Technical Report: Microstructural Characterization of a Knife with Damask Patterning

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1 Introduction

A knife blade exhibiting a damask pattern was provided for investigation by Mr. Daniel Watson of Angel Sword in Driftwood, TX. Mr. Watson reported this blade to be created from a commercial tool steel using a combination of thermal and mechanical processing steps. Photographs of this blade are provided in Fig. 1, showing clear damask patterning on both the right-hand and left-hand blade surfaces. The present investigation focuses on characterizing the microstructure of this damask-patterned steel blade, with the goal of providing data on the origin of this damask pattern. The blade was sectioned into multiple pieces, and the two labeled as A and B in Fig. 1 were prepared as specimens for microstructural examination. Specimens A and B were mounted in phenolic resin and subsequently ground and polished to reveal clean, undeformed blade material, i.e. internal material away from the original blade surface. These prepared specimens were then characterized using the following techniques: Knoop microhardness indentation, Rockwell type C hardness indentation, optical microscopy, scanning-electron microscopy (SEM), and energy-dispersive spectroscopy (EDS). For observation under optical and scanning-electron microscopy, the polished specimens were etched with a solution of nitric acid and methanol, referred to as "nital" in standard metallographic practices, in order to reveal microstructural features.

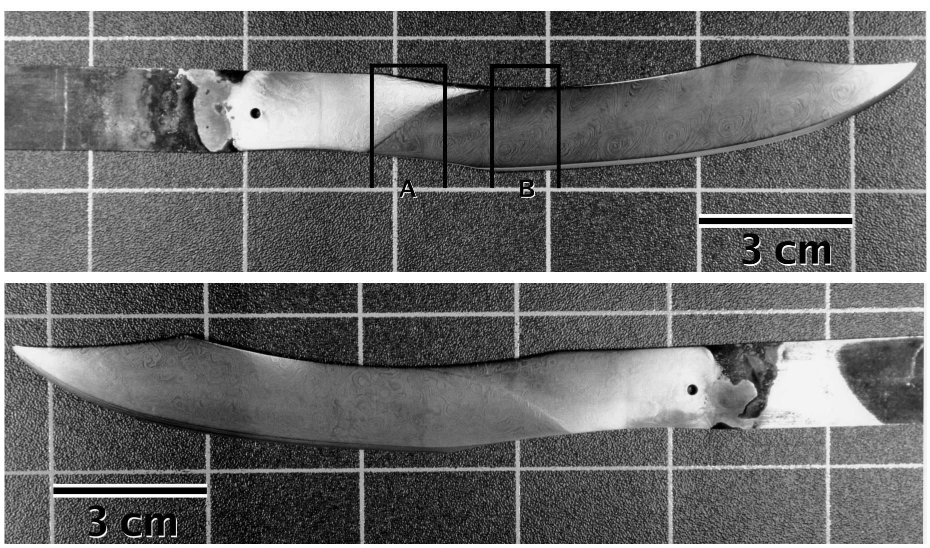


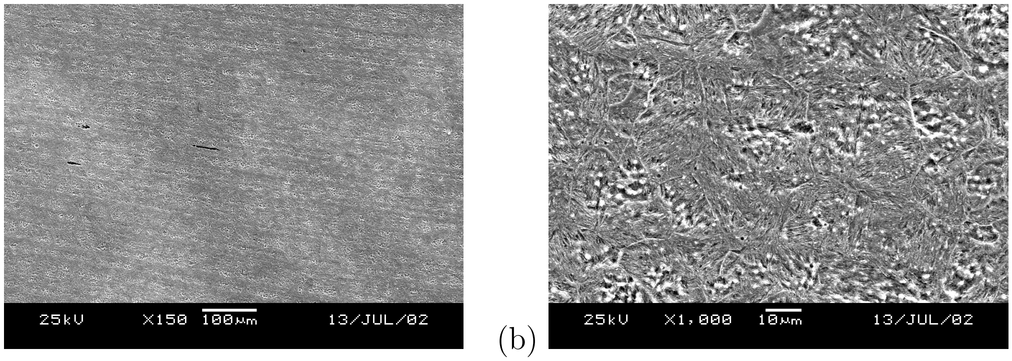
Figure 1: Photographs of the knife exhibiting a damask pattern are shown for the (top) right-hand and (bottom) left-hand blade surfaces.

2 Experimental Results

Macroscopic indentation experiments were conducted on both specimens A and B using the Rockwell type C indentation test. Indentations were conducted on material internal to the blade, which was revealed by grinding away the surface material using silicon-carbide papers, followed by polishing with diamond compounds to remove surface deformation. The average hardness value measured from multiple tests on both specimens is 53 HRC, with a standard deviation of 1.7 in the data set. This value of hardness is within the range of hardnesses expected from quenched-and-tempered tool steels produced by standard heat-treating practices [1].

Damascus steels, those steels which exhibit damask surface markings, have been divided into two categories by Wadsworth and Sherby [2, 3]. *Genuine* damascus steels are those which are composed of a single steel composition and have a damask associated with microstructural features which pervade the entire material. The other primary category of damascus steels is the *pattern-welded* variety, which is created by the lamination of two different steels, typical one with a high carbon composition and a second with a low carbon composition. For *genuine* damascus steels, damask patterning is generally not observable on a freshly polished surface of the steel. This is the case for the ground-and-polished specimens of the present blade. Upon etching with a nital etchant, however, a damask pattern similar to that of the original blade surface is again revealed in the polished specimens of the knife blade. This is a clear indication that the damask pattern in this blade is associated with microstructure which exists throughout the blade. The damask pattern revealed after etching is found to be associated with microstructural banding shown in the SEM image of Fig. 2(a). An SEM image at a higher magnification, shown in Fig. 2(b), reveals a microstructure of tempered martensite with a dispersion of fine carbide particles, as expected in a quenched-and-tempered tool steel. Moreover, the microstructural banding is clearly associated with variations in the density of very fine carbide particles. This is in contrast to the coarse carbide particles associated with the damask patterning of genuine damascus steels investigated by Verhoeven and Pendray and co-workers [4–12] and by Wadsworth and Sherby and co-workers [2, 3, 13–22]. The fine carbides present in this blade are expected to lead to mechanical properties superior to those of damascus steels with coarse carbides. The origin of the damask pattern, which is observed with the naked eye, is in the microstructural bands shown in Fig. 2(a). Slight variations in the spacing of these microstructural bands lead to darker and lighter macroscopic bands on the steel surface after etching, which are the damask pattern.

Knoop microhardness indentations were made across the damask pattern bands on specimen A, with indentations falling into both the light and dark bands. Indentations were made using a 1000 gram load, and the resulting indentations are shown in the



(a) (b)

Figure 2: Micrographs of a polished-and-etched section from the knife blade are shown at (a) low and (b) high magnification. The banding of the etched microstructure is associated with slight variations in the densities of fine carbide particles, shown in (b) to reside within a background of tempered martensite.

optical micrograph of Fig. 3. Each of the four indentations shown is of the same size, regardless of falling within either a light or dark band. This result proves that hardness does not vary between the dark and light bands within the damask pattern and indicates that major composition variations are unlikely between these bands. EDS was conducted along a line crossing several dark and light bands within the damask pattern of specimen *A*. Fig. 4(a) shows the result of elemental composition analysis by EDS across several damask bands for the elements Si, Cr, Mn, and C. No meaningful variation in these element concentrations is detected; all variations shown are within the resolution limit of the instrument. Fig. 4 shows these same data superimposed on an SEM image of the region analyzed; the line along which composition was measured is also shown. The results of Knoop hardness indentations and EDS analysis show conclusively that the knife blade is a single steel composition. Thus, it fits into the category of genuine damascus steels. Moreover, the homogeneous composition of the blade material and the very fine carbide dispersion it evidences are both characteristic of high-quality, modern tool steels. One of the fine carbide particles, shown in the SEM micrograph of Fig. 5(a), was analyzed for element content using EDS. The EDS results, shown in Fig. 5(b), indicate the presence of elements expected in and near the carbides formed within modern tool steels, including Si, Cr, Mn, and Mo. The exact composition of the steel was not determined.

3 Conclusions

The knife blade examined clearly falls into the category of a genuine damascus steel. The damask pattern it exhibits results from microstructural bands in the distribution

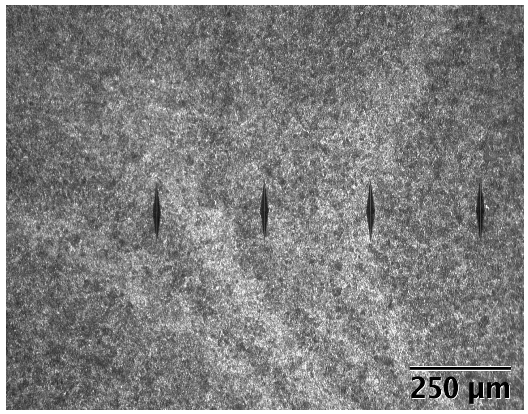


Figure 3: Knoop microhardness indentations (1000 gram load) across the damask bands are shown to have identical sizes, indicating no hardness variation across the banded microstructure.

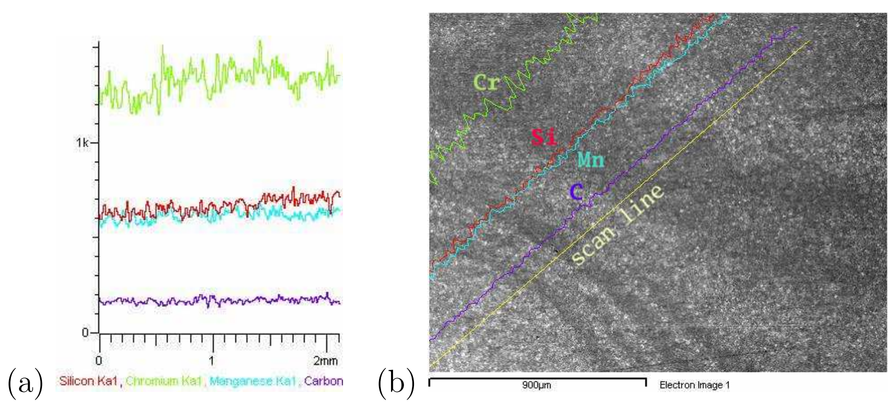


Figure 4: Data from an EDS line scan for the elements Si, Cr, Mn, and C are shown as (a) a histogram of composition variation versus position and (b) element concentration variation as a function of position superimposed upon an SEM image of the actual microstructure scanned, with the scan line indicated.

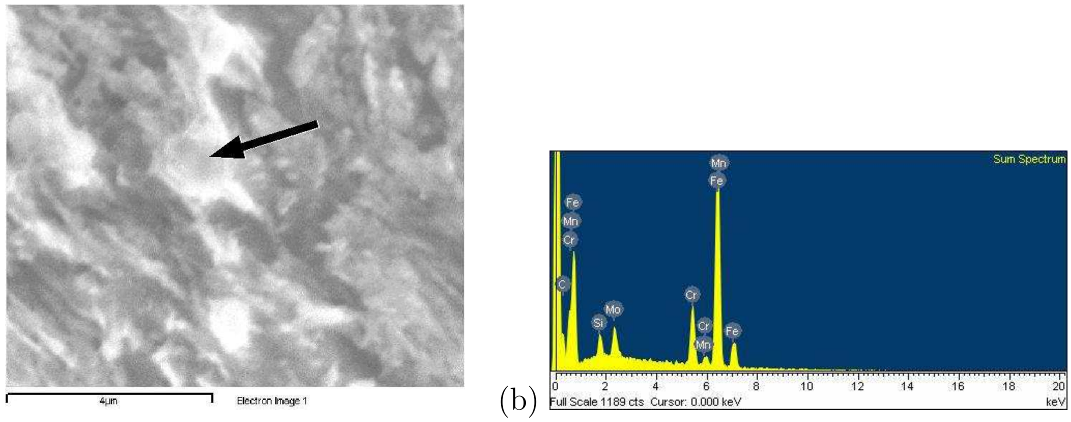
(a) (b)


Figure 5: The results of EDS analysis on the small carbide, shown in the high-magnification image of (a), are provided in (b) as a energy spectrum, on which important energy peaks for particular elements are labeled.

of very fine carbide particles. The variation in spacing of these microstructural bands leads to an etching contrast which reveals a damask pattern observable to the naked eye. This mechanism is similar to those proposed to explain the patterning of other genuine damascus steels in that it is associated with carbide particles. However, the carbide particles of this damascus steel are finer than those reported in the literature for other genuine damascus steels. The small carbide particle sizes and homogeneous composition and hardness of this knife blade are characteristic of a modern tool steel material, which leads to an expectation of excellent mechanical performance.

4 Acknowledgments

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