ARTICLE IN PRESS

EFA-02954; No of Pages 9

Engineering Failure Analysis xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Analyses of the failures on shear cutting blades after trimming of ultra high-strength steel

Dongmin Son [a,b], Hoyoung Kim [c], Jun-Yun Kang [c,*], Hyo Yun Yun [d], Jae-Jin Lee [d], Soon Keun Park [a], Tae-Ho Lee [c], Jehyun Lee [b,*]

[a] SĕAH CSS, 147 Jeokhyeon-ro, Seongsan-gu, Changwon, Gyeongnam, 51708, Republic of Korea
[b] Department of Metallurgy & Advanced Materials Engineering, Changwon National University, 20 Changwondaehak-ro, Uichang-gu, Changwon, Gyeongnam, 51140, Republic of Korea
[c] Korea Institute of Materials Science, 797 Changwon-daero, Seongsan-gu, Changwon, Gyeongnam, 51508, Republic of Korea
[d] Shinhwa ST, 28 Seongseogongdanbuk-ro 5-gil, Dalseo-gu, Daegu 42710, Republic of Korea

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 22 July 2016
Accepted 22 August 2016
Available online xxxx

Keywords:
Tool and die failures
Cold working
Metallurgical failure analysis
Microstructures

ABSTRACT

Damages on shear cutting blades were analyzed after 50,000 strokes of trimming on an ultra high-strength steel sheet. Traditional D2 alloy and an advanced one (Cr08H) based on the composition of 1C-8Cr were quenched from 1030 °C, tempered at 180 °C and submitted to the shear cutting test. Cr08H had lower hardness, a smaller volume fraction of M_7C_3 carbides while it contained a larger volume fraction of retained austenite. And these resulted in more scratches and rounded edges because of degraded resistance to wear and local plastic deformation. In spite of higher impact toughness, Cr08H exhibited inferior resistance to chipping which was the consequence of localized brittle fracture. It could be concluded that this was caused by more transformation of austenite as well as by insufficiently hardened matrix, both of which were attributed to inappropriate conditions of the heat treatment.

1. Introduction

Many kinds of metallic components are produced by cold-forming of metal sheets at room temperature. Various operations such as bending, drawing, piercing and trimming of work metals are conducted with various forms of cold-work dies. The core parts in these dies which directly contact work-metals are composed of inserts which are generally made of cold-work tool steels. Therefore, appropriate choices and processing of the tool steels are of critical importance in determination of the durability and the reliability of the dies.

AISI-D2 steel has served as a general material to build cold-work dies and their inserts [1–3]. Its high C and Cr content resulted in a large fraction of hard carbides in tempered martensitic matrix and the consequent wear resistance for cold-working. However, its poor toughness due to excessive amount and size of the brittle carbides can limit its applications under severe conditions. Demands for lighter and stronger structures and devices drive increasing strength of work metals, which results in severer working conditions for tool materials in dies. This general trend is most well represented in automobile industry. Recently, various types of advanced high-strength steels (AHSS) for car body have been developed [4] and their usage will be ever increasing [4–5]. Thus, concern about the durability of conventional tool materials emerged, which resulted in the development and the application of various advanced tool steels [6–8].

* Corresponding authors.
E-mail addresses: firice@kims.re.kr (J.-Y. Kang), ljh@changwon.ac.kr (J. Lee).

http://dx.doi.org/10.1016/j.engfailanal.2016.08.003
1350-6307/

Please cite this article as: D. Son, et al., Analyses of the failures on shear cutting blades after trimming of ..., Engineering Failure Analysis (2016), http://dx.doi.org/10.1016/j.engfailanal.2016.08.003

A number of works have been devoted to characterize the microstructures and the mechanical properties of the advanced cold-work tool steels in comparison with the conventional one, i.e. D2 [9–16]. Additionally, a limited number of works are provided to assess their improved performance in commercial or pilot forming processes of AHSS [15,17]. However, detailed microstructure analyses on the failures of the tools to identify the mechanisms and the material factors for them are hardly found [18]. In this study, the performance of two shear cutting blades which were made of D2 and an advanced cold-work tool steel respectively were tested in shear cutting of a ultra high-strength steel (UHSS) sheet. The results of microstructure analyses to identify the failure mechanisms are presented, and the metallurgical factors for the different performances of the tool (blade) materials are discussed.

2. Material and methods

2.1. Materials and processes

The two types of cold-work tool steels were prepared to make the blades for shear cutting. The advanced alloy (denoted as Cr08H) was belonging to the class called 8% Cr steel [9–20] which had much lower C and Cr content than D2. The chemical compositions of the two blade materials analyzed by optical emission spectroscopy are presented in Table 1. The Cr content of Cr08H approximates 8% as the designation of the alloy indicates. The tool steels were provided in spheroidizing-annealed condition for rough machining to the blades. These blades were submitted to hardening heat treatment, i.e. quenching and tempering in a commercial vacuum furnace. In the quenching cycle, they were austenitized at 1030 °C for 170 mins, cooled to room temperature by N_2 gas injection. And double tempering was conducted according to the traditional recommendation [1,21,22]. In each cycle of the tempering, the blades were heated to 180 °C, held for 300 min and cooled to room temperature by N_2 gas.

The quench-and-tempered blades were fine machined to the final shape and inserted into the die body. Fig. 1(a) shows the blade assembly engaged in a press machine with 250 ton load capacity. The work-metal was the UHSS sheet of 1.2 mm thickness supplied by POSCO and had the ultimate tensile strength of 1.2 GPa. Fig. 1(b) shows the blade pair made of D2 and describes the shear cutting test schematically. Clearance was determined to be 0.07 mm following a few previous studies [23–24] in which optimum clearance ranged from 5 to 10% of sheet thickness. The cross head speed was 0.4 m/s and total 50,000 strokes were conducted.

2.2. Characterization of the blade materials and the damages on the blades

To compare the basic mechanical properties of the two blade materials, their hardness and impact toughness after the heat treatment were evaluated. The hardness was measured in Vickers hardness with 10 Kg load (HV_{10}) [25] as well as Rockwell C-scale hardness (HRC) [26]. Although the latter was preferred in industrial fields, it was rather insensitive to small hardness difference. The impact toughness was evaluated via Charpy impact test [27] with C-notched specimens [28] which were drawn in Fig. 2.

To characterize the microstructures of the blade materials, a field emission scanning electron microscope (FE-SEM, JSM-7001F by JEOL) with an electron backscatter diffraction system (EBSD, NordlysNano detector with AZTEC software by Oxford Instruments) was used. The initial microstructures were observed using dummy materials which were subject to the same heat treatment with the blades. The specimens were prepared following the conventional metallographic methods, i.e. polishing and etching. The etchant to reveal the microstructures was Villela's reagent which was the solution of 95 ml ethanol, 5 ml hydrochloric acid and 1 g of picric acid. The detailed microstructures near the edges of the upper blades were observed after the cutting test, in which the micrographs were obtained both on the blade surfaces (shear plane) and their cross sections. X-ray diffraction (XRD) to measure the volume fraction of retained austenite was performed using a high power X-ray diffractometer (D/Max-2500 by Rigaku) which was operated at 40 kV–100 mA with Cu-K_α radiation. The volume fraction of retained austenite (V_γ) was evaluated by the following equation [29].

$$V_\gamma = \frac{1.4 \times \dfrac{I_{\gamma(220)} + I_{\gamma(311)}}{2}}{I_{\alpha(211)} + 1.4 \times \dfrac{I_{\gamma(220)} + I_{\gamma(311)}}{2}} \quad (1)$$

where I was the integrated intensities for a specific reflection plane of a phase, the subscripts α and γ represented the ferritic (or martensitic) and austenitic phase respectively.

Table 1
Chemical compositions of the blade materials (wt.%).

Alloy	C	Al	Si	Mn	Cr	Mo	W	V	Cu	Nb
D2	1.55	0.01	0.26	0.30	11.36	0.81	–	0.20	0.15	–
Cr08H	1.00	0.36	0.98	0.55	8.36	0.97	0.40	–	0.42	0.14

Please cite this article as: D. Son, et al., Analyses of the failures on shear cutting blades after trimming of ..., Engineering Failure Analysis (2016), http://dx.doi.org/10.1016/j.engfailanal.2016.08.003