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Characterisation of a San Mai Steel Composite for the Manufacture of Knives

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Abstract. The term San Mai is used for the manufacture of knife blades consisting of three layered steel composites. The middle layer, which forms the cutting edge, consists of hard steel and on the outside a soft stainless steel is forged. Mr. Benjamin Kamon, an Austrian blacksmith, provided the examined sample. Three different steels and a thin Ni layer are symmetrically connected (1.4301/1.3520/Ni/1.2519/Ni/1.3520/1.4301). The middle layer is a cold work steel (1.2519) and the Ni layer is to prevent diffusion processes. 1.3520 is a heat treatable steel for rolling bearings, followed by an austenitic stainless steel (1.4301). Metallography and SEM-EDX were used to study the microstructure, the interfaces between the different steels as well as diffusion zones. It can be stated that all layers are well connected and no defects are evident.

Introduction

In the context of a knife blade the term San Mai is used for the manufacture of a usually three layered steel composite produced by forging [1].

Forging is the oldest method of working and shaping metal and it's also suitable for joining different metals to create composite materials with a wide variety of properties [2]. For the combination of different carbon steels, this method is called the Damascene technique and has been used in Europe since the 3rd century AD [3]. Blades and weapons were produced by this technique.

It was already possible by combining a ductile, low C steel with a hardenable, high C steel to produce a very resistant composite material, Damascus steel. In recent times, such modern Damascus steels have been created by combining modern steels [4 - 9].

In order to achieve special design effects, not only steels were processed, but other compounds were also produced by combining steel with non-ferrous metals [10, 11].

Experimental Procedure

Starting materials. Three different steels and a thin Ni layer were symmetrically connected (1.4301/1.3520/Ni/1.2519/Ni/1.3520/1.4301) by forging. The steel grades are summarized in Table 1. The initial thicknesses of the metal sheets were: 1.4301 – 7 mm; 1.3520 – 1,5 mm; Ni – 0,4 mm; 1.2519 – 15 mm.

The middle layer is a cold work steel (1.2519) which forms the cutting edge in the finished knife. The Ni layer is to prevent diffusion processes. 1.3520 is a heat treatable steel for rolling bearings, followed by an austenitic stainless steel (1.4301).

Table 1 Composition of the used steels (wt. %)

Mat. Nr.	C	Si	Mn	Cr	Ni	W	V	steel
1.4301	< 0.07	< 1	< 2	18.25	9.25	-	-	austenitic
1.3520	1	0.6	1.1	1.5	-	-	-	heat treatable
1.2519	1.1	0.23	0.3	1.2	-	1.3	0.2	tool

Forging of the different steels and Ni sheets. A cross-section through the composite after the starting sheets have been forged at about 1200 °C can be seen in Fig. 1. The initial height of this stack was about 35 mm, the intermediate thickness after the first forging step was about 10 mm.

The next production step was the forging of the composite sheet to the thickness of the knife blade (about 3 mm) and heat treatments to adjust the steel qualities. The heat treatments normalization, softening and stress relieving were carried out. Subsequently, this composite material was examined by metallographic methods.

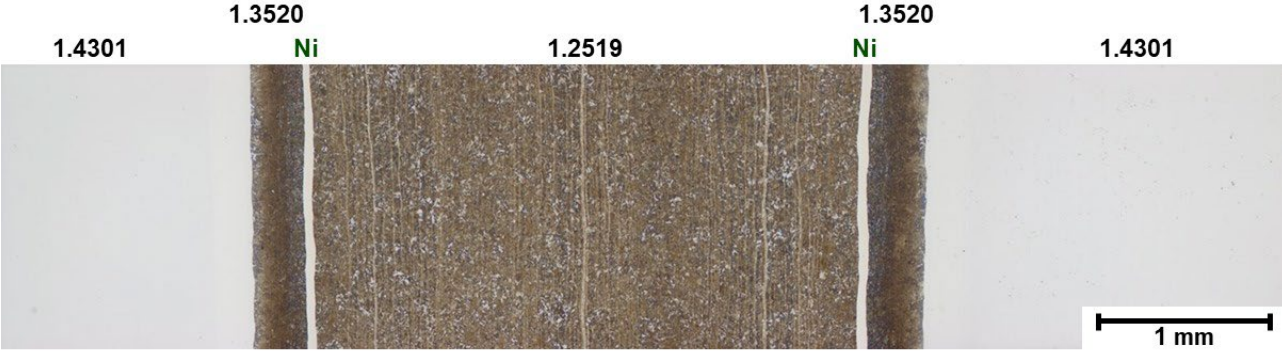

Fig. 1 Composite after forging the starting sheets and before forging to final knife blade dimension. Overview images of the cross-section etched with Nital.

Metallography. The samples were sectioned with a cut-off machine and warm embedded in phenolic resin. The preparation started with a plane-grinding disc, followed by polishing with 9 – 1 µm diamond suspensions. To reveal the microstructures 3 % Nital, conc. Murakami and Lichtenegger-Blöch etchants were used.

The polished samples were investigated by a light optical microscope (LOM), scanning electron microscope (SEM) and with energy dispersive X-ray analyses (EDX).

Vicker´s Microhardness measurements HV0.1 were performed.

Results and Discussion

Microstructure of tool steel 1.2519. After Nital etching the tool and the heat treatable steel were attacked selectively, austenite and Ni show no reaction (see Fig. 1). At higher magnifications in the core a bainitic-martensitic microstructure and some fine-pearlite (sorbite) respectively martensite with retained austenite is visible (Fig. 2a, b). Special mixed carbides of W, Cr, V and Fe are dissolved. Microhardness values between 340 and 530 HV0.1 were measured. By etching with Nital and Murakami at the Ni-tool steel interface a white unattacked zone is visible, i.e. Ni acts as a carbon barrier. Ni itself reacts faintly with Murakami and shows a coarse grain structure. Near the interface the tool steel microstructure consists of bainite, martensite and fine pearlite (Fig. 2c).

Microstructure of Ni intermediate layer. Again, Ni acts as a carbon barrier and after Nital-Murakami etching the interfaces between Ni and the high carbon steels are bright, unattacked zones (Fig. 3a). The Ni layer is faintly etched by Murakami and more intensely by Lichtenegger-Blöch (Fig. 3b) and the coarse grain structure is revealed in both micrographs. The Microhardness was 170 HV0.1.

In Fig. 4 overview images in LOM respectively in SEM are shown. Notable are the slightly increasing peaks of tungsten in the Ni layer and the Ni peak at the interface between heat treatable and austenitic steel. This interface will be discussed in the following paragraph.

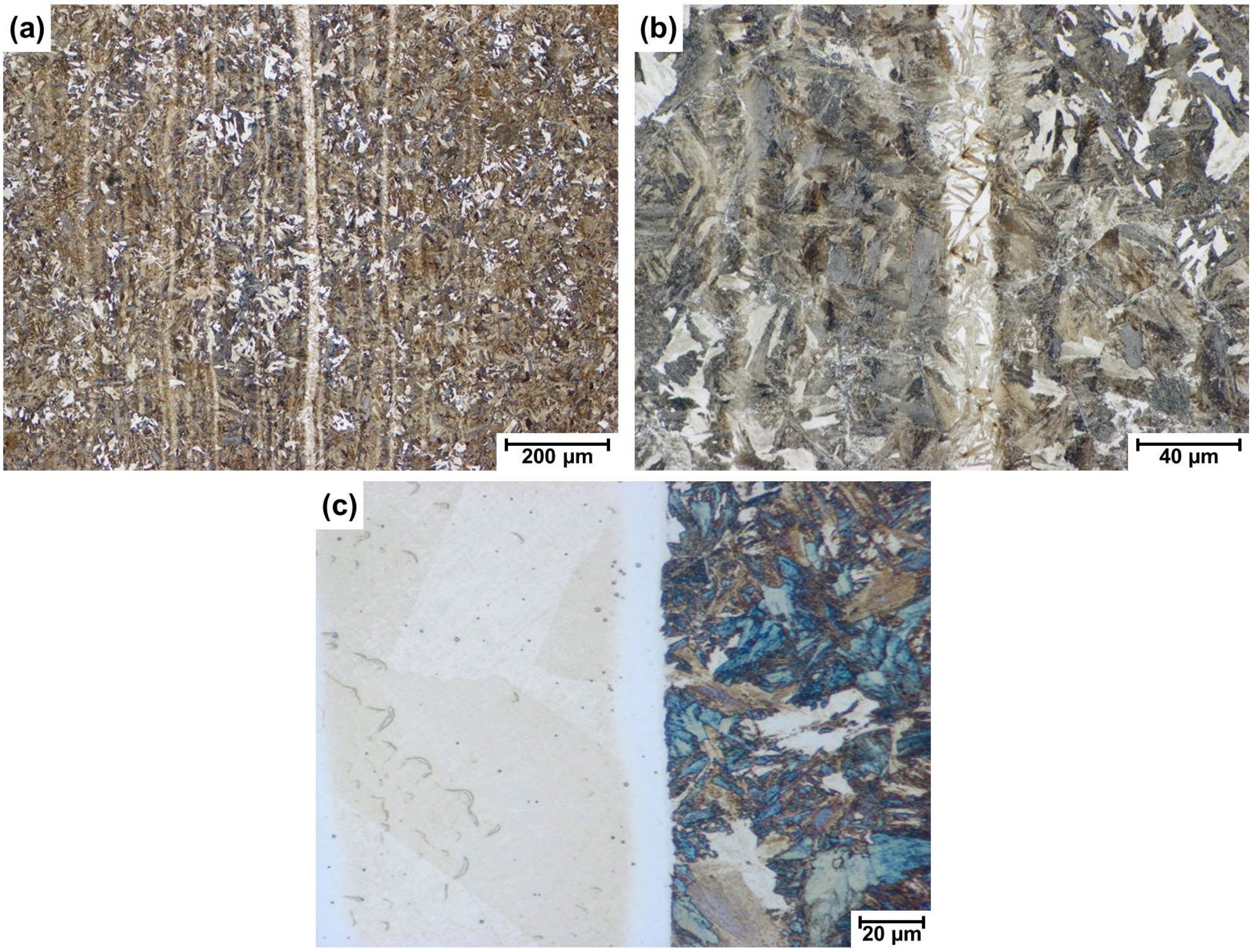

Fig. 2 Tool steel and interface with Ni. (a) core, (b) detail of (a), Nital etched, (c) Ni-interface-steel, Nital and Murakami etched.

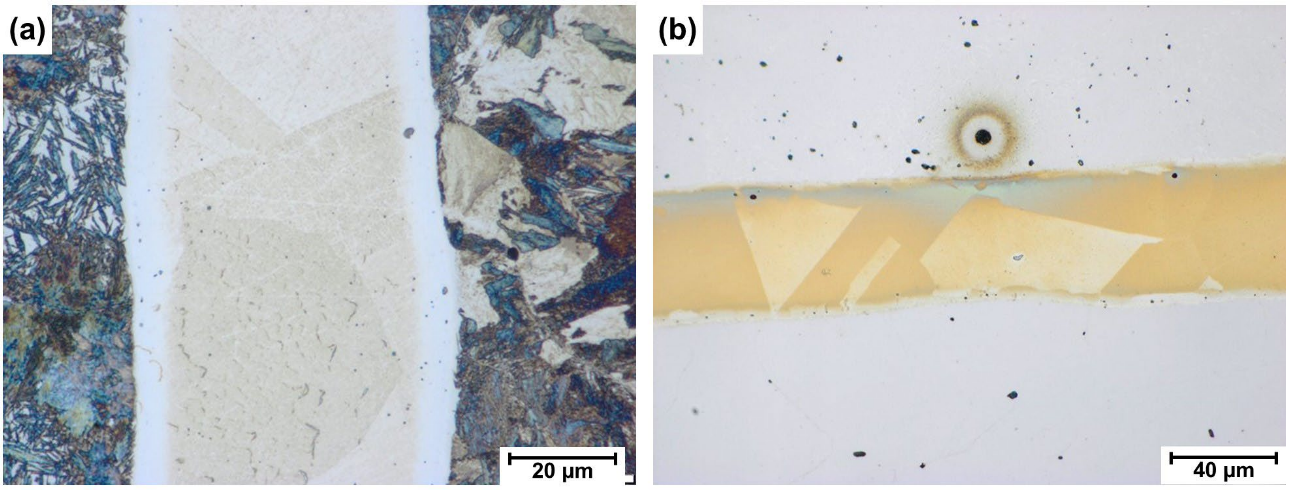

Fig. 3 Ni-steel interfaces. (a) heat treatable steel – interface – Ni – interface – tool steel, Nital and Murakami etched, (b) Ni layer colored by Lichtenegger-Blöch.

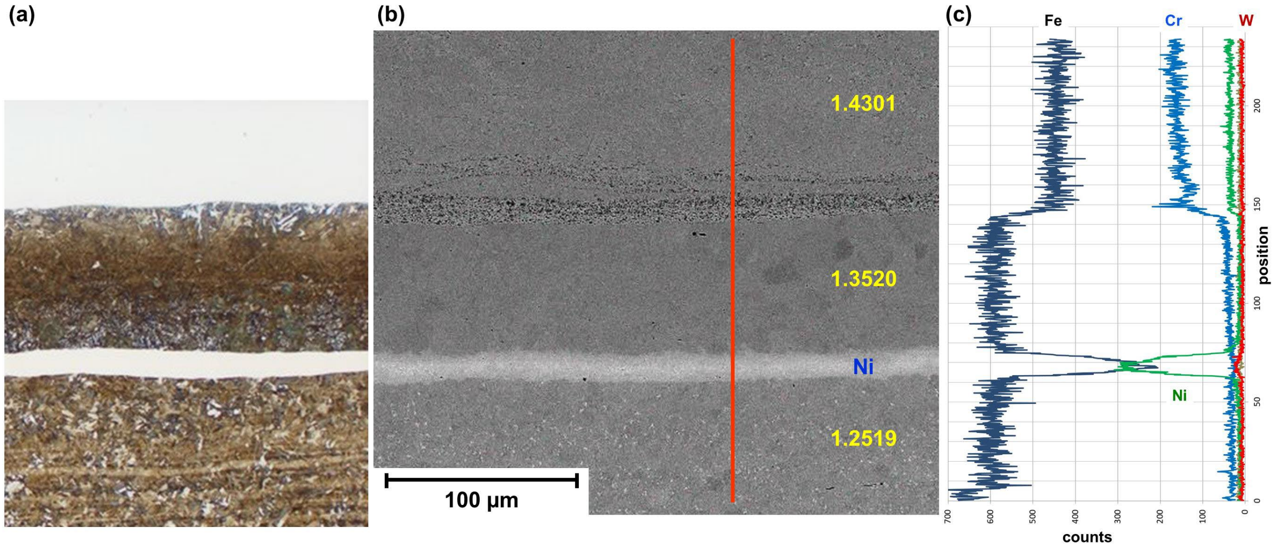

Fig. 4 Overview images of the cross section. (a) Nital etched in LOM, (b) SEM micrograph and (c) corresponding SEM-EDX line scan.

Microstructures and interfaces of steel 1.3520 and 1.4301. The basic microstructure of the heat treatable steel is martensite and chances at both interfaces with the austenite respectively Ni (Fig. 5). Thus, microhardness values between 320 – 570 HV0.1 were measured.

At the austenite-heat treatable steel interface an upper bainite and ferrite can be distinguished to a depth of approximately >40 µm (Fig. 5a). At the interface with Ni coarse martensite with retained austenite was formed (Fig. 5b, left side), i.e. austenite stabilization by Ni.

Carbon diffusion from the heat treatable steel to austenite took place and appropriate gradients, detected (Fig. 6a, b).

Due to the high Cr content in austenite, the diffusing carbon produces Cr-containing carbides, primarily at the austenite grain boundaries (Fig. 6b, c). The actual composition of the carbides could not be determined, but based on the etching behavior and the literature it should be $(Cr, Fe)_{23}C_6$ carbides [12].

Microhardness values between 210 – 300 HV0.1 were measured in the austenite near the interface.

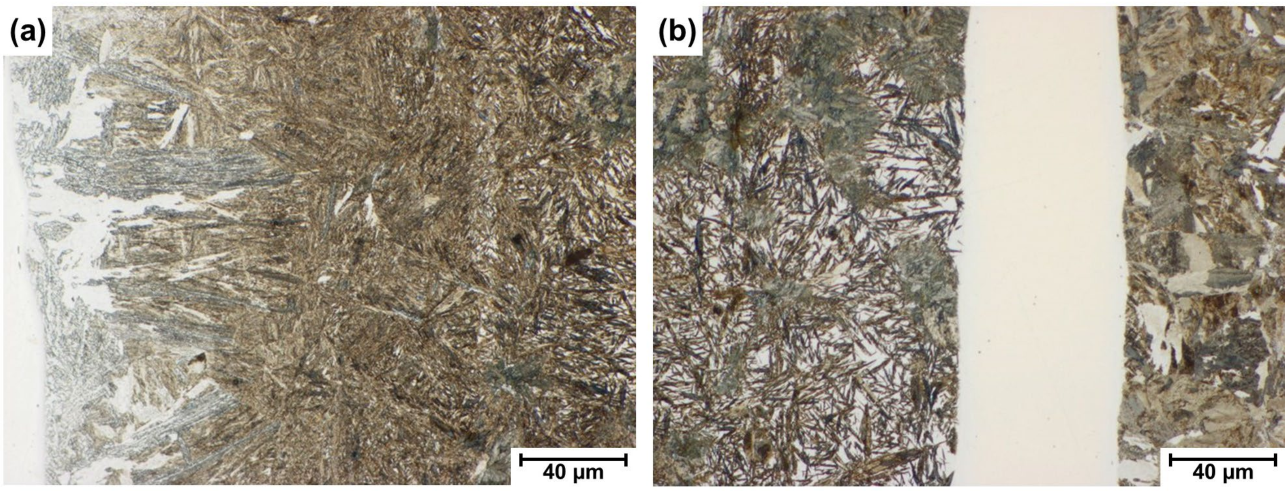

Fig. 5 Heat treatable steel. (a) austenite interface and core, (b) heat treatable steel interface with Ni, Nital etched.

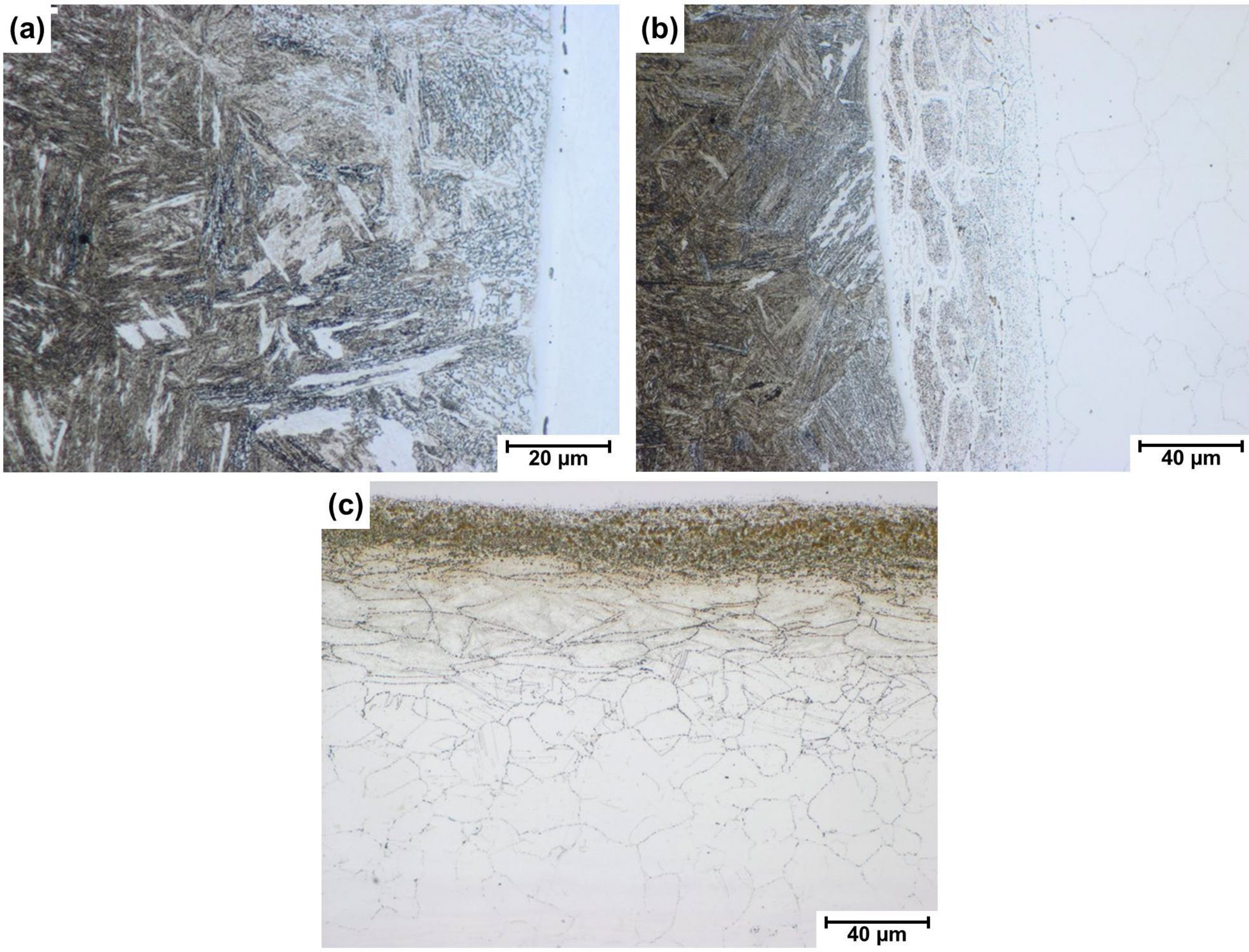

Fig. 6 Heat treatable steel and austenite. (a) heat treatable steel and interface to austenitic steel, Nital etched, (b) heat treatable steel and interface to austenite, Nital and Murakami etched, (c) interface and austenite, Murakami etched.

Summary

Forging of Ni and different steel sheets results in a composite material which was used for the manufacture a knife blade (San Mai technique).

The various steel compositions – especially the C content – leads to C diffusion and therefore the microstructure is influenced.

From the heat-treatable steel C diffuses via the interface in the austenitic material forming a region with a lot of (Cr, Fe)-carbides followed by the precipitation of grain boundary carbides.

This C depletion changes the microstructure of the heat treatable steel from martensite to bainite.

At the interface heat treatable steel - Ni coarse martensite and retained austenite is formed, because Ni stabilizes the austenite.

The interaction of Ni and the tool steel leads to a W diffusion in Ni. The basic microstructure is a mixture of martensite, bainite, fine pearlite and coarse martensite with retained austenite. Special mixed carbides of W, Cr, V and Fe are dissolved.

Ni acts as a carbon barrier and the interfaces between Ni and the high carbon steels are bright, unattacked zones. The Ni layer is faintly attacked by Murakami and more intensely by Lichtenegger-Blöch and Ni has a coarse grain structure.

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