Characterization and Application of Nanomaterials (2019) Volume 2 Issue 1
doi:10.24294/can.v2i1.650

Dynamic crack toughness of austempering steel

Tatyana Avdjieva

Nuclear Engineering Division
Department of Physics, Sofia University
James Bourchier 5 blvd, 1164 Sofia, Bulgaria

ABSTRACT

This work is a part of research on the microstructure and mechanical properties of Cr-Ni-Si steels after various thermal treatments [1, 2]. The need to minimize damage and losses caused by emerging failures in complex engineering facilities such as nuclear, thermal and hydroelectric power stations, and gas and oil pipelines necessitates the creation of materials of high strength, plasticity, welding and high rigidity.

Keywords: *dynamic crack resistance; austempering; steel; microstructure*

1. Introduction

The subject of this study isto explore the relationship between the dynamic crack strength of low carbon micro alloyed steel at different structure condition and crack surface micro relief. To determine the material crack strength is used three point bending test. The special case is that, in addition to standard Sharpy Test specimens, test specimens with additional two side notchesare used[3].When performing dynamic tests, the condition for a flat deformed condition must be complied with. A significant amount of energy is consumed to form this state during the tests, which is accompanied and illustrated by the absence of lateral deformation of the test piece in cross-section. In other words, after the flattened deformation state, the shape and dimensions of the cross-section of the test body are preserved the same as the parent–not distort (deformation) the side walls of the test body.

In order to increase the resistance of the materials against rupture it is necessary to possess simultaneously high strength and plasticity at the same time. Normally, in conventional metals, this is impossible.It is known[5 -11] that sub microcrystalline and nanocrystalline materials exhibit high strength and, in certain cases, unique strength and plasticity properties.One possible method for producing a high crack resistanceand toughness material is the preparation of a bainitic structure. The aim of this research is to obtain astructure of low carbon bainitic steel after isothermal quenching from austenite temperature.Different processes like austempering has become the most powerful and effective manufacturing process to satisfy increased hardenability, improved strength, and superior low-temperature toughness[5]. That is why, different structural morphologies have been investigated as a result of cooling from the austenitic temperature at different rates or after annealing.

2. Materials and Methods

Specimens of low carbon steel of the chemical composition listed in Table 1 were subjected to study.

Table 1. Chemical composition (wt. %)

ElementCSiMnCrNiAlPS

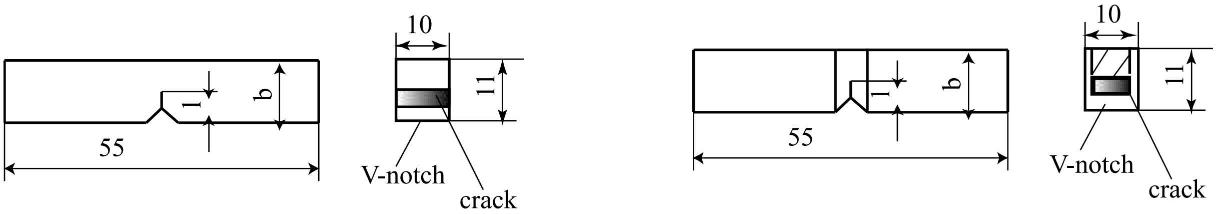
wt. %)0, 291, 271, 01, 12 0, 050, 070,018 0,018

Steel bulk material was initially forged to a 12 x 12 mm square profile to reach approximately 18% deformation texture. The profile is then subjected to recrystallization annealing at 1200 ° C, holding 30 minutes and cooling with the furnace was adopted to remove the texture. From the square are cut samples for metallographic analysis and mechanical tests, which are subsequently subjected to different thermal treatments.

doi: 10.24294/can.v2i1.650

The metallographic analysis are performed on pre-prepared screeds after etching with 3% nitric acid, according to E3-95 Preparation of Metallographic Specimens, E407-93 Micro etching Metals and Alloys. Analyzes were performed on a SEM electron microscope (SEM Lyra, Tescan with Quantax EDS detector - Bruker) at various magnifications. The impact was measured at room temperature on all specimens (fig. 1) after each heat treatment.

At the base of each concentrator deep 2 mm in all specimens, with a special device, a notch with 1 mm of depth is applied eextra. This was necessary in order to determine the energy for spreading the crack and not the total energy of destruction in the three-point bending test.The fulfillment of the flat deformed condition during the dynamic loading is made possible by increasing the length of the exit initial crack as well as by applying two additional side notches of the same depth (**Figure 1**, b).



b)

№	Heat treatment	Hardness [HRC]	Microstructure	
1	quenching (880 ^{o}C) and tempering (350 ^{o}C)	45		Tempered martensite - troostite

Figure 1. Specimens for Sharpy test: a) specimen with V-notch and crack, b) specimen with two side notches and crack

All thermal treatments of the material begin with austenization at 880 ° C for 30 minutes. The processing temperatures were selected taking into account the martensite transformation temperature, Mn = 358 °C experimentallee defined. Temperatures of isothermal quenching are selected in the rangefrom 360 till 390 $^{\circ}$C.

Results

The mechanical properties are summarized in Table 2.No significant change in hardness was found - ranging from HRC44 to HRC45 in different heat treatments.

№	Heat treatment	Hardness [HRC]	Kev [J/sm^2]	GIC[J/sm^2]
1	quenching (880 ^{o}C) and tempering (350 ^{o}C)	45	16,25	12,78
2	austempering at 360^{o}C	43	39,48	31
3	austempering at 380^{o}C	43,5	45,31	41,12
4	austempering at 390^{o}C	44	27,85	22,23

Table 2. Mechanical properties

An especially important parameter of the material, consciously sought, is its crack resistance. Rresults obtained in a double sided specimens test are independent of the length of the pre-cracked crack -= l/b (fig. 1, b) and can be considered as the G_{IC} - dynamic crack resistance of the steel.Specific work of fraction propagation (K_{ev}) is found to exceed in all cases the work in the plane strain condition (G_{ic}). Maximum crack resistance is obtained at the processing temperature 380 ^{o}C and minimum – after quenching with tempering.

The microstructure of the steel after various heat treatments is shown in Table 2[1]. At micrographs of steel, ferrite appears gray, bainite appears dark, and both martensite and retained austenite appear white.

After quenching and tempering at 350 ° C (Table 3, a), the structure has a temperedmartensitic - a plate typemartensitic.The individual areas are located within the former austenitic grain. Extremely detached structure - sharp boundaries between the different phase elements.

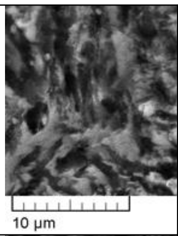
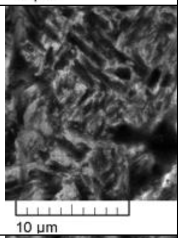
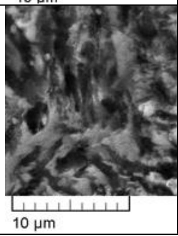
2	austempering at 360°C	43		Low bainite and martensite
3	austempering at 380°C	43,5		Low bainite
4	austempering at 390°C	44		Upper bainite

Table 3. Microstructures of Cr-Mn-Si steel

The observed at table3, 2microstructure is alow bainite consisting of a number of clusters located within the "paternal" austenitic grain. It consists of ferrite lamellas, some quantity martensitic and residual austenite, which quantity is about 15, 6 %. At a very high magnification in some places there are observed separations along the boundary of the lamellae formationsand individual cement carbides (small rounded formations at high magnification, r ≈0, 20 – 0, 21 m).

Clusters (individual cereal formations) with bainite ferrite and separate cement separations are observed(table 3, 3). As can be seen in the picture, the sizes of the individual structural formations are extremely small. The structure is low bainite. There is no residual austenite on the X-ray difraction.

The structure after 390 °C (table 3.4) is an upper bainite consisting of alternating ferrite lamellas and residual austenite – 21 %. Cluster sizes are relatively large. They are located at a different angle within the former austenitic grain.

The difference in the microstructure is also the size of the individual lamellae in the clusters - with an increase in the temperature of the isothermal quench the size increases. At a temperature of 360 °C, the average size is 0.23 – 0, 25 μm and at 390 °C - 1.55 – 1, 72 μm, which thickens the laminates.

Fractography is a method in failure analysis for studying the fracture surface of materials. The fractured surface are shown at table. 4 to help determinnation of the cause of failure. We can see different modes of failure produce characteristic features on the fracture surface.

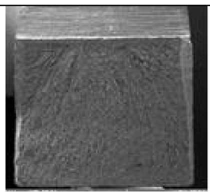
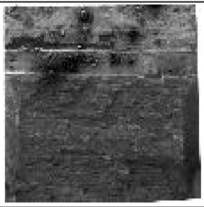
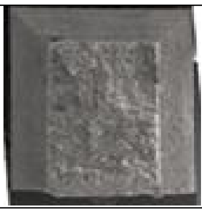
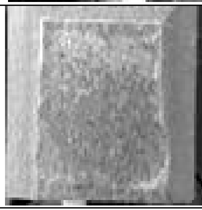
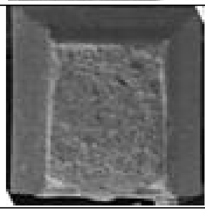
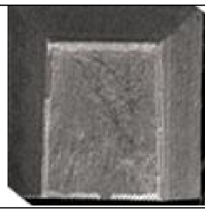
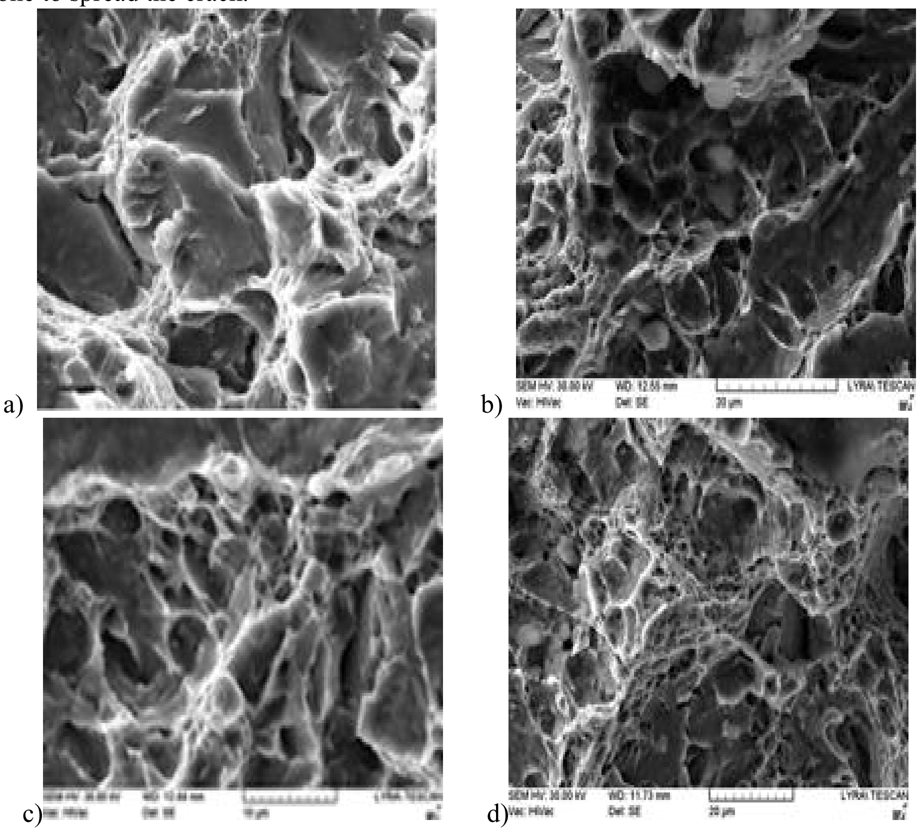
Heat treatment	1	2	3	4
Standard Sharpy specimens				
Specimens with 2 V-notches				

Table 4. Fracture surfaces

The failure in all of the specimens begins along the entire length of the overshoot. In the tempered patterns the direction of the major crack points are arranged fan-shaped from the bottom of the notch to the opposite end of the sample body. In the samples after isothermal quenching there is no visible movement of the crack. At the beginning of the crack propagation (immediately after the bottom of the overshoot) there are areas located transversely to the direction of impact with the presence of secondary cracks in them, which suggest a delay in the movement of the highway crack. There are no deformations in the destroyed test bodies with 2 V-notches, as expected. Thus all the energy for has gone to spread the crack.



a) – after quenching and tempering, b) austempering at 360 °C, c) austempering at 380 °C, d) austempering at 390 °C

Figure 4. The fracture surface of tested steel after different heat treatment

It is known that the crack resistance of the metal is determined by the dominant fracture mechanism in each case[3,4]. The absence of distortion on the fracture surface of two V-notch specimens allowed to test into the influence of structure condition on dynamic crack strength G_{IC}.

After quenching the crack follows the grain boundaries(intergranular fracture) – intergranular cleavage facets appear together with quasi cleavage facets (fig. 4, a).After isothermal quenching at 360 °C, the structure changes - multiple flat dimples appear withcomplex carbides at the bottom (fig. 4, b).Numerous flat dimples are combined with few quasi cleavage facets at the fig.4, c. Low bainite structure leads to ellimination of the brittle fraction - ductile fracture is characterized by a deeper dimple structure. As a result of the presence of an upper bainite in the structure (fig. 4, d, the fracture surface again changes– flat dumples with quasi cleavage facets appears.

3. Discussion

Two low-carbon steel alloyed with Cr,Si, Mn have been tested. The low carbon is preferred for the current steel from the viewpoint of low segregation, good toughness, and superior weldability.

Conclusion

The increasing dynamic crack strength G_{IC} to be determine in appearing of low bainite is conditioned by growing of large and deep dimples.

The method for determining the dynamic crack resistanceof the metal with 2 V-notch specimens is easy, fast and sufficiently representative.

It has been found that bainitic steel has maximum crack resistance

References

1. Avdjieva T. Microstructure features of Cr-Ni steel after isothermal tempering, Annual of Sofia University 2016; 109.
2. Avdjieva T, *et al*.(2013). Microstructure and crack resistance of low carbon Cr-Ni and Cr-Ni-W steel after austempering, Central European Journal of Engineering 2013; 3(3): 484-491.
3. Georgiev M, *et al*. The relation Between Dynamic Crack Strength of structural Steels and Schnook Loading Fracture Structures, Material science 2011; 12: 118-128.
4. Георгиев М, *et al*. Оценка работы разрушения ударных образцов с боковыми надрезами, Заводская лаборатория. 2012; 9: 56-61.
5. Litovchenko I, *et al*. The Features of Microstructure and Mechanical Properties of Metastable Austenitic Steel Subjected to Low-temperature and Subsequent Warm Deformation, Russian Physics Journal 2016; 59(6).
6. Lang HF, *et al*. Microstructure and Mechanical Properties of a Low CarbonBainitic Steel, Mat. Res. 2013; 84(4): 352–361.
7. Yong Tiana, *et al*. The analysis of the microstructure and mechanical properties of low carbon micro alloyed steels after Ultra-Fast cooling, Mat. Res. 2017; 20(3).
8. Zuo X, *et al*. Study of pipeline steels with acicular ferrite microstructure and ferrite-bainite dual-phase microstructure, Materials Research 2015;18(1): 36-41.
9. Pedrosa IRV, *et al*. Study of phase transformations in API 5L X80 Steel in order to increase its fracture toughness, Materials Research 2013; 16(2): 489-496.
10. Sung HK, *et al*. S Effects of Cooling Conditions on Microstructure, Tensile Properties, and Charpy Impact Toughness of Low-Carbon High-Strength Bainitic Steels, Metallurgical and Materials Transactions A 2013; 44(1): 294-302.
11. Gallego J, *et al*. Second phase precipitation in ultrafine-grained ferrite steel. Materials Research 2014.