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Effect of Galvanizing Furnace Temperature on Material Property and Galvanized Surface of Hot Rolled Galvanized Steel

Jong Chan Jeong[1,†], Jae Joong Kim[2], and Seong Ho Han[2]

[1]*Quality technology department automotive steel quality control section, POSCO Gwangyang works, Gwangyang, Korea*
[2]*Automotive Steel Research Lab, POSCO Technical Research Laboratories, Gwangyang, Korea*

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Recently, hot rolled galvanized steel is widely used in automotive parts. As the paradigm of the automotive market has changed from fossil fuel vehicle to electric vehicle, the automotive industry needs more high-strength steels to reduce weights of automobiles. However, because high-strength steel contains high solute carbon, it is expected to have a risk of stretcher-strain on the surface due to dislocation trapping by solute [C] and [N]. Generally, galvanized steel is supposed to pass through a furnace around the temperature of Zinc pot to increase material temperature. Otherwise, the inhibition layer could not be formed. However, solute carbon and nitrogen are volatile enough to move around the furnace temperature. Moreover, the ratio of ferrite phase and precipitated Fe3C can be variable, resulting in yield point elongation related to the stretcher strain. Furthermore, the quality of the galvanized surface can be affected by a high temperature of the furnace. Although a relatively hot rolled galvanizing line furnace has a lower temperature than an annealing line furnace, it can affect various quality aspects. In other words, this paper aims to determine how these phenomena appear concerning furnace temperature.

Keywords: *Galvanizing furnace, Yield point elongation, Galvanized surface quality*

1. Introduction

The steel industry plays a significant role in supplying materials for vehicle parts, with the automobile sector being a major consumer of steel. To address society's growing demand for environmentally friendly products in the automotive industry, companies are increasingly focusing on producing lightweight steel. Consequently, the steel industry has made advancements in high-strength steel, including phase transformation steel and precipitation hardening steel. Precipitation hardening steel, characterized by its phase known as ferrite, undergoes hardening processes such as grain refinement, solid solution, and precipitation hardening. Due to the presence of precipitates, this type of steel can achieve a tensile strength exceeding 800 MPa.

The automobile industry demands materials that offer both excellent corrosion resistance and high strength. This is why galvanized steel was developed in the past. Unlike cold-rolled galvanized steel, hot-rolled galvanized steel not only comes at a reasonable price but also boasts good corrosion resistance. However, a notable phenomenon occurs when high-strength precipitated galvanized steel undergoes the hot continuous galvanizing process: its yield strength tends to increase. Interestingly, pickled and oiled steel, which shares the same grade as hot-rolled galvanized steel, does not show this characteristic

Hence, we conducted experiments to ascertain the reason behind the strength increase following the passage through the hot continuous galvanizing line and evaluated the condition of the galvanized surface.

1.1 High carbon steel

Carbon steel, composed primarily of carbon, is categorized into three types: low, medium, and high carbon steel, with carbon contents ranging from 0.25%, 0.25-0.5%, and 0.5-1.25%, respectively. Iron with a carbon content exceeding 1.25% is referred to as cast iron. Low, medium, and high carbon steel are commonly utilized in the automotive industry due to their favorable properties. However, steel containing over 1.25% carbon tends to be brittle and has limited weldability [1]. While high carbon steels exhibit exceptional hardness, strength,

[†]Corresponding author: jjc657@posco.com
Jong Chan Jeong: Junior Manager, Jae Joong Kim: Researcher, Seong Ho Han: Senior Researcher

and wear resistance, they also suffer from reduced ductility [2]. Typically containing 0.3-0.9% manganese [Mn], high carbon steel is primarily employed in specialized applications such as cable wire, punches, and

Table 1. Main chemical composition of the hot rolled high carbon steel used in this study

Element	Fe	C	Mn	Ti	N
wt%	Bal.	0.07	1.2	0.04	0.003

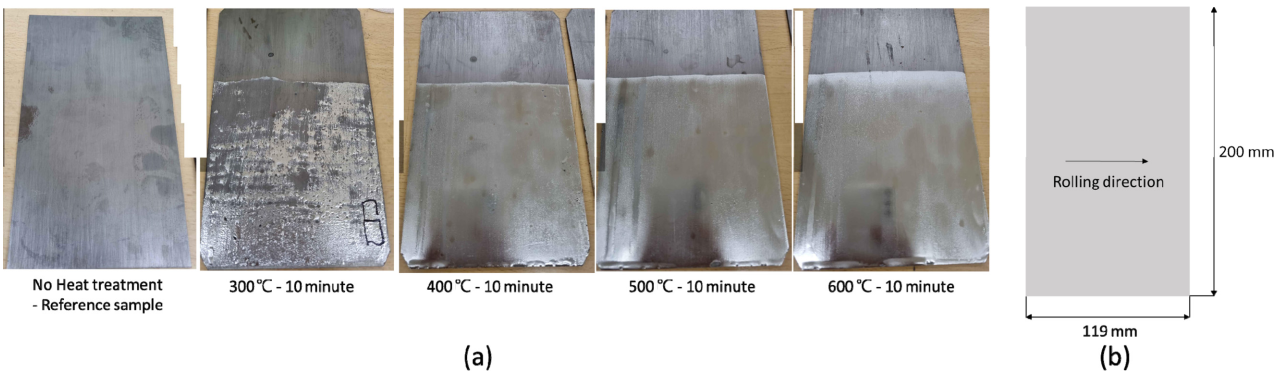
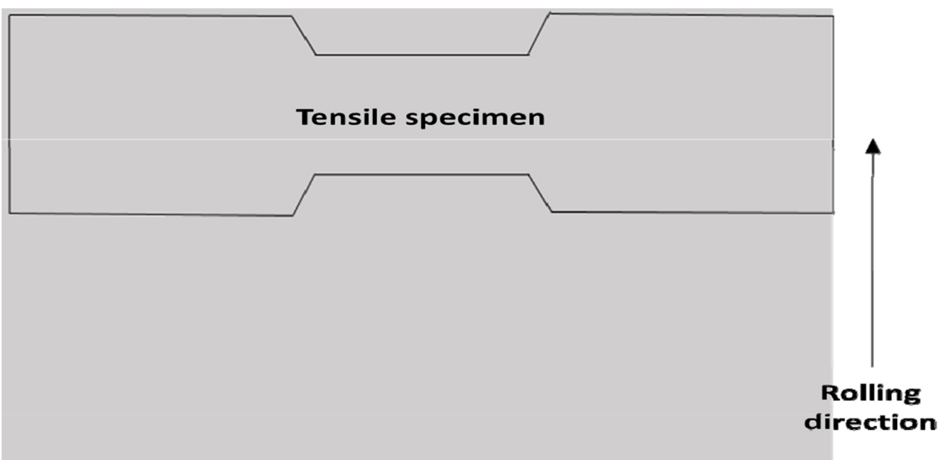
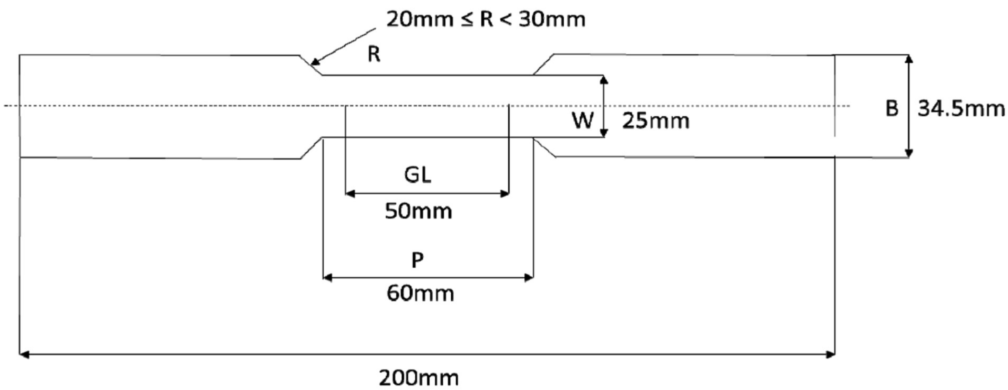


Fig. 1. The samples for the experiment and their detailed dimensions



(a) specimen direction



(b) Tensile specimen dimension

Fig. 2. Tensile Specimen (R: Radius fillet, W: Width of parallel part, GL: Gauge Length, P: Length of parallel part, B: width of specimen, P: Overall length of specimen)

dies, owing to its poor ductility, weldability, and higher production costs [2].

2. Experiemt

2.1 Alloy contents

We produced samples containing 0.7 wt% [C], 1.2 wt% [Mn], 0.04 wt% [Ti], and 0.05 wt% [Nb]. We anticipate that the microstructure of these samples will consist primarily of a ferrite phase, without low-temperature phases such as bainite or martensite. Both [C] and [Mn] play crucial roles in solid solution hardening. Typically, every 0.1 wt% increase in [Mn] leads to a 5 MPa increase in tensile strength [3]. However, the strength of the steel is also influenced by [C], with higher [C] content generally resulting in increased hardness. Nonetheless, elevated [C] levels may precipitate cementite or induce the formation of low-temperature phases [4]. We expect that [Ti] and [C] will combine to form precipitation compounds such as [TiC] or [TiN], thereby significantly enhancing the strength of the material.

3. Results and Discussion

3.1 Variation of tensile strength by heat treatment temperature

The results of tensile strength are presented in Table 2. The yield strength demonstrates an upward trend with increasing heat treatment temperature. However, the tensile strength and elongation remain consistent across different heat treatment temperatures. Notably, only the yield strength and yield point elongation exhibit changes.

Yield point elongation is closely linked to stretcher strain. Severe stretcher strain can manifest as stripes on the surface of deformed steel. Carbon and nitride elements diffuse within the steel to reach a stable state, facilitated by heat energy, which aids in their uniform distribution. As these elements spread within the steel, they trap dislocations. This leads to discontinuous yielding behavior as dislocation movement is restricted by these trapping elements (carbon and nitride), resulting in increased yield strength. However, tensile strength and total elongation remain unchanged because there are sufficient dislocations for continuous slipping in the plastic deformation zone. The yield point elongation indicates that a heat temperature above 300 ºC is adequate for element diffusion within the steel. The reference specimen exhibits a yield strength value 40 MPa lower than the heated specimens, with low elongation at yield strength and continuous yielding behavior due to the absence of diffusion of trapping elements. Conversely, the yield strength value is approximately 10 MPa higher in the 600 ºC specimen compared to the other heated specimens. This difference may be attributed to variations in specimen strength, as indicated by the Yield Strength to Tensile Strength Ratio (YR) values, which are consistent across all heated specimens, including the 600 ºC specimen. This suggests that the overall strength is higher in the 600 ºC specimen. A variation of approximately 10 MPa is typical in steel industry products. Therefore, considering the YR values and the YS/TS gap among other specimens, the difference in strength of the 600 ºC specimen may be attributed to product variation

3.2 Microstructural observation

SEM images of the specimen surface are shown in Fig. 3. The inhibition layer has formed in pictures (c), (d), and (e). However, the inhibition layer is not found in pictures (a) and (b). The inhibition layer is not formed even if the

Table 2. The tensile strength after the heat treatment and galvanized

Heat temperature	Yield Strength (0.2% off-set)	Tensile Strength	Elongation	YS-Elongation	YR (YS and TS ratio)
No heat treatment (Reference sample)	562 MPa	644 MPa	19%	0.27%	87%
300 ºC	604 MPa	648 MPa	19%	3.57%	93%
400 ºC	606 MPa	649 MPa	19%	2.99%	93%
500 ºC	609 MPa	646 MPa	19%	4.31%	94%
600 ºC	621 MPa	654 MPa	19%	2.33%	95%

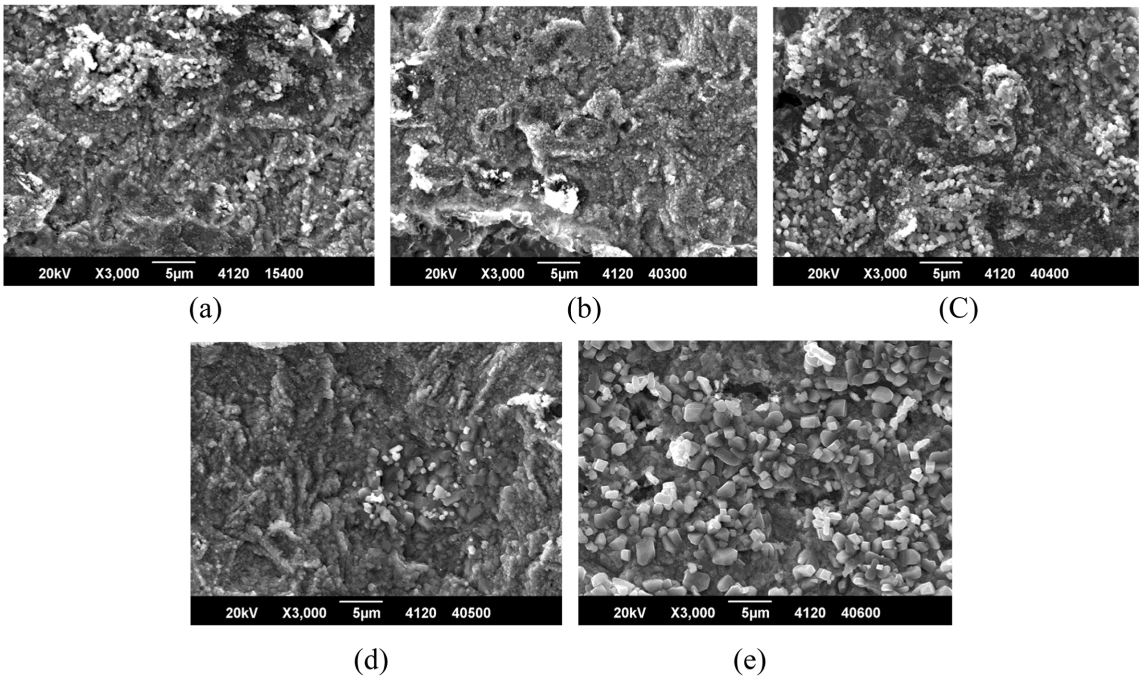


Fig. 3. Surface microstructure (Plan View) observed by SEM; (a) Reference specimen (b) 300 ºC-10 min (c) 400 ºC-10 min (d) 500 ºC-10 min (e) 600 ºC-10 min

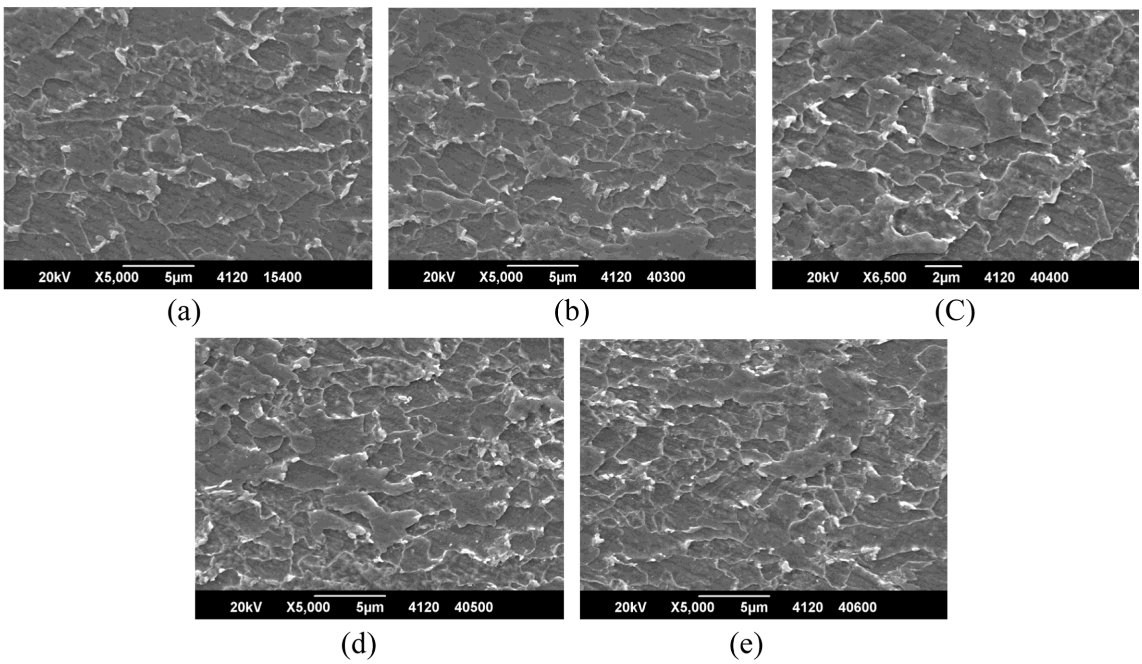


Fig. 4. Cross sectional microstructure observed by SEM; (a) Reference specimen (b) 300 ºC-10 min (c) 400 ºC-10 min (d) 500 ºC-10 min (e) 600 ºC-10 min

melt [Zn] has a sufficiently high temperature if the metal has not been heated sufficiently. Although pictures (c) and (d) show the presence of an inhibition layer, it appears to be insufficient to produce a product with stable Zn-coating quality. These products may result in quality problems when deformed in the industry. Fig. 3 informs us that the metal needs to reach around 600 ºC to form an adequate inhibition layer.

The cross-sectional microstructures are illustrated in Fig. 4. The microstructure appears consistent across all specimens, irrespective of the heat treatment temperature, and has been observed at a 1/4 thickness spot of each specimen. The Ferrite Grain Size (FGS) is consistent at 12.5 for all specimens, determined according to ASTM E112 Standard. This suggests that the heat treatment in the furnace does not affect the grain size, possibly because the temperature is not sufficiently high for grain growth in high carbon steel. Furthermore, no low-temperature phases have been identified, and the main phase is ferrite, with no other phases observed. This data serves as evidence that the slightly higher tensile strength observed in the specimen at 600 ºC may be attributed to product variation, possibly stemming from unstable heat treatment or unknown factors.

4. Conclusion

We investigated the mechanical and zinc-coating property variations of high carbon hot rolled galvanized steel that underwent the furnace process prior to immersion in the zinc pot, focusing on furnace temperature. Relatively low temperatures (300 ºC) can influence the diffusion of carbon and nitrogen, leading to increased elongation at the yield point by trapping dislocations and reducing their mobility. This results in a rise in yield strength, while tensile strength and total elongation values remain unchanged.

Furnace temperature also impacts the zinc-coating property, with lower heat levels delaying the formation of the steel's inhibition layer. Furnace temperatures need to exceed 600 ºC to generate a sufficient inhibition layer; however, temperatures below this threshold do not affect the grain size and phase of high carbon steel. To produce desirable high carbon hot rolled galvanized steel with appropriate properties, it's crucial to ensure that the yield point surpasses our expectations. This can be achieved by controlling the chemical composition, considering the effects of low temperatures.

Secondly, controlling the appropriate furnace temperature is essential to achieve the desired coating properties. Poor coating properties can lead to issues not only with vehicle quality but also with automotive industry productivity. Zinc powder may drop onto the mold, causing minor dents on the steel coating surface, which can impact both its appearance and mechanical properties. Therefore, careful consideration of these critical factors is necessary to prevent such problems.

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