Bulgarian Chemical Communications, Volume 45, Number 4 (pp. 549–553) 2013

Microstructure and texture analyses on spring steel

L. V. Nikolova*

University of Chemical Technology and Metallurgy – Sofia,
8 St. Kl. Ohridski Blvd. 1756 Sofia, Bulgaria

Received February, 2013; Revised May, 2013

For this study hourglass shaped specimens of spring steel were subjected to rotating-bending fatigue at different stress ranges to fracture. Microstructure observations showed eutectoid (lamellar) structure and characteristics of the lamellar microstructure were described. Deeper observations described the influence of the fatigue process on microstructure and the crystallography – is there a crystallographic influence on the fatigue as it is seen with other materials or not. Electron backscatter diffraction (EBSD) analyses were performed to characterize the crystallography of the specimens at different parts of the fractured surface as well as in direction perpendicular to the fracture surface to investigate crack path.

Key words: spring steel; microstructure, texture, EBSD.

INTRODUCTION

The materials applied for springs are extended to metallic and nonmetallic types, in addition, among the metals there are many types, such as, spring steel, stainless steel, nickel alloy and so on. Their required properties vary accordingly. However, whatever the applications are, it is certain that a high stress during cyclic loading and prolonged reliability should be required. It is generally recognized that the linear fracture mechanics allows to be defined the threshold condition of fatigue crack propagation. In high strength materials such as spring steels very small cracks lead to fatigue fracture. It is well known that the fatigue process can be influenced by many different factors such as temperature, applied stress, environment, microstructure of the material etc. most of the measurements on pearlite structures are pointed to morphology and formation mechanism of pearlite steels and to give more insight into the problem of the nucleation and growth process of pearlite [1, 2, 3, 4, 5, 6]. Not so many researches are pointed to determine the crystallographic orientation in the pearlite colony [7, 8]. The aim of this study was to investigate the influence of the crystallography on specimens tested on specific plastic deformation.

EXPERIMENTAL

Material and specimens: The studied material was steel wire, used for springs, with a diameter φ = 8 mm and tensile strength σ_B = 1522 MPa. The chemical composition of the steel contains 0,819 weight % Carbon i.e. hypereutectoid steel and is presented in Table 1. The specimens were machined from a coiled on reel drawn steel, no additional heat treatment was performed before

Table 1. Chemical composition of the investigated steel (weight %)

C	Mn	P	S	Si	Al	Cr	Ni	Cu	Mo	N_2
0.819	0.760	0.010	0.001	0.257	0.034	0.251	0.016	0.011	0.003	0.005

* To whom all correspondence should be sent:
E-mail: lyubov_nikolova@abv.bg

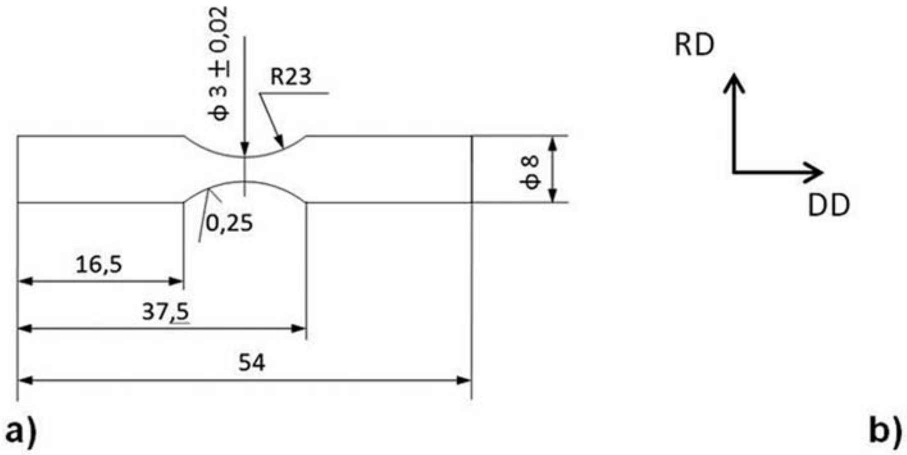

Fig. 1. Geometry of the specimens (a) and the named directions of the axis (b)

testing. The geometry of the specimens is shown on Figure 1(a). Figure 1 (b) represents the directions of the axis of the specimens i.e. DD – drawing direction (longitudinal axis), RD – radial direction (transverse axis). The specimens were polished with silicon carbide papers (starting with 400-grid, after 500-grid, 600-grid, 800-grid, 1000-grid, 2000-grid and 2500-grid) before testing so that all surface defects to be removed.

Testing: Hourglass shaped specimens were subjected to symmetric cyclic rotating-bending fatigue at different stress ranges (R = –1, f = 11 Hz) in air and room temperature to fracture. Tests were performed on a table model Fatigue Rotating Bending Machine, FATROBEM-2004, designed and assembled in "Fracture and Fatigue" Laboratory in UCTM – Sofia [9]. All the tests were done in the range of high cycle fatigue accordingly to the S-N curve of the material.

Equipment for characterization and sample preparation: Scanning electron microscope (SEM) Jeol JSM-6490 was used for microstructure and fatigue fracture surface observations and Jeol JSM-6500F equipped with field emission electron gun (Oxford instruments, HKL technology) for Electron backscattered diffraction (EBSD) analysis. Channel 5 system (HKL Technology) was used for analyzing and presenting the obtained results. A step size of 0,8 μm was used to collect data over the surface of the specimen, accelerating voltage inside of the vacuum camera was 15 kV.

To reveal the microstructure of the samples 4% picric acid solution was used after polishing with a 4000-grid silicon paper. The samples for EBSD analyses were polished with a 4000-grid silicon carbide paper followed by final polishing with colloidal silica solution.

The specimens were characterized in two mutual perpendicular directions (parallel and perpendicular to fracture surface). Successive polishing steps over the fracture surface were performed to identify the microstructure behind the nucleation site using EBSD technology. Because of the fine microstructure of the material and the fact that for the most materials the ferrite could not be read the EBSD analysis for this study were performed with a very small step size i.e. 0,08 μm. The characterization of the material and the EBSD analysis were done in the laboratory LEM3, University of Lorraine – Metz, France.

RESULTS AND DISCUSSION

The steel used in this study contains 0,819 wt.% carbon which accordingly to the Fe-C phase diagram means that it is eutectoid steel with lamellar microstructure (alternate layers of ferrite and cementite). This is confirmed by proceeded microstructure observations (Fig. 2). Typical characteristics of the eutectoid microstructure were noticed such as curvature of cementite lamellae, discontinuous cementite lamellae, bridges connecting two cementite lamellae, branching of the cementite and also primary cementite (Fig. 2 (c)). The presence of primary cementite (Fig. 2 (a)) is explained by the higher percentage of carbon i.e. hypereutectoid steel. Flattening and widening of the lamellae respectively oriented parallel and perpendicular to DD were noticed on specimen's microstructure (//DD) what could be a result of the drawing process. Curvature of the cementite lamellae oriented parallel to DD in the zones close to the fracture surface was also found. The interlamellar spacing λ at different zones (//DD) of the specimens

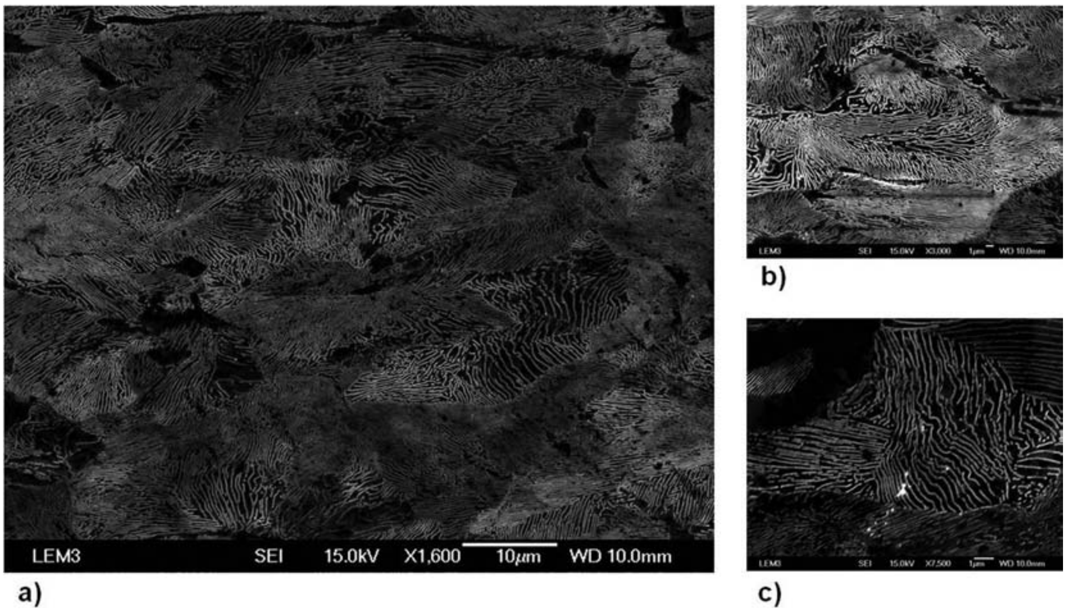

Fig. 2. Lamellar microstructure of the material at different areas and different magnifications: (a) x1600; (b) x3000; (c) x7500;

was measured. Each one of the obtained results for each zone is an average value from 50 to 60 measurements. The values for the different zones are as follows: zones close to the fractured surface (//DD) $\lambda = 0.2808$ μm; zones from the middle part of the specimens (//DD) $\lambda = 0.2847$ μm; zones from the not deformed specimen (//DD) $\lambda = 0.2668$ μm.

EBSD analyses (Fig. 3) were performed to characterize the crystallographic orientation at different parts of the fractured surface as well as in direction perpendicular to the fracture surface to investigate crack path. As could be seen from the performed analysis, the fatigue process in this study was not influenced by the crystallography of the material's microstructure. On Figure 3 are illustrated colored pole figures for both phases obtained by Channel 5 system. The figure is showing the texture analysis of different specimens and different zones of the polished surface. It can be concluded that there is no significant change of the texture, but it can be

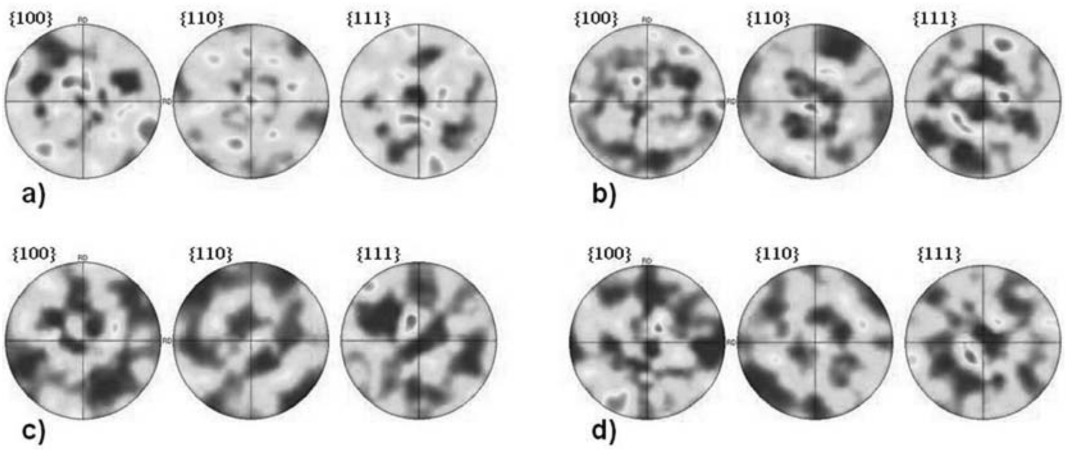

Fig. 3. Pole figures (coloured) illustrating the texture of different specimens and in different directions of geometrical form: (a) zone of the initiation, applied stress $\Delta\sigma = 1500$ MPa; (b),zone of final fracture, applied stress $\Delta\sigma = 1500$ MPa; (c) analysis of surface parallel to RD, applied stress $\Delta\sigma = 1500$ MPa; (d) initial texture of not-deformed material

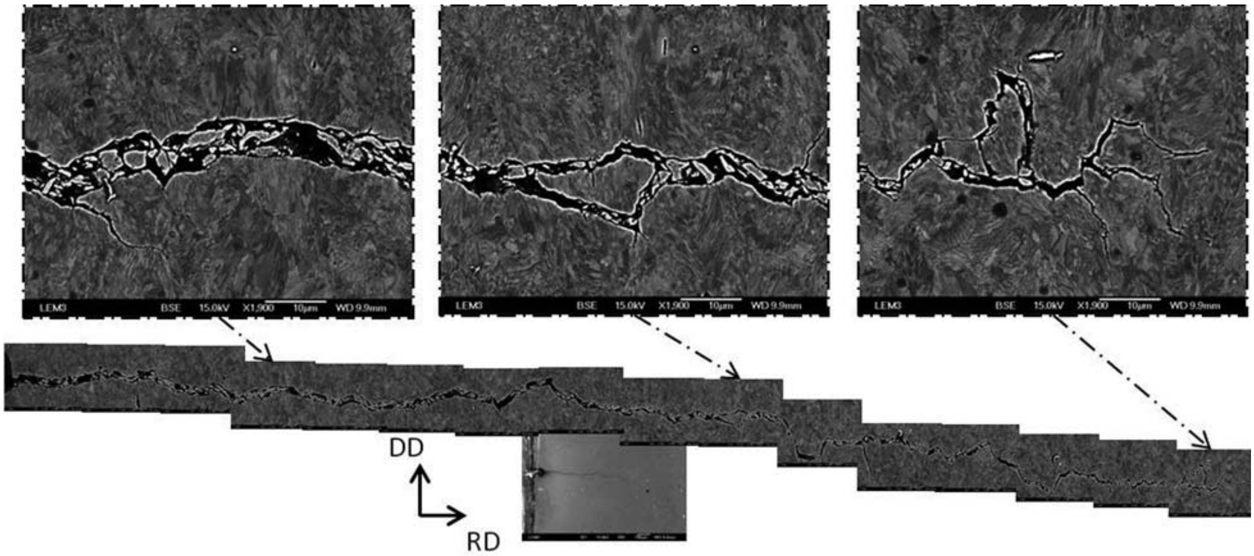

Fig. 4. Crack path on a fractured surface of a specimen subjected to Rotating-Bending Fatigue under $\Delta\sigma = 1200$ MPa

noticed only a small difference in the intensity i.e. zones with a higher rate of deformation (Fig. 3a, b) showed higher rate of texture in comparison to analysis of the surface parallel to RD (Fig. 3c) and of that of not-deformed material (Fig. 3d). As is it seen on Fig. 3a there is expressed a slow rate of fiber texture clearly seen on pole figure {110} showing the texture in planes (101), (110), $(01\bar{1})$.

The initial texture (not-deformed specimens) that had been measured showed slow rate of texture what could be a result of the process of drawing of the material. It is known that by drawing the rate of texture is influenced by the difference in the ratio of initial diameter/final diameter of the drawn material which is confirmed also by other researchers [10, 11].

As it is seen on Figure 4 the fatigue crack propagation also was not influenced by the fatigue process. The crack is not propagating on a specific crystallographic planes or directions. This might be due to very low texture or very high applied stresses when we investigate the mentioned kind of influence. However, more investigations at low stresses are necessary to determine whether the crack propagation in this material could be influenced by the crystallographic orientation.

CONCLUSIONS

In this work the influence of the crystallography on a tested under rotating bending fatigue spring steel has been studied. EBSD analysis were performed and expressed by pole figures obtained for both phases. The results showed higher rate of fiber texture of the more deformed zones of the specimen in comparison to the initial one. But still it cannot be said that the texture was significantly changed by the performed deformation.

From the performed observations it can be concluded that the crack path had not been influenced by the crystallographic orientation. An illustration of that is shown though the crack path of a specimen tested on Rotating-Bending Fatigue at $\Delta\sigma = 1200$ MPa.

Acknowledgements: *I, Lyubov Nikolova would like to express my gratitude to all those who gave me the possibility to complete this report. I am deeply indebted to my supervisor Dr. Nathelie Gey (laboratory LEM3 – Metz, France) whose help, stimulating suggestions, knowledge, experience and encouragement helped me in all the times of study and analysis of the project in the research period. I am also grateful to all other researchers in laboratory LEM3 – Metz who helped to a great extent in the project.*

REFERENCES

1. P. R. Howell, *Materials Characterization*, **40**, 227 (1998).
2. M. X. Zhang, P. M. Kelly, *Materials Characterization*, **60**, 545 (2009).
3. F. G. Caballero, C. Garcia de Andreas, C. Capdevila, *Materials Characterization*, **45**, 111 (2000).

4. A. W. Wilson, G. Spanos, *Materials Characterization*, **46**, 407 (2001).
5. A. Walentek, M. Seefeldt, B. Verlinden, E. Aernoudt, P. Van Houtte, *Materials Science and Engineering A*, **483–484**, 716 (2008).
6. A. Walentek, M. Seefeldt, B. Verlinden, E. Aernoudt, P. Van Houtte, *Journal of Microscopy*, 224, (Pt 3), 256 (2006).
7. N. Guo, Q. Liu, Y. C. Xin, B. F. Luan, Z. Zhou, *Science China – Technological Sciences*, **54** (9), 2368 (2011).
8. N. Nakada, N. Koga, T. Tsuchiyama, S. Takaki, *Scripta Materialia*, **61**, 133 (2009).
9. A. Davidkov, PhD Thesis, UCTM, Sofia, 2006.
10. M. Zidani, S. Messaoudi, T. Baudin, D. Solas, M. H. Mathon, *International Journal of Materials Forming*, **3**, 7 (2010).
11. G. Langford, *Metallurgical Transactionsa*, 8A, 861 (1977).

МИКРОСТРУКТУРНИ И ТЕКСТУРНИ АНАЛИЗИ НА ПРУЖИННА СТОМАНА

Л. В. Николова*

Химикотехнологичен и Металургичен университет – София,
бул. „Климент Охридски“ 8, София 1756, България

Постъпила февруари, 2013 г.; приета май, 2013 г.

(Резюме)

За това изследване са използвани образци от пружинна стомана, изработени във форма тип пясъчен часовник и подложени на умора със схема на натоварване „огъване при въртене“ до разрушаване. Микроструктурните наблюдения показаха евтектоидна (ламеларна) структура, като резултатите от тях са описани. По-подробни анализи описват влиянието на уморния процес върху микроструктурата и кристалографията – има ли влияние на кристалографията върху процеса на умора и забелязва ли се и при други материали или не. EBSD анализи бяха проведени за охарактеризиране на кристалографията и изследване на пътя на пукнатината в различни области от образците, както по разрушената повърхност, така и в посока перпендикулярна на нея.