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The Effect of Quenching Process on Chrome and Carbon-Coated Carbon Steel on Hardness Level and Microstructure

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ABSTRACT

The increasing demand for wear-resistant steel components, such as excavator buckets, necessitates improvements in surface hardness and durability. This study aims to evaluate the effect of electrode modification using Chrome and Carbon powder and subsequent quenching in coolant on the hardness and microstructure of low carbon steel. Modified E7018 electrodes were manually coated with Chromium, Carbon, or a combination of both and used to weld low carbon steel specimens. Post-weld heat treatment involved heating at 1000°C for 20 minutes, followed by coolant quenching. Vickers hardness testing and optical microscopy were performed to evaluate mechanical and microstructural changes. The highest hardness value of 348.98 VHN was recorded in the specimen treated with Carbon-modified electrodes and quenched in coolant, correlating with a dominant martensitic microstructure. In contrast, untreated specimens exhibited ferrite-pearlite phases and significantly lower hardness. The findings indicate that the combination of Carbon addition and coolant quenching substantially enhances hardness through martensite formation, offering a practical solution for improving the wear resistance of structural steel.

Keywords*: Quenching, Hardfacing, Carbon, Chromium, Martensite, Vickers Hardness*

1. INTRODUCTION

Low carbon steel is extensively used across various industrial sectors due to its affordability, weldability, and good mechanical workability [1]. Its mechanical properties—particularly hardness and tensile strength—can be enhanced through heat treatment processes such as quenching and tempering [2]. However, increasing the carbon content, while improving hardness, often leads to reduced ductility and increased brittleness [3]. These trade-offs become critical in heavy-duty applications such as excavator buckets, where components are continuously subjected to abrasive forces from soil, rocks, and debris during operation.

Therefore, improving wear resistance becomes essential for extending the service life of such parts. One widely adopted method to improve surface wear resistance is hardfacing, which involves depositing a wear-resistant layer onto a base metal using consumable electrodes, such as E7018 [4].

Hardfacing forms, a protective hard layer that resists deformation and material loss under mechanical stress [5]. Rather than directly coating the steel surface with hard elements, this study adopts a more integrated approach: modifying the chemical composition of the electrode itself. In particular, incorporating alloying elements such as Chromium (Cr) and Carbon (C) into the electrode has been shown to significantly influence the hardness and microstructure of the deposited weld metal [6]. Chromium enhances hardness and corrosion resistance by forming stable carbides and promoting the formation of martensitic structures, while Carbon contributes to hard phase formation during rapid cooling [7].

In this study, a modified HV350-type electrode containing elevated levels of Chromium and Carbon is used to investigate its effect on the resulting weld deposit. It is important to emphasize that this research focuses on electrode modification rather than direct surface coating of the base metal. The modified electrode is used in welding to deposit Cr- and C-enriched metal, which subsequently undergoes quenching to achieve the desired microstructure.

Quenching is a thermal treatment process in which steel is heated to its austenitizing temperature—typically between 800°C and 950°C for low carbon steel—and then rapidly cooled using a quenching medium such as water or coolant [8]. This rapid cooling transforms the austenitic microstructure into martensite, which is characterized by high hardness and increased wear resistance. A holding time of 20 minutes was selected to ensure uniform austenitization, while coolant quenching was applied to optimize martensitic transformation while minimizing thermal distortion.

Previous studies have confirmed that quenching with coolant is effective in increasing surface hardness [9]. Despite the growing interest in hardfacing and quenching, most existing studies have focused either on electrode modification or on heat treatment in isolation. Limited research has explored the combined effect of both techniques—particularly when applied to low carbon steel using Cr- and C-enhanced electrodes followed by coolant quenching. Furthermore, while several investigations have examined the role of alloying elements in improving mechanical properties, the correlation between specific microstructural phases (such as ferrite, pearlite, and martensite) and hardness levels remains insufficiently addressed.

Therefore, this study aims to investigate the combined effects of electrode modification using Chromium and Carbon and subsequent quenching in coolant on the surface hardness and microstructure of low carbon steel. It is hypothesized that the addition of Cr and C in the electrode, followed by controlled quenching, will promote the formation of a dominant martensitic phase and yield significantly higher surface hardness compared to non-modified or non-quenched conditions.

2. METHODOLOGY

The research was conducted using an experimental method with the following stages:

1) Material Preparation

a) Base metal: Low carbon steel, cut into 9 specimens (100 mm × 50 mm × 10 mm).
b) Electrodes: E7018 type, modified by coating with:
  - Chrome (Cr) powder,
  - Carbon (C) powder,
  - Combination of Chrome + Carbon (Cr+C).

c) Electrode coating method: manual application using adhesive binder.

2) Welding Process

a) Equipment: Shielded Metal Arc Welding (SMAW) using DC+ polarity.
b) Parameters: 95 A current, single pass weld on one surface of each specimen.
c) Welding variations:
  - 4 specimens with modified electrodes, no quenching (NT group).
  - 4 specimens with modified electrodes, quenched in coolant (PC group).
  - 1 raw specimen as control.

3) Heat Treatment and Quenching

a) Heating temperature: 1000 °C using electric furnace.
b) Holding time: 20 minutes.
c) Quenching medium: Water-based coolant (fast cooling rate).
d) Quenching applied only to PC group after welding.

4) Hardness Testing

(a) Method: Vickers Hardness Test.
(b) Load: 5 kg.
(c) Measurement: 5 indentations per specimen.
(d) Average hardness value recorded for each variation.

5) Microstructure Examination

(a) Sample preparation: Cutting, polishing, and etching using 2% Nital.
(b) Observation tool: Optical microscope at 10×–100× magnification.
(c) Target analysis: Identification of ferrite, pearlite, and martensite phases.

6) Data Processing

a) Data tabulated per specimen.
b) Hardness trend compared across all groups.
c) Correlation analyzed between electrode composition, quenching, and microstructure.

3. RESULTS AND DISCUSSION

3.1 Vickers hardness results

The Vickers hardness values for all specimens are presented in Table 1. The results show a clear trend: specimens treated with Carbon-modified electrodes and quenched in coolant (PC-EC) exhibited the highest hardness of **348.98 VHN**, while the raw material recorded the lowest at **134.10 VHN**.

Table 1. Vickers Hardness Test Results

Specimen Code	Electrode Composition	Quenching	Hardness (VHN)
Raw	None	No	134.10
NT-E	Standard E7018	No	191.26
NT-ECr	E7018 + Cr	No	200.88
NT-ECCr	E7018 + Cr + C	No	218.78
NT-EC	E7018 + C	No	326.68
PC-E	Standard E7018	Yes	205.94
PC-ECr	E7018 + Cr	Yes	211.78
PC-ECCr	E7018 + Cr + C	Yes	239.84
PC-EC	E7018 + C	Yes	**348.98**

Carbon addition significantly increased surface hardness, particularly when combined with coolant quenching. Among the quenched specimens, PC-EC achieved the greatest hardness, while PC-ECr and PC-ECCr showed moderate improvements.

Figure 1 showed that vickers hardness values of all specimen variations based on electrode composition and quenching treatment. Highest hardness was observed in PC-EC (Carbon + Quenched).

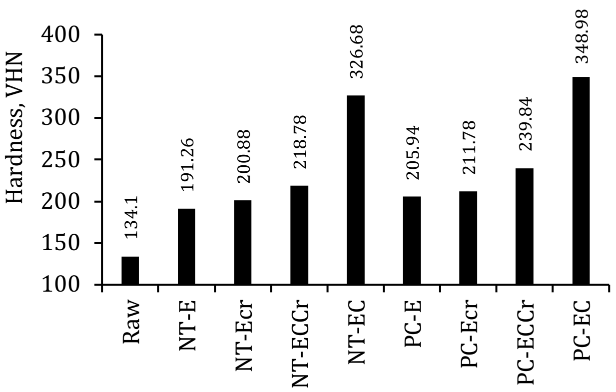


Figure 1. Vickers hardness of specimens by treatment and electrode composition

3.2 Statistical summary

A statistical analysis was performed to assess the consistency of measurements. Each specimen was tested at five points. The mean and standard deviation (SD) are listed in Table 2. This confirms that the highest hardness values are both repeatable and distinct across groups.

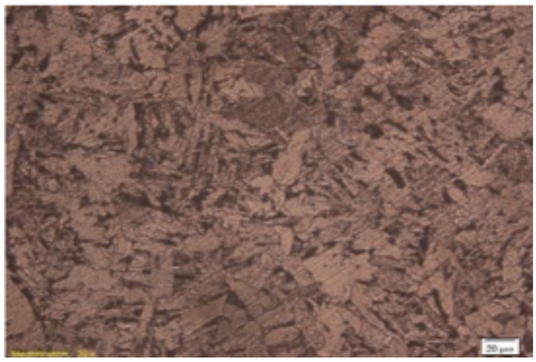
Table 2. Statistical Summary

Group	Mean VHN	Standard Deviation
NT-E	191.26	±3.42
NT-EC	326.68	±6.89
PC-EC	348.98	±7.11

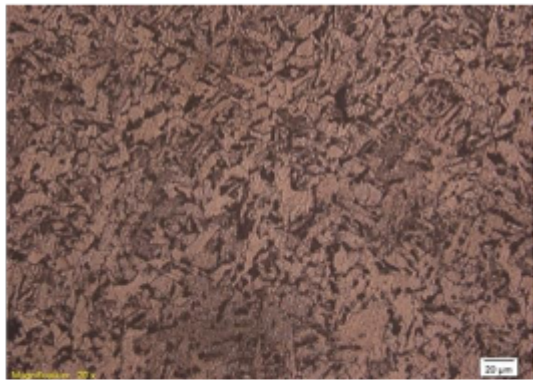
3.3 Microstructure observation

Optical microscopy revealed distinct microstructures for different treatments. The raw specimen displayed coarse ferrite and pearlite grains. In contrast, quenched specimens, especially PC-EC, exhibited a fine martensitic matrix, indicative of rapid transformation from austenite. Chromium-containing specimens showed refined structures with partial martensite formation. However, without carbon addition, the martensitic phase was less dominant.

The microstructure obtained after heat treatment at a temperature of 1000°C for a holding time of 20 minutes, followed by quenching with a coolant medium, resulted in varying microstructures. The heat rate and rapid cooling yielded different levels of hardness, which influenced microstructural changes depending on the cooling rate and the type of cooling medium used.



(a)



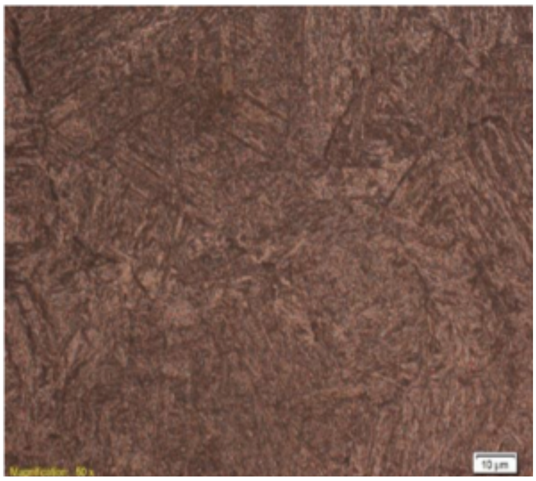
(b)

Figure 2. Microphotograph description of non-treatment specimens

Figure 2(a) shows the microstructure is dominated by ferrite (light areas) and pearlite (darker, lamellar colonies), the pearlite is evenly distributed within the ferritic matrix, indicating a low-carbon steel in the as-welded or untreated condition, and No martensitic structure is observed, confirming that the specimen did not undergo rapid cooling or quenching.

Figure 2(b) shows the presence of ferrite remains dominant, with well-formed pearlite colonies throughout the matrix and this structure is typical of untreated low-carbon steel, showing no transformation to martensite.

(a)



(b)

Figure 3. Microstructure observation data of coolant quenching

Figure 3(a) shows the microstructure is predominantly composed of martensite with fine needle-like morphology. This phase indicates a rapid transformation from austenite due to the quenching process. The random and interlaced orientation of the martensitic needles suggests a uniform and rapid cooling rate. The grain size is extremely fine, reflecting instant quenching that significantly influences the material's hardness. No significant ferrite or pearlite phases are observed, indicating extreme cooling conditions that prevent the formation of equilibrium phases.

Figure 3(b) shows the observed microstructure is also dominated by martensite, although the features appear coarser compared to Figure 1. The presence of martensitic colonies or regions with preferred orientation patterns suggests variations in cooling rate or differences in section thickness of the metal. Despite the coarser appearance, the structural distribution remains relatively uniform, which may cause a slight reduction in hardness compared to the finer structure in Figure 1. No evidence of major segregation or porosity is detected, indicating good microstructural homogeneity.

Based on the microstructure observations and hardness data, it is evident that the **PC-EC** specimen exhibited the most refined and densely packed needle-like martensitic structure**,** which is characteristic of specimens subjected to rapid cooling during quenching. This microstructure directly correlates with the highest hardness value of 348.98 VHN**,** indicating a successful transformation from austenite to martensite facilitated by both quenching and carbon addition in the electrode composition.

In contrast, non-quenched specimens such as NT-EC and NT-ECCr revealed predominantly ferrite-pearlite or mixed coarse pearlite structures, resulting in significantly lower hardness values ranging from 218.78 to 326.68 VHN. The presence of ferrite, a softer phase, contributed to this reduction in hardness. Furthermore, other quenched specimens like PC-ECCr and PC-ECr also demonstrated martensitic transformation, albeit with less refinement and lower hardness (239.84 VHN and 211.78 VHN respectively). This suggests that carbon plays a more dominant role than chromium in promoting martensitic formation and enhancing hardness under quenching conditions.

These findings confirm that the combination of quenching treatment and carbon-enriched electrodes effectively alters the microstructure toward a harder martensitic phase, significantly improving the material's mechanical performance—particularly its resistance to abrasive wear in heavy-duty applications.

3.4 Correlation between microstructure and hardness

Hardness values were found to correlate directly with the presence of martensite. Specimens with carbon and quenching (PC-EC) achieved a fully martensitic structure and the highest VHN. Chromium alone contributed to secondary hardening effects but was less effective than carbon in initiating phase transformation. The synergy between carbon addition and coolant quenching is critical. Rapid cooling trapped carbon atoms within the iron lattice, forming a supersaturated martensitic phase known for its high hardness but reduced ductility.

4. CONCLUSION

Based on the experimental results and data analysis, the following conclusions can be drawn:

1. Electrode modification with Carbon powder, especially when followed by coolant quenching, significantly increases the surface hardness of low carbon steel, reaching a maximum value of 348.98 VHN.
2. Specimens quenched using coolant exhibited martensitic microstructures, which are responsible for the high hardness. In contrast, untreated specimens showed ferrite and pearlite phases with much lower hardness.
3. The addition of Chromium alone resulted in a moderate increase in hardness (from 205.94 VHN to 211.78 VHN), while the combined addition of Chromium and Carbon led to a more substantial increase (up to 239.84 VHN).
4. Among all variations, Carbon addition had the greatest effect on hardness improvement, demonstrating its critical role in martensite formation during quenching.
5. These findings support the effectiveness of modified E7018 electrodes combined with controlled quenching as a practical method for improving the wear resistance of structural steel in demanding industrial applications.

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