THE INFLUENCES OF SPECIMEN DIAMETER ON CONTINUOUS COOLING TRANSFORMATION CURVES MEASURED WITH DILATATION METHOD

X. Zhou[1*] –X. Liu[2]

[1]Material Science & Engineering College, Henan University of Science & Technology, Luo Yang 471003, People's Republic of China
[2]Physics & Engineering College, Henan University of Science & Technology, Luo Yang 471003, People's Republic of China

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Abstract:

The continuous cooling transformation (CCT) curves of C45 steel were measured with different diameter specimens by the dilatation method in the Gleeble 1500D. The microstructures were analyzed with an optical microscope OLYMPUS-PMG3. The experimental results prove that the effects of the specimen diameter on the CCT curves are significant. With an increase in the specimen diameter, the temperature in the specimen core also increases while the measured supercooled austenite transformation temperature decreases, which makes the CCT curves move down. It is worth pointing out that, the specimen diameter has no significant influence on the microstructures of the sample. In order to obtain precise CCT curves measured in the Gleeble 1500D, the specimen diameter should be machined into the small size, such as Ø6 mm or even less in diameter.

1 Introduction

The continuous cooling transformation curves (CCT) of steels systematically describe the relationships of the cooling rate, phase transformation and microstructure. The CCT curves are really the practical standard to determine the metal forming and its heat treatment processes. Therefore, the CCT curves and phase transformation are very important for material researchers and mechanical engineers to design manufacture processes.

Actually, there is no standard for the dimensional specimen size to determine the CCT curves with the dilatational method, but in practice the specimens are either Ø8 mm or Ø6 mm in diameter, tested in the physical thermal-mechanical simulator Gleeble 1500D [1]. Generally, specimens with Ø10 mm [2-5], Ø8 mm [6-9], or sometimes Ø6 mm [9-11] in diameter are used. This paper is therefore concerned with the effect of the specimen size on the CCT curves measured with the dilatation method. Accordingly, the CCT curves of C45 steel with different diameters were measured with the dilatation method in the Gleeble 1500D. The temperature distribution of the CCT specimen is analyzed using DEFORM 2D software.

[*] Corresponding author. Tel.: +86 15838536866;
E-mail address: syuuzhou@163.com

2 Experimental investigation

The material used in this experiment is C45 steel, which is hypo-eutectoid steel. The chemical composition is shown in Table 1. The specimens were machined into Ø10 mm × 10 mm and Ø6 mm × 10 mm cylinders. The experimental procedure is as follows: heating the specimen from room temperature to 1050°C at 20°C/s, soaking for 5 minutes at 1050°C for complete austenitization, cooling to 950°C at 10°C/s, then soaking for 1 minute, finally cooling to room temperature at different cooling rate, such as 50°C/s, 40°C/s, 30°C/s, 20°C/s, 10°C/s, 5°C/s, 2°C/s, 1°C/s and 0.5°C/s respectively while measuring the dilatation information in diameter in the Gleeble 1500D.

Table 1. C45 steel chemical composition (wt %)

C	Cr	Si	Mn	V
0.42	0.15	0.22	0.66	0.02

3 Results and discussion

3.1 The continuous cooling transformation of supercooled austenite

The CCT curves measured with the different specimen diameters are presented in Fig. 1. It shows that both starting and finishing points of the phase transformation move down when increasing the cooling rate or increasing the diameters of the specimens. The reasons are explained as follows.

In this experiment, the average temperature in the profile of the sample is an important factor. If the specimen diameter increases, the specimen average temperature is higher than that on its surface. This phenomena have been confirmed by the finite element analysis using the DEFORM 2D. The simulation model meshed with 400 elements was established with a quarter of the specimen because of its symmetry. The simulation conditions are as follows: the thermal conductivity is calculated by JmatPro code, see Figure 2, the environment temperature is 40°C, the emissivity is 0.7, the heating power of Gleeble 1500D has a linear relationship with the specimen surface temperature, the temperature at the contact surface between the specimen and anvil has also a linear relationship with the sample surface temperature. The simulation results are shown in Fig. 3. The temperature fields of all specimens at 950 °C are shown in Figs 4 and 5.

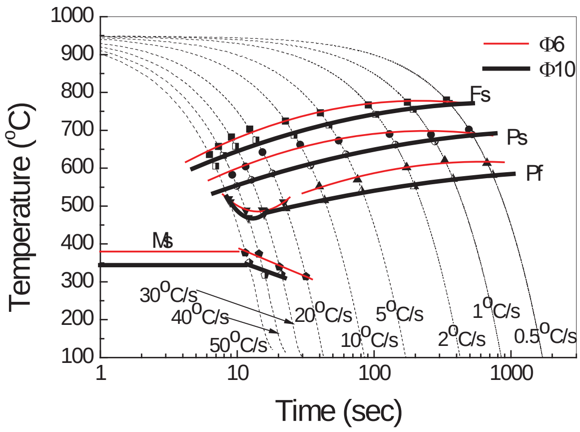


Figure 1. CCT curves of the Ø6 mm and Ø10 mm specimens, where Fs - ferrite start; Ps - pearlite start; Pf - pearlite finish; Ms - martensite start

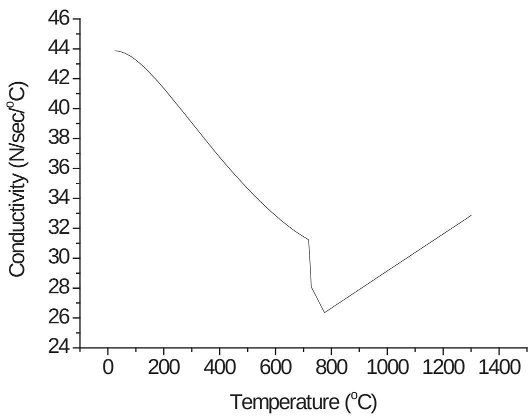


Figure 2. Diagram of thermal conductivity with temperature

(1) During the soaking period at 950°C, the temperature in the sample core is higher than that on the sample surface. For example, the core temperature for the specimen with Ø6 mm diameter is 1100°C. The core temperature for specimen with Ø10 mm diameter is 1225°C. So, the core temperature of the Ø6 mm specimen is 16% higher than that on the surface, and the core temperature of the Ø10 mm specimen is 29% higher than that on the surface.

(2) The cooling rate in the specimen core is higher than that on the specimen surface. For example, when the cooling rate on the surface of the specimen of Ø6 mm is 50°C/s, the cooling rate at

the specimen core is 60°C/s, which means that the core cooling rate is 20% faster than that on the surface. Accordingly, when the cooling rate is 50°C/s on the surface of the Ø10 specimen, the cooling rate at the center is 70°C/s, which means the core cooling rate is 40% faster than that on the surface. While the cooling rate on the surface of the Ø6 specimen is 1°C/s, the cooling rate at the center is 1.18°C/s, which means the core cooling rate is 18% faster than that on the surface; For the cooling rate of 1°C/s on the surface of the Ø10 specimen, the cooling rate at the center is 1.34°C/s, that means the core cooling rate is 34% faster than that on the surface.

In summary, the larger the specimen diameter is, the higher the core temperature is, and consequently, faster the core cooling rate is. Moreover, the average temperature in the profile of the specimen must be higher than the controlling temperature on the specimen surface in the Gleeble 1500D test when testing larger diameter sample, which means the supercooled austenite transformation temperature becomes lower in the same case, which has the significant effect on the phase transition of the supercooled austenite.

3.2 Microstructure analysis

The samples with the cooling rate of 50°C/s, 40°C/s and 1°C/s were selected for metallographic analysis. First the samples were cutting out at the welded points of thermocouple, and mounted up with the metallographic mounting press XQ-2B. The samples were analyzed with the optical microscope OLYMPUS-PMG3 after polishing and properly etching. The microstructures were shown in Fig. 6.

The microstructures of the specimen with the cooling rate of 50°C/s and 40°C/s consist of grain-like martensite (in white colour) and mesh troostite (in black colour) as shown in Figure 6(a) and Figure 6(b). The martensite content is far more troostite. At the same cooling rates, the Ø10 specimen has slightly more martensite structure than that of the Ø6 specimen, but actually the specimen diameter has no significant effect on its microstructure.

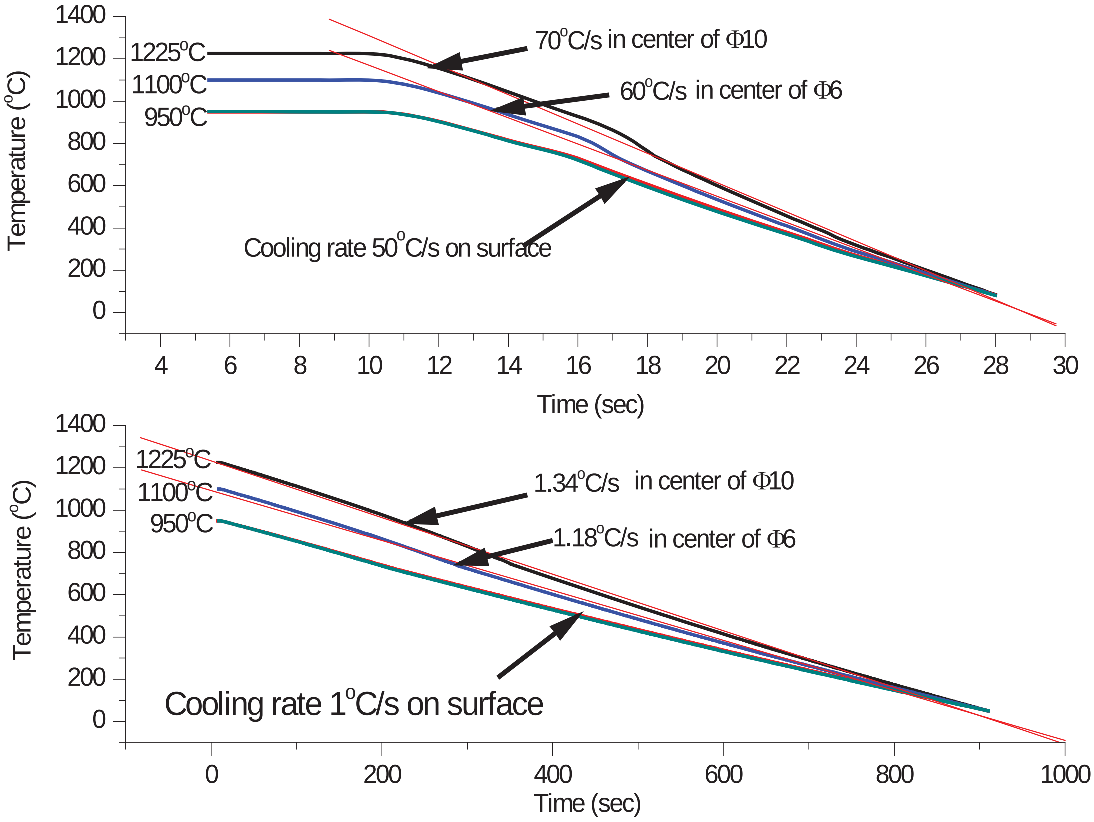
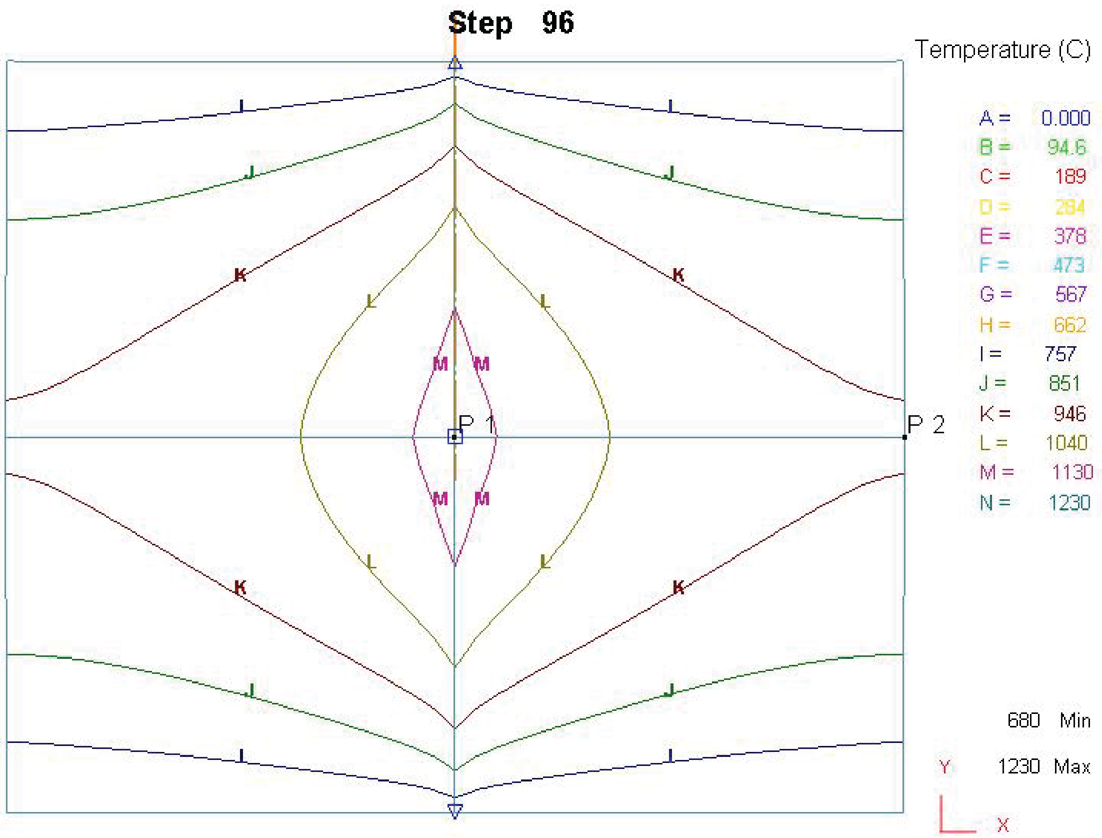
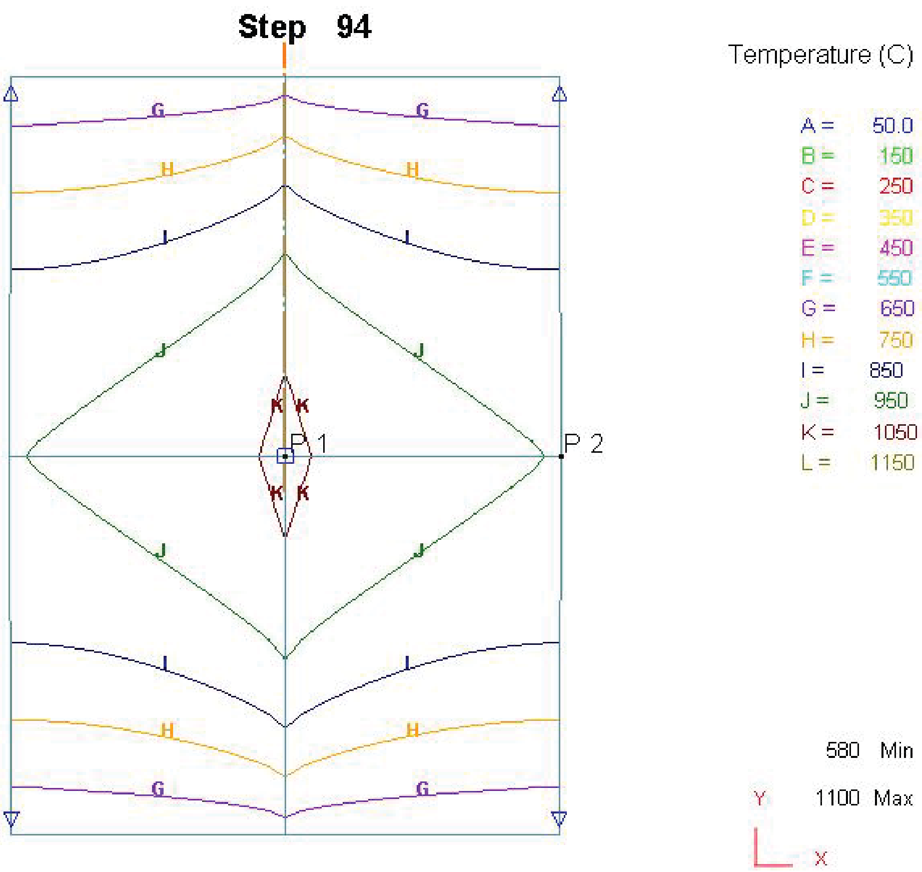


Figure 3. Temperature and cooling rate in the specimen

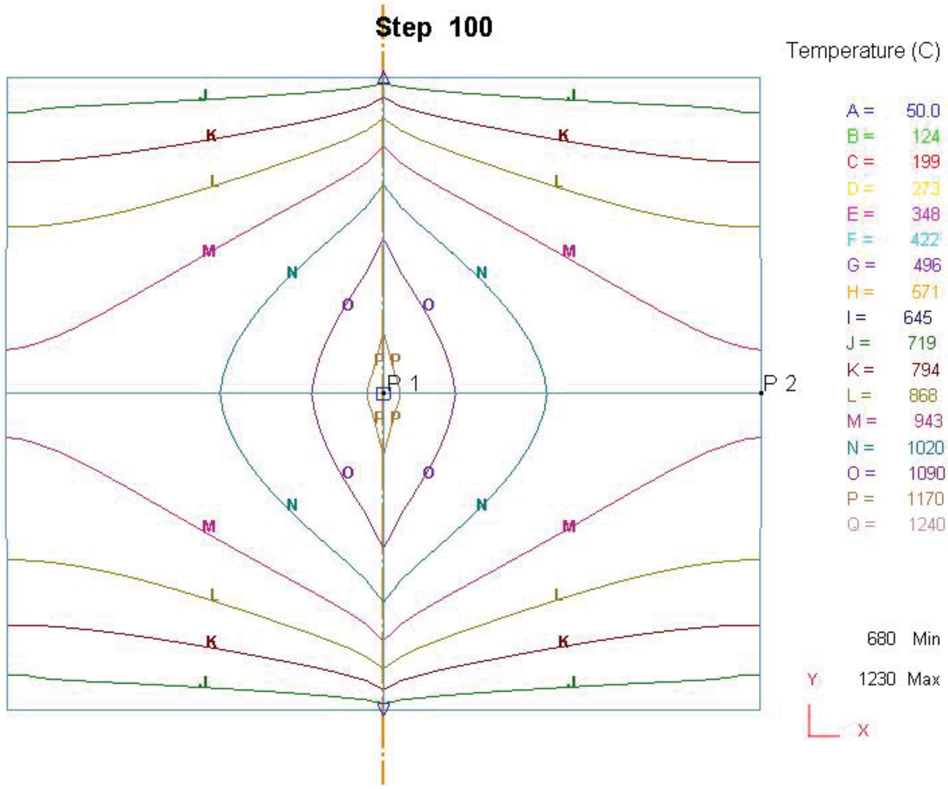


(a) Ø10 mm specimen at 50°C/s

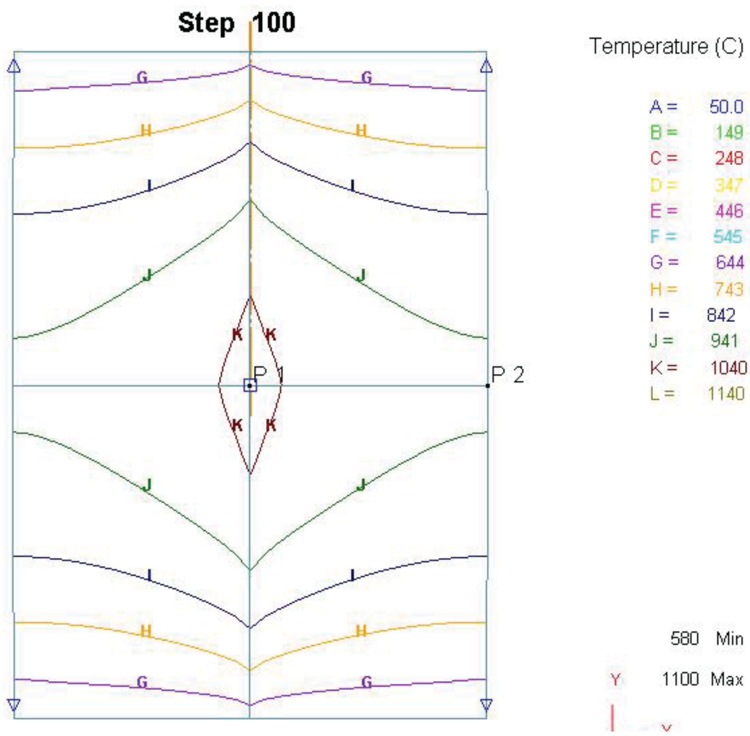


(b) Ø6 mm specimen at 50°C/s

Figure 4. Temperature field over the cross section of the specimen at 950°C (Part 1)

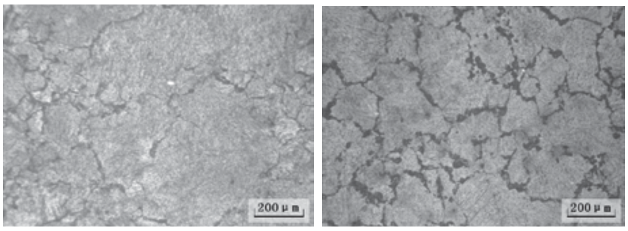


(c) Ø10 mm specimen at 1°C/s



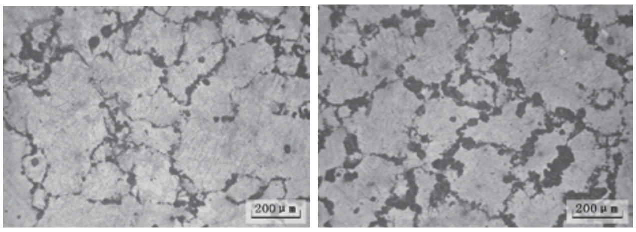
(d) Ø6 mm specimen at 1°C/s

Figure 5. Temperature field over the cross section of the specimen at 950°C *(Part 2)*



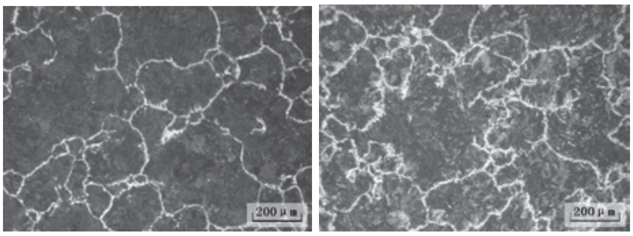
Ø10 mm×10 mm *Ø6 mm×10 mm*

(a) microstructure at 50°C/s（100×）



Ø10 mm×10 mm *Ø6 mm×10 mm*

(b) microstructure at 40°C/s（100×）



Ø10 mm×10 mm *Ø6 mm×10 mm*

(c) microstructure at 1°C/s（100×）

Figure 6. Microstructures at the specimen core

In the similar way, the microstructures of the specimen with the cooling rate of 1°C/s are made up of grain-like pearlite (in white colour) and ferrite network (in black colour) as shown in Figure 6(c). The pearlite content is far more ferrite. The Ø10 specimen has slightly more pearlite microstructure than that of the Ø6 specimen, but certainly, the specimen diameter has no significant effect on the microstructure of the specimen, either.

4 Conclusion

The effects of the specimen diameters of C45 steel on its CCT curves and microstructures have been discussed in this paper. We can conclude that:

(1) With the increase of the sample diameter, the starting and end points of the phase transition on the CCT curves move down.

(2) The core temperature of the specimen is higher than that on the surface, and it increases with an increase in the sample diameter. When soaking the sample at 950°C, the core temperature of the Ø6 sample is 16% higher than that on the surface, the core temperature of the Ø10 sample is 29% higher than that on the surface.

(3) The cooling rate in the specimen core is faster than that on the surface, and it increases with an increase in sample diameter. When soaking the sample at 950°C, the core cooling rate of the Ø6 sample is 20% faster than that on the surface, the core cooling rate of the Ø10 sample is 40% faster than that on the surface.

(4) The specimen diameter has no significance to the final specimen microstructures.

(5) In order to reduce the effects of the specimen diameters on the CCT curves, the specimen with smaller diameter for measuring the CCT curves is proposed, especially the specimen with not more than Ø6 mm in diameter is recommended to be used.

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