partially improves mechanical properties.
3. Combining electrode drying with preheating greatly enhances weld quality (24 HRC, 130 J).
4. Reduced porosity strengthens mechanical properties of the weld.
5. Recommended practice: preheating at 250°C and electrode drying at 200°C before welding.

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