ISSN:2790-1688 DOI: 10.56028/aetr.2.1.356

Effect of heat treatment process on impact toughness of a Ni-containing stainless steel 3Cr13 Precision Die

Anastasiia Isayeva[1], Lulu Feng[2,a,*], Hui Luo[3], Song Liu[2], Riqing Huang[4], Xuezhong Huang[4], and Kaiming Wu [1,a,*]

1 Collaborative Innovation Center on Advanced Steels, Wuhan University of Science and Technology, Wuhan 430081, China

2 School of Mechanical Engineering, Guangdong Songshan Polytechnic, Shaoguan 512126, China

3 SGIS Songshan Co., Ltd., Shaoguan 512123, China

4 Iron and Steel New Technology Research institute, Guangxi BG New Materials Co LTD, Beihai 536000, China

*Corresponding authors. E–mail address:

fenglulu@gdsspt.edu.cn (Feng Lulu); wukaiming@wust.edu.cn (Wu Kaiming)

Abstract. Nowadays 3Cr13 martensitic stainless steel is increasingly used for precision molds. However, its low-temperature impact toughness below room temperature requires further improvement. This study investigates the effect of heat treatment process of a Ni-containing at low temperature impact toughness of 3Cr13 stainless steel used for precision die. Various characterization techniques are combined in order to unveil different heat treatment processes on impact toughness. The test results show that after three different heat treatment processes, the low-temperature impact toughness of the investigated steel at 0 ℃ has been greatly improved. After the investigated steel is heated at 1040 ℃ for 15 minutes, then water-cooled quenched, and then heated to 540 ℃ for 30 minutes, the impact fracture is a dimple shaped plastic one, and its low-temperature impact absorbed energy is higher than that of other heat treatment processes. It shows that the holding time under quenching heating temperature and tempering temperature also have important effects on the improvement of low-temperature impact toughness, which provides technical support for heat treatment design for the Ni-alloyed 3Cr13martensitic stainless steel.

Keywords: heat treatment; stainless steel; impact toughness; precision die.

1. Introduction

In recent years, mold has been widely used in different industries, such as electronic communication, automotive appliances, instrumentation, aerospace and other fields. With rapid and tremendous development of high-end intelligent equipment, the advanced equipment manufacturing industry have a requirement for mold products to achieve the following characteristics: high precision, high complexity, and high consistency. Therefore, the mold is being developed towards the direction of precision corrosion resistance, intelligence and high efficiency [1]. In the process of using the precision corrosion-resistant die, the precision cannot be reduced due to the deviation of the cavity size caused by corrosion, which will affect the dimensional accuracy of the die parts. Therefore, the raw materials for manufacturing molds must have good corrosion resistance [2]. Martensitic stainless steel has the characteristics of high strength, high hardness, high temperature resistance, wear resistance, excellent impact resistance and good corrosion resistance. At present, it has been widely used in major intelligent equipment manufacturing fields. In recent years, more and more 3Cr13 martensitic stainless steel is used for precision molds [3-4]. After quenching and tempering heat treatment (980-1050 ℃ heat preservation for 15-30 min oil cooling or air cooling quenching), 3Cr13 martensitic stainless steel not only meets the requirements of precision die steel for hardness, wear resistance, corrosion resistance and other properties, but also has good cold machining performance and is convenient for NC milling [5-9]. However, at present, 3Cr13

ISSN:2790-1688 DOI: 10.56028/aetr.2.1.356
martensitic stainless steel used in high-end precision molds still requires further improvement of its comprehensive mechanical properties, especially its low-temperature impact toughness at 0 ℃.

It was reported that different heat treatment processes have an important influence on the 0 ℃ low temperature impact toughness of 3Cr13 martensitic stainless steel. The high and low quenching temperature affects the growth of austenite grains during quenching and heating, and reduces the 0 ℃ low temperature impact toughness. Similarly, the tempering temperature is also important to the low-temperature impact toughness. A lower tempering temperature affects the carbon diffusion rate of steels in the tempering stage, which is not conducive to the improvement of low-temperature impact toughness [10-11].

In the present work, in order to clarify the effect of heat treatment process on low temperature impact toughness of a Ni-alloyed 3Cr13 martensitic stainless steel. Three different heat treatment processes were designed. The effects of heat treatment processes on the microstructure and properties of Ni-alloyed 3Cr13 martensitic stainless steel for precision dies were studied through comparative tests.

2. Material and experimental procedure

In order to improve the impact toughness for precision dies, a Ni-alloyed martensitic stainless steel with the chemical composition of 0.29C-0.56Si-0.48Mn-13.78Cr-1.40Ni (wt.%) was investigated. The test steel was smelted in a 100 kg vacuum furnace with industrial pure iron and carbon powder. At the same time, Si, Mn, Cr, Ni alloy elements were added. After smelting, the specimen was cast into ingots. The chemical composition of the ingots is shown in Table 1. The samples were reheated and forged to 50 mm × 50 mm × 1000 mm steel bar, then cut into several pieces with 50 mm length, width and height by cold machining.

The 20 mm × 25 mm sample was used for further heat treatment quenching and tempering tests. The quenching heating temperature was set 1040 ℃ and 1000 ℃. After holding for 15 min and 60 min, it was oil cooled to room temperature 25℃, and then it was heated to 540 ℃ and 490 ℃ again before tempering. After holding for 30 min, it was air cooled to room temperature 25℃. The three different heat treatment processes are shown in Figure 1. The 1 # sample is the test steel under forging process, 2 # sample is the steel under quenching and tempering process (quenching at 1040 ℃ for 60 min +540 ℃ for 30 min tempering), 3 # sample is the steel under quenching and tempering process (quenching at 1040 ℃ for 15 min + 540 ℃ for 30 min tempering), 4 # sample is the steel under quenching and tempering process (quenching at 1000 ℃ for 15 min + 490 ℃ for 30 min tempering). The quenched and tempered sample was cut into standard low-temperature impact samples by cold machining for mechanical properties investigation. The metallographic test samples were cut to observe microstructural changes.

The microstructure and low temperature impact toughness of the test steel after different heat treatment processes were observed. The optical microscope (Olympus, pem3-3) and scanning electron microscope (SEM, Sirion 200) inspection helped to perform microstructure characterization. The samples were prepared by standard grinding and polishing procedure using diamond paste. The low-temperature impact toughness was studied by pendulum impact tester (JBD-300W). The data of low-temperature impact toughness was statistically analyzed in original 8.0 software. The change of low-temperature impact toughness was plotted.

Table 1. Chemical composition of the tested steels (mass fraction) %

Element	C	Si	Mn	P	S	Cr	Ni	Fe
Content	0.29	0.56	0.48	0.008	0.005	13.78	1.40	Bal.

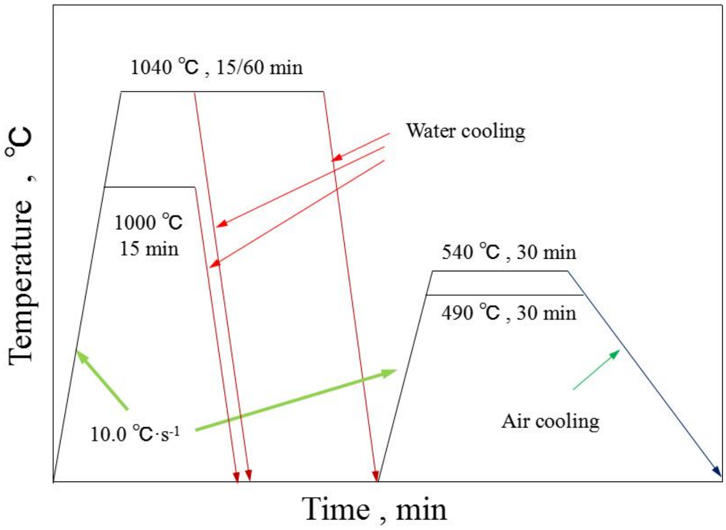

Figure 1. Schematic diagram of the heat treatment processes

3. Results and discussion

3.1 Microstructure characterization

The comparison of microstructure of the test steel before and after heat treatments is shown in Fig. 2, where (a) refers to prior heat treatment condition, and (b), (c), (d) refer to post heat treatment results, respectively. The SEM image in Fig. 2(a) shows that the test steel is in the forging state before heat treatment. After ingot forging and rapid cooling in air the martensitic microstructure is formed. The result also shows that original austenite grain boundary can be observed. However, the carbide structure after tempering is not visible in the SEM image. Figure 2 (b) demonstrates the microstructure of the test steel after heating at 1040 ℃ for 60 min and subsequently quenching into water, and then tempering at 540 ℃ for 30 min. It can be seen that the microstructure of the test steel after heat treatment has changed greatly comparing with the forging state. The lath spacing of lath martensite has become smaller. It can be observed that more fine carbides have precipitated on the martensite structure. After the test steel is heated at 1040 ℃ for 15 min and quenched into water, it is then heated again to 540 ℃ for 30 min. The microstructure after tempering is shown in Figure 2 (c). Due to the shorter quenching and holding time of the test steel, it can be observed that the austenite grain size becomes smaller under the above heat treatment condition. The martensitic plate size after quenching also becomes smaller. A large number of carbides are also precipitated during tempering. Furthermore, it can be seen that the carbides are gradually growing after holding for a period of time, as indicated by arrows in Figure 2 (c). After the test steel is heated at 1000 ℃ for 15 min and subsequently water-cooled quenching, it is then heated to 490 ℃ for 30 min. Figure 2 (d) reveals that the spacing of lath martensite after quenching becomes smaller due to the lower quenching temperature and shorter holding time. However, due to the lower tempering temperature, the diffusion rate of carbon decreases and the resistance to carbide formation becomes larger, and therefore large carbides are not observed.

ISSN:2790-1688 DOI: 10.56028/aetr.2.1.356

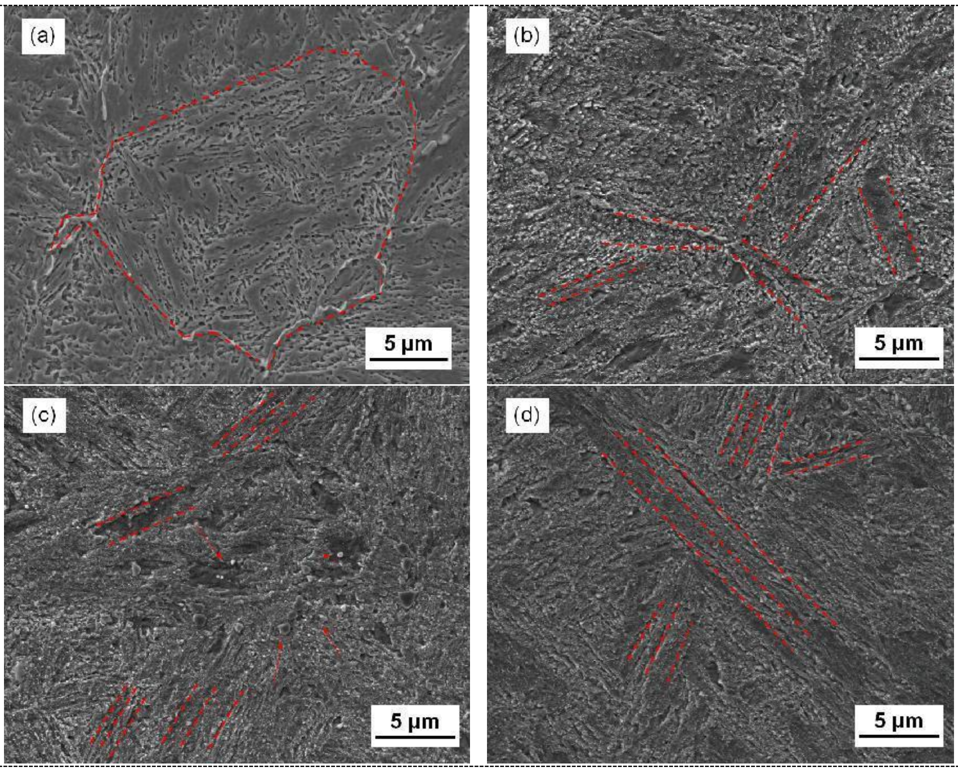

Figure 2. SEM microstructure of the test steel before and after quenching and tempering
(a)—1#; (b)—2#; (c)—3#; (d)—4#

3.2 Impact fracture morphology before and after heat treatments

The fracture morphology of 0 ℃ low temperature impact toughness of the test steel before and after heat treatments is shown in Figure 3. Fig. 3 (a) demonstrates the fracture morphology of 1 # sample before heat treatment, which is the cleavage fracture morphology. There is no dimple fracture observed, and the brittle fracture phenomenon is observed. Fig. 3 (b) shows the fracture morphology of the 2 # sample at 0 ℃ low temperature impact sample. It can be seen from the figure that the 2 # sample has also brittle fracture, and its cleavage morphology is clearly visible. However, some dimple shapes appear in the fracture morphology, and its low temperature impact toughness is slightly improved. Fig. 3 (c) shows the fracture morphology of the 3 # sample at 0 ℃ low temperature impact sample. It can be clearly observed that the fracture surface presents dimple shape, which is a ductile fracture, and its 0 ℃ low temperature impact toughness value is high. Fig. 3 (d) shows the fracture morphology of 4 # at 0 ℃ low temperature impact sample. Dimples appear in some areas, while big holes also appear in a few areas, which reduces the 0 ℃ low temperature impact toughness.

ISSN:2790-1688 DOI: 10.56028/aetr.2.1.356

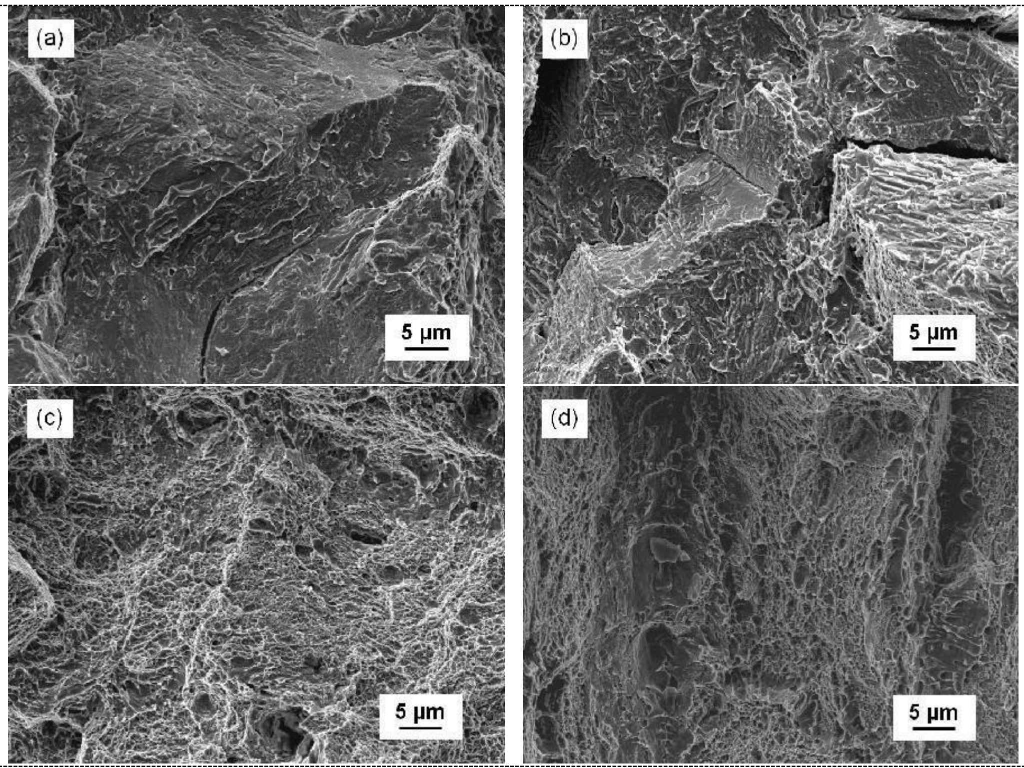

Figure 3. Microstructure of test steels before and after quenching and tempering
(a)—1#; (b)—2#; (c)—3#; (d)—4#

3.3 Mechanical properties

The 0 ℃ low-temperature impact toughness value of the test steel before and after heat treatments is shown in Figure 4. It can be seen that the test steel is air cooled to room temperature immediately after forging. Since the test steel is added with about 13% Cr element, the test steel can also obtain martensite structure under air cooling. Its 0 ℃ low-temperature impact toughness value is very low, which is about 6 J/cm2. When the forged test steel is heat treated by quenching + tempering process, its low-temperature impact toughness at 0 ℃ is greatly improved. After 2 # process, The low-temperature impact toughness value at 0 ℃ is increased to 44 J/cm2. When the 4 # sample is quenched at 1000 ℃ for 15 min and then 490 ℃ tempered for 30 min, the low-temperature impact toughness value at 0 ℃ is increased to 33 J/cm2, but it is about 11 J/cm^2 lower than that of the 3 # sample.

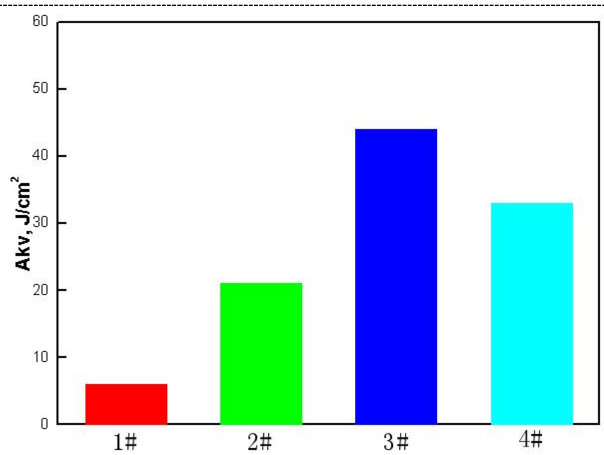

Figure 4. Impact toughness of test steels before and after heat treatments

ISSN:2790-1688 DOI: 10.56028/aetr.2.1.356

4. Conclusions

(1) After comparing different heat treatment processes, the best 0 ℃ impact toughness can be obtained by the heat treatment process of 1040 ℃ isothermal holding for 15 min and subsequent quenching into water and then tempering at 540 ℃ for 30 min.

(2) At the same quenching temperature, better low-temperature impact toughness can be obtained at 0 ℃ for the shorter holding time. At 1040 ℃, longer holding time leads to larger austenite grains and reduces its low-temperature impact toughness after tempering.

(3) The lower quenching heating temperature with lower tempering temperature do not improve the 0 ℃ impact toughness of the test steel. The lower isothermal holding temperature reduces the diffusion capacity of carbon elements during tempering, resulting in lower low-temperature impact toughness.

Acknowledgments

This work was financially supported by Shaoguan Science and Technology Funding Plan Project (No. 210728104530543), Guangdong Songshan Polytechnic College Scientific Research Project (No. 2021KJZD001), Characteristic Innovation Project of Higher Education Institutions of Guangdong Province (No. 2021KTSCX226), Science and Technology Program of Guangxi Province (Grant No. AA22068080), and the 111 Project (2018018).

References

[1] Xia S M and Zhang Z M 2000 Hot Working Technology 3 39

[2] Zhao C S 2011 Mold manufacture (4) 83

[3] Li C Y, Liu H, Liu G H, Wang J B, Wang T and Cao M Y 2019 J of Netshape Form Eng 11(1) 36

[4] Nan H, Chang R J, Li J Y, Xu F H and Zhang W 2020 J Iron Steel Res Int 32(12)1148

[5] Zhang Y J, Hu W T and Han J T 2015 Trans of Mater and Heat Treatment 36(Supple1) 37

[6] Zhao L, Chen K, Ding H and Gu Y 2021 Precision Machining and Testing Technology (3) 17

[7] Liu B S, Lin Z M and Yin F X 2021 J of Netshape Forming Eng 11(1) 36

[8] Wang S, Yang C H, Xu D K, Shen M G, Nan L and Yang K 2014 Acta Metall Sinica 50(12)1453

[9] Yuan C W, Huang J J, Li S C and Liu S C 2020 Nonferrous Metals Sci and Eng 11 (4) 37

[10] Li B, Wang S, Xiao C, Xu W, Jin Y and Liu X 2019 Metallic Functional Materials 26(4) 30