# THE INFLUENCE OF ORIGINAL STRUCTURES ON THE MICROSTRUCTURE AND PROPERTIES OF 27SiMn STEEL AFTER ZERO TIME HOLDING QUENCHING

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***Abstract:***

*27SiMn steels with different original structures were zero time holding quenched after pretreatments including general quenching and normalizing, respectively, then their tensile strength and hardness were determined and also microstructures were analyzed.. The experimental results show that thus quenched 27SiMn steel by zero time holding quenching obtains a fine lath martensite structure and higher tensile strength and hardness. The mechanical properties of the thus quenched 27SiMn steel are better than that of the thus normalized 27SiMn steel. The effect of original structure on the mechanical properties of 27SiMn steel is prominent when the zero time holding quenching temperature is lower, but it decreases with an increase of the quenching temperature. The austenite inverse transformation zero time holding quenching at low temperature can improve the mechanical properties of 27SiMn steel. The mechanical properties of 27SiMn steel can be improved by austenite inverse transformation during zero time holding quenching at lower temperature.*

## 1 Introduction

Zero time holding quenching is defined as the process of quenching starting just at the surface temperature of the part reaching the required value. Compared to the conventional quenching process, "Zero-holding-time" quenching reduces the time of the heat penetration and microstructure transformation in a workpiece. "Zero-holding-time" quenching process can not only decrease the energy consumption and increase the labor productivity, but also reduce or eliminate oxidization, de-carbonization and other defects of parts during the process of holding time. Therefore, it can improve the quality of the products [1-3]. 27SiMn steel is popularly used as cylinder material of hydraulic props, whose conventional quench process is 880 ºC × 60 min. However, the axial and radial deformation on the cylinders easily occur during the quench process, and some have to be scrapped since straightening is infeasible. The practice shows that "zero time holding" quenching technique can effectively reduce the deformation of the cylinders.

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In recent years, domestic and foreign scholars have achieved many valuable experiences and data by investigating zero time holding quenching of different structural steels [4-7].
Many investigations focus on the effect of process parameters on the mechanical properties of the steel. However, there are relatively few(er) reports of the structural inheritance of structural steels with zero time holding quenching.
In this work, the microstructure and mechanical properties of the zero time holding quenched 27SiMn steel were measured, which were pretreated by general quenching and normalizing respectively, but also the investigation of the influence of the original structure on the microstructure and properties of zero time holding quenched steel were implemented.

## 2 Experimental Material and Methods

### 2.1 Experimental Material

The chemical composition of experimental 27SiMn steel (wt,%): 0.30C, 1.18Si, 1.18Mn, 0.030S, 0.031P, and the rest is Fe. The tensile sample is a short sample with a dimension of d0 = 10 mm, L0=5d0, respectively. The dimension of hardness samples is Φ30×30×10 mm.

### 2.2 Heat Treatment Process

The samples heated in a box-type electric furnace are conventionally pre-normalized or pre-quenched at 880 ºC × 20 min, after cooling the air or oil respectively. In this way, the martensite or sorbite structures can be obtained in the samples. The final heat treatment process is zero time holding quenching. Holding time for the later tempering is 40 min. The samples serial numbers and the corresponding heat treatment process are shown in Table1.

## 3 Results and discussion

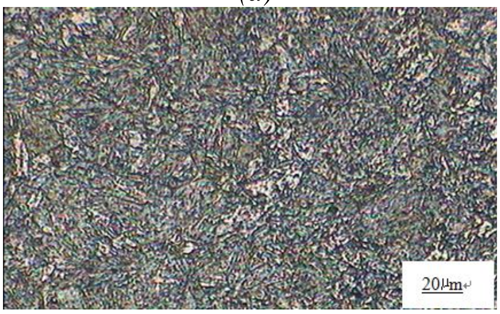
### 3.1 Austenitizing temperature and martensite content

Metallographic analysis shows that the martensite content of the pre-normalized samples varies according to different quenching temperatures.

*Table 1. Heat treatment parameters and mechanical properties of 27SiMn steel*

| Code | Quenching temperature (℃) | Tempering temperature (℃) | Normalizing pretreatment | | Quenching pretreatment | |
|---|---|---|---|---|---|---|
| | | | Hardness (HBS) | Tensile Strength (MPa) | Hardness (HBS) | Tensile Strength (MPa) |
| A1 | 860 | 480 | 295 | 1008 | 317 | 1152 |
| A2 | 880 | 480 | 308 | 1049 | 335 | 1202 |
| A3 | 900 | 480 | 325 | 1098 | 330 | 1155 |
| A4 | 920 | 480 | 320 | 1079 | 322 | 1108 |
| A5 | 860 | 520 | 278 | 955 | 302 | 1109 |
| A6 | 880 | 520 | 294 | 1008 | 319 | 1156 |
| A7 | 900 | 520 | 312 | 1060 | 312 | 1130 |
| A8 | 920 | 520 | 308 | 1045 | 308 | 1079 |
| A9 | 860 | 560 | 259 | 918 | 288 | 1065 |
| A10 | 880 | 560 | 276 | 978 | 303 | 1121 |
| A11 | 900 | 560 | 292 | 1025 | 298 | 1092 |
| A12 | 920 | 560 | 285 | 1005 | 292 | 1042 |


*(a)*




*(b)*

*Figure 1. Microstructure of 27SiMn steel for pretreatment after normalizing (a) quenched at 860ºC (b) quenched at 900ºC.*

Some ferrite exists in the zero time holding quenched structure at 860-880 ºC (Fig.1-a), the strength and hardness of this sample are therefore lower. The content of ferrite decreases with increasing quenching temperature, while the content of martensite increases. A complete martensite structure can be obtained when the quenching temperature exceeds 900 ºC (Fig.1-b).

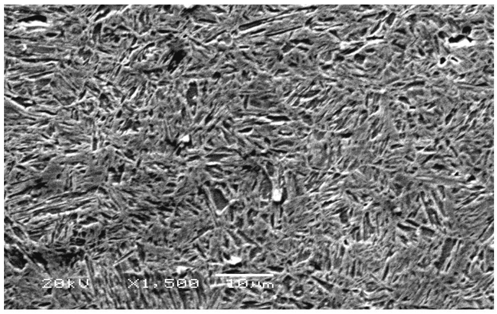
A little ferrite exists in the samples of pre-quenched 27SiMn steel undergoing 860 ºC zero holding time quenching, whose content is obviously lower than the pre-normalized one with the same zero holding time quenching. Complete lath martensite structure can be obtained when 27SiMn steel is quenched in the range 880-920 ºC with zero holding time (Fig.2). The martensite gradually becomes coarse with the increase of the quenching temperature.

## 3.2 The effect of original structure on phase transformation after quenching

Differential thermal analysis is carried out on a SDTQ600 Differential Scanning Calorimeter (DSC) and the results show that the austenite transformation temperature of thus quenched 27SiMn steel is lower than that of thus normalized 27SiMn steel, which should result from the metastable microstructure of martensite where a lot of crystal defects such as dislocations exist, finally leading to higher free energy volume than in the equilibrium microstructures. According to the formula of the new phase nucleation energy during solid transition,

$$\Delta F = \frac{4n\gamma^3}{27(\Delta f_v + E_s)^2}\,, \qquad (1)$$

(where $n$ - shape factor; $E_s$ - strain energy of every atom in the grain; $\Delta f_v$ - the difference of unit volume free energy between new and old phases; $\gamma$ - the interfacial energy), increasing $\Delta f_v$ (negative value), can decrease nucleation energy $\Delta F$. Therefore, the nucleation energy, $\Delta F$ is low for austenite nucleation in martensite. The smaller nucleation energy, the greater nucleation rate and the finer austenite grains are. Meanwhile, since there is a big difference in free energy between martensite and austenite, and since the powerful phase of transformation driving force and the low degree of supercooling needed, the transition temperature decreases consequently.



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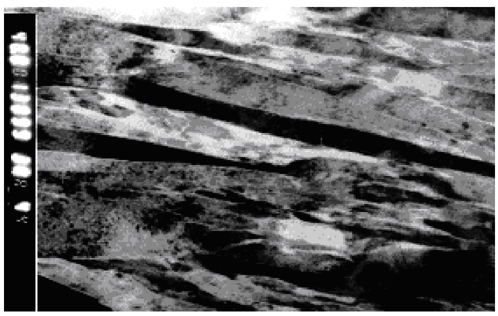


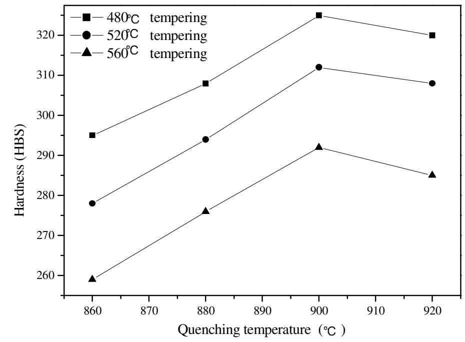
*(b)*

*Figure 2. The microstructure of 27SiMn steel pre-quenched by quenching at 880 °C (a) SEM (b) TEM.*

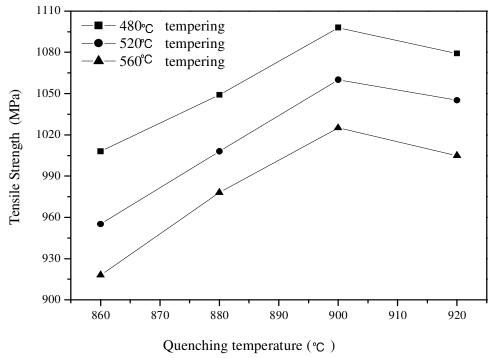
The measured grain fineness of the thus quenched 27SiMn steel by zero time holding quenching at 880 ℃ is 11 grade, while the grain fineness of the thus normalized 27SiMn steel by zero time holding quenching at 880 ℃ is 10 grade. From the point of view of the nucleation, more and finer spheroidal austenite grains can be formed during the austenite transformation in the thus quenched structure due to the quick heating rate of zero time holding quenching. Simultaneously, it is possible that acicular austenite could nucleate in the martensite boundary, which makes the steel structure get further refined [8]. Therefore, the above should be the key role in the improvement of mechanical properties of 27SiMn steel /undergoing the austenite inverse transformation by means of zero time holding quenching.

### 3.3 The effect of original structure on tensile strength and hardness of the steel quenched

Fig. 3 and Fig. 4 show the effect of quenching temperature on the strength and hardness of 27SiMn steel. Both the tensile strength and hardness of zero time holding quenched at 860-880 ℃ 27SiMn steel samples pre-quenched are higher than that of the one pre-normalized, while the differences of properties of zero time holding quenched at 920 ℃ samples become smaller. The results indicate that the effect of the original structure on tensile strength and hardness of the thus quenched 27SiMn steel samples decreases with increasing quenching temperatures. The reason should be that the martensite of pre-quenched 27SiMn steel samples after 920 ℃ zero time holding quenching gradually becomes coarse.
Toughness tests have showed that the toughness value of normalized sample of 27SiMn steel is about 43.6 J/cm$^2$ when it is quenched at 880 ℃ and tempered at 520 ℃. Meanwhile, the toughness values of quenched sample of 27SiMn steel are about 44.7 J/cm$^2$ when it is quenched at 880 ℃ and tempered at 520 ℃. During the zero time holding quenching process, austenite reverse phase transformation at 860-880 ℃ can not only improve strength but also increase toughness, which improve the quality of mine hydraulic prop cylinder.




*(a)*



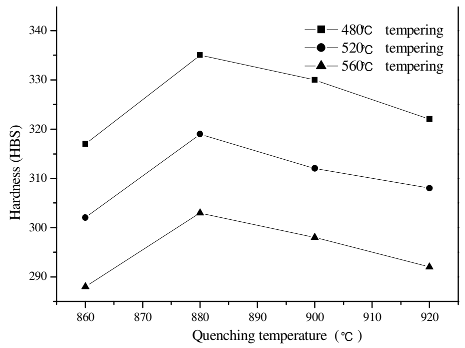

*(b)*

*Figure 3. The effect of quenching temperature on tensile strength and hardness of the thus normalized 27SiMn steel (a) The effect of quenching temperature on hardness of the thus normalized 27SiMn steel (b) The effect of quenching temperature on tensile strength of the thus normalized 27SiMn steel.*

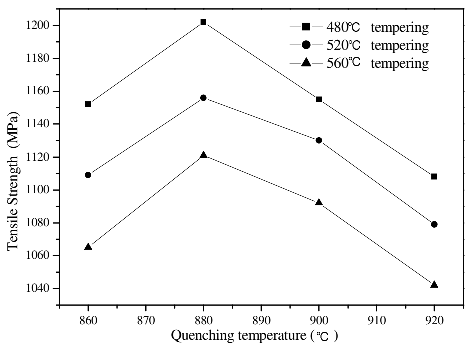
## 4 Conclusion

(1) Lath martensite structure in the pre-quenched 27SiMn steel is obtained at the zero time holding quenching temperature range of 840-920 ℃. The structure obviously gets refined when the quenching temperature is lower.
(2) The ferrite and martensite structure appears in the pre-normalized 27SiMn steel when the quenching temperature is lower than 900 ℃. When the quenching temperature increases, the content of martensite, the tensile strength and hardness of the steel also increase. The full-scale lath martensite structure can be obtained when the quenching temperature exceeds 900 ℃.
(3) The effect of original structure on the mechanical properties of 27SiMn steel is prominent when the zero time holding quenching temperature

is lower, but it decreases when the quenching temperature increases.




(a)




(b)

*Figure 4. The effect of quenching temperature on tensile strength and hardness of the thus quenched 27SiMn steel (a) The effect of quenching temperature on hardness of the thus quenched 27SiMn steel (b) The effect of quenching temperature on tensile strength of the thus quenched 27SiMn steel.*

(4) The austenite inverse transformation during zero time holding quenching at lower temperature can notably improve the mechanical properties of 27SiMn steel.

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