

Effect of Titanium Addition on Behavior of Medium Carbon Steel

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ABSTRACT

This work aims at investigating the influence of titanium addition on behavior of medium carbon steel. Three types of medium carbon steel with different titanium content and one reference steel titanium free were produced in 100 kg induction furnace. Titanium addition was increased up to 0.230%. The produced steels were forged at start temperature 1150°C. Forging process was finished at temperatures 900°C, 975°C, and 1050°C. Microstructure examination and hardness measurement were carried out for forged steels. Mechanical properties and impact measurements were carried out for quenched tempered steels. Ti addition was found to have significant influence on refinement of grains and increase of ferrite/pearlite ratio. It was also, observed that grain size decreases as finishing temperature of forging process decreases. Both Ti addition and lowering finishing forging temperature have positive effect on hardness. In addition, results indicated that addition of titanium has significant effect on the mechanical properties and toughness.

Keywords: Titanium; Refinement; Ferrite; Pearlite; Forging

1. Introduction

Mechanical properties of steels are strongly connected to their microstructure obtained after heat treatments that are generally performed in order to achieve a good hardness and/or tensile strength with sufficient ductility [1].

Microalloyed steels have been developed for many years and are widely used in modern industry. It is well known that microalloyed high-strength low-alloy steels are essentially carbon low-alloy steels that contain small additions of alloying elements such as Nb, V, or Ti [2-6]. These elements act as solution atoms or precipitation to suppress the recrystallization and grain growth of austenite. Microalloying of carbon steels is widely used in practice. At the same time, little attention has been given to medium carbon steels containing vanadium, niobium and titanium.

The obtained fine grain microstructure can enhance the mechanical properties of steels obviously. In addition, multimicroalloying can lead to the formation of carbide and nitride particles which can further influence on the mechanical properties of steels [7-10].

Due to the high price of niobium and vanadium, the development of titanium microalloyed steels seems to be attracted and get more attention recently.

Steel alloyed with titanium alone especially the formation mechanism of TiC precipitation during different

processes and its effect are seldom studied in carbon steel.

This work aims at investigating the influence of titanium additions in medium carbon steels on mechanical properties and also investigation of the effect of finishing forging temperatures on grain refinements.

2. Experimental

Four steels with different titanium contents were melted in induction furnace of capacity 100 kg and cast in sand mold. Complete chemical analysis has been carried out for all cast steels. Ingots with diameter 90 mm were hot forged to about 40 mm square. The ingots were reheated up to 1200°C and hold to 30 min then start forging. Starting forging temperature was 1150°C while forging process was ended at temperatures 900°C, 975°C, and 1050°C for the four steels. Microstructure examination and hardness measurements were carried out after forging process. Ferrite/pearlite ratios were measured using software Paxit program for forged steels. The forged bars—which ended at 975°C—were reheated up to 960°C for 1 hour and water-cooled followed by tempering at 260°C for 30 min. The mechanical properties were measured for tempered steels. The standard V-notch Charpy specimens samples (10 mm × 10 mm × 55 mm, notch depth 2 mm) was prepared to investigate the influence of the titanium addition on impact toughness at 25°C for tempered steels.

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3. Results

The melted steels have the chemical composition given in **Table 1**. The microstructure examination of forged steels at finishing temperatures 900°C, 975°C, and 1050°C is given in **Figures 1-3** respectively.

It is clear that the grain size decreases as titanium content increases at finished forging temperature 900°C as illustrated in **Figure 1**. This can be attributed to the presence of titanium forming titanium carbides and/or titanium nitrides on the austenite grains that retard the grains growth and hence grain of ferrite decrease. The same results observed at finishing forging temperatures 975°C and 1050°C as shown in **Figures 2** and **3**. However, it was observed that for the same steel, the grain size increase by increasing the finishing forging temperature. This can be due to the grain growth of austenite phase during forging process and hence the ferrite and pearlite grain size increase. Also, it may be due to the solubility of titanium in austenitic phase increase as temperature increases leading to decrease of TiC formation which suppress the growth of austenitic grains.

The microstructure examination show that the ferrite/pearlite ratio increases by increasing titanium content. This can be attributed to the formation of titanium carbides and consequently the free carbon is decreased leading to the increase of ferrite/pearlite ratio.

Table 1. Chemical composition of melted steels.

| Type | Chemical composition (%) | | | | | | |
|------|--------------------------|-------|------|-------|-------|-------|--------|
| | C | Si | Mn | P | S | Cr | Ti |
| T0 | 0.301 | 0.108 | 1.13 | 0.040 | 0.030 | 0.401 | 0.0015 |
| T1 | 0.277 | 0.083 | 1.01 | 0.030 | 0.013 | 0.404 | 0.0485 |
| T2 | 0.275 | 0.104 | 1.04 | 0.033 | 0.019 | 0.414 | 0.0997 |
| T3 | 0.296 | 0.110 | 1.02 | 0.034 | 0.015 | 0.409 | 0.2300 |

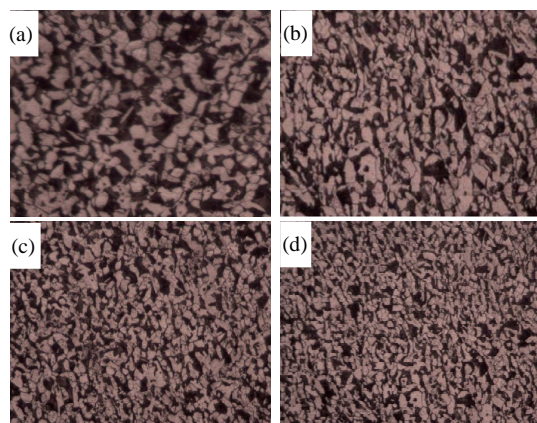


Figure 1. Microstructure of forged steels at finishing forging temperature 900°C ((a) reference steel 0.0015%Ti, (b) 0.0485%Ti, (c) 0.0997%Ti, (d) 0.230%Ti)—X400.

However the finished forging temperature has little influence on the ferrite/pearlite ratios as illustrated in **Table 2**.

It is clear from **Table 2** that ferrite percentage increases from 10% to 12% as titanium content increases from 0.0015% to 0.2300%. While, there is little change in ferrite/pearlite ratio that results from finishing temperatures of forging.

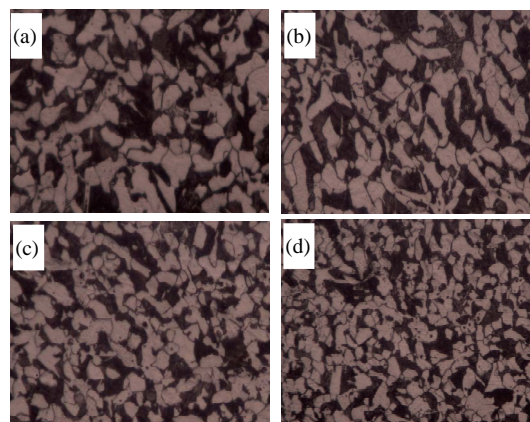


Figure 2. Microstructure of forged steels at finishing forging temperature 975°C ((a) reference steel (b) 0.0485%Ti, (c) 0.0997%Ti, (d) 0.230%Ti)—X400.

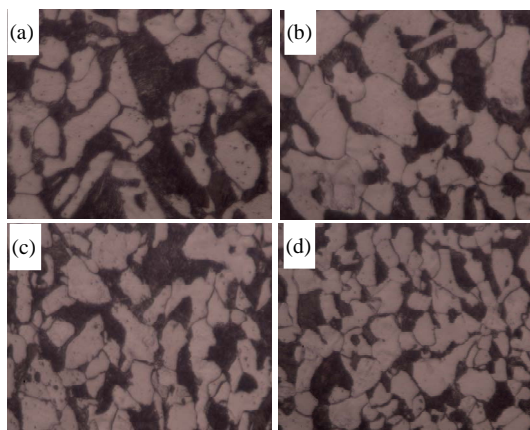


Figure 3. Microstructure of forged steels at finishing forging temperature 1050°C ((a) reference steel (b) 0.0485%Ti, (c) 0.0997%Ti, (d) 0.230%Ti)—X400.

Table 2. Show ferrite percentage of different Ti steel grades at different finishing forging temperature.

| Type | Ferrite (%) at temperature (°C) | | |
|------|---------------------------------|-------|-------|
| | 900 | 975 | 1050 |
| Ti 0 | 68.28 | 65.02 | 63.13 |
| Ti 1 | 69.46 | 70.94 | 69.12 |
| Ti 2 | 73.53 | 71.78 | 70.01 |
| Ti 3 | 78.21 | 76.95 | 75.12 |

The results show that the hardness increases by increasing titanium content for each finishing forging temperatures and increases by decreasing the finishing of forging temperature as illustrated in **Figure 4**. Therefore, it is clear that the main controlling parameter for hardness is the grain refinement.

Titanium content has great influence on mechanical properties of steels, where it was noticed that the yield and ultimate tensile strength increase by increasing titanium content but elongation decreases as given in **Figure 5**. This can be attributed to the effect of grain refinement of titanium.

Impact toughness is of importance for the evaluation of the resistance capability of steel against the crack initiation and rupture. In general, it is of significant evidences that the addition of low alloy element (such as V, Ti, and Ni, etc.) [11-12].

Titanium is used to retard grain growth and thus improve toughness as it is clear from **Figure 6**.

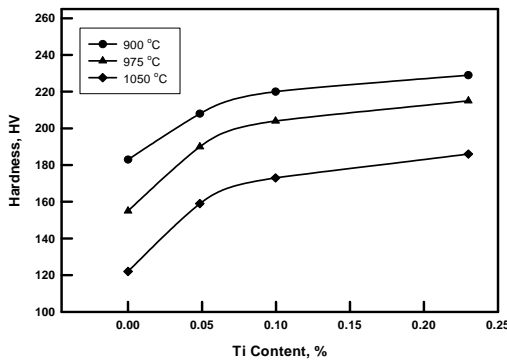


Figure 4. Variation of hardness with titanium content at different finishing forging temperatures.

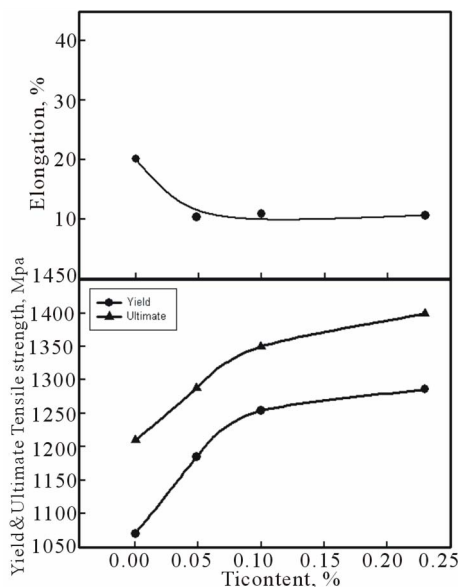


Figure 5. Yield, ultimate tensile strength and elongation of tempered steels with different titanium content.

The relation between the solubility products of carbides and nitrides as a function of temperature illustrated by Aronsson [13] is given in **Figure 7**. From this figure, it is clear that the solubility product of TiC in austenitic phase increases by increasing temperature from 770°C to 1050°C.

From the results given in this figure the solubility of titanium at this temperature range can be calculated and is given in **Table 3**. From this table, it is clear that the solubility of titanium increases by increasing temperature. Consequently, TiC will decrease by increasing temperature in the austenitic phase. As, there is a direct effect of TiC on the formed ferrite grain size, therefore by decreasing temperature the ferrite grain size decreases. The actual atomic mole fraction of Ti and its solubility product of four types of steels is given in **Table 4**.

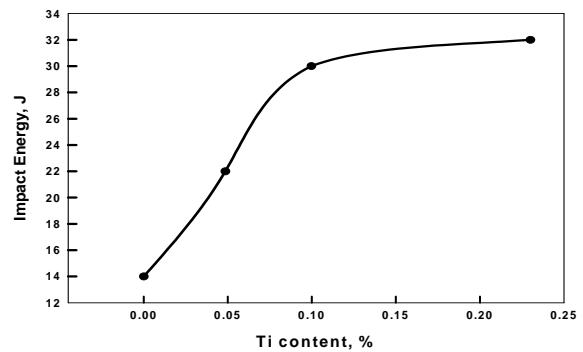


Figure 6. Impact energy of tempered steels at different titanium content.

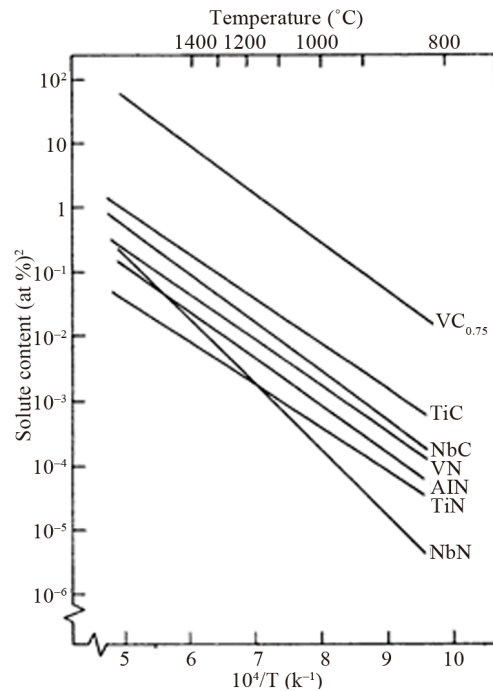


Figure 7. Solubility products of carbides and nitrides in austenite as a function of temperature [13].

Table 3. The predicted solubility and solubility product of TiC with temperature according to Aronsson [13].

| Temp K | 10000/T(K) | Intercept | Solubility product (S^2) | Solubility (S) Atomic (mole fraction) % |
|--------|------------|-----------|------------------------------|---|
| 1173 | 8.525149 | 2.8807 | 0.317188 | 0.563194 |
| 1248 | 8.012821 | 2.8807 | 0.471245 | 0.686473 |
| 1323 | 7.558579 | 2.8807 | 0.607835 | 0.779638 |
| 1073 | 9.319664 | 2.8807 | 0.078277 | 0.27978 |
| 1053 | 9.496676 | 2.8807 | 0.025049 | 0.15827 |
| 1044 | 9.578544 | 2.8807 | 0.000432 | 0.02078 |
| 1043 | 9.587728 | 2.8807 | -0.00233 | - |

Table 4. Actual solubility and solubility product of investigated steels.

| Type | Ti mole Fraction | Solubility product |
|------|------------------|--------------------|
| Ti 0 | 0.0017 | 2.972E-06 |
| Ti 1 | 0.0559 | 3.124E-03 |
| Ti 2 | 0.1148 | 1.318E-02 |
| Ti 3 | 0.2644 | 6.992E-02 |

Figure 7 and Table 3 show that the formation of TiC is function in temperature of austenitic phase. Solubility of Ti decreases by increasing temperature as indicated from decreasing of solubility and solubility product. The solubility of Ti at 770°C equal zero that is mean that any Ti content must form TiC. At 800°C the solubility is 0.27978% atom. This means that any titanium content less than 0.2797% atomic present as soluble and start to form TiC by decreasing temperature. This means that the grain refinement is controlled at stage of cooling above and near to Ac₃, Ti & C content.

Actually, this study shows that the grain growth is restricted as finishing forging temperature decreased (from 1050°C to 900°C). But, Ti content has positive effect on grain refinement at high temperature (up to 1050°C). The later need to more investigation in future work.

4. Conclusions

The addition of titanium has great influence on grain refinement and hence has positive effect on hardness, mechanical properties, and impact toughness. The grain refinement increases as finished forging temperature decreases from 1050°C to 900°C passing through 975°C.

Ferrite/pearlite ratio increase as titanium content increase from 0.0015% to 0.2300%. The finishing forging temperature has little negative influence on ferrite/pearlite ratio. The precipitation of TiC is took place in temperature above and close to Ac₃.

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