Metallurgical phase transition reveals pattern in new decorative steel

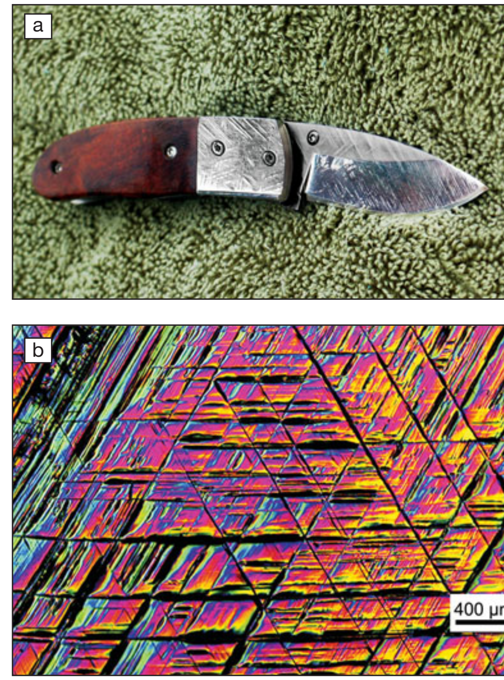
A new type of decorative steel has been formed using a process that differs from that used to generate ancient or modern patterned steels. The metal exhibits an almost infinite variety of three-dimensional (3D) patterns, thus enabling bladesmiths and jewelers to create unique knives and jewelry.

More than 2000 years ago, sword makers valued a patterned steel called Damascus steel for its hardness and ability to hold a sharp edge. However, the process used to make Damascus steel was lost around the mid-18th century. Modern metallurgical engineers have attempted to reproduce Damascus steel in the lab, discovering that aggregates of iron carbide created the wavy patterns in the material. However, the methods that were used to form the original Damascus steels remain under debate.

Early swordsmiths and modern knifemakers have created patterned steels by first forging layers of different metals, commonly iron and steel, together to make a solid billet. They then repeatedly folded and reforged the billet, creating a layered material that revealed the contrasting colors of each component. Modern knifemakers use the patterned steel to enhance the aesthetic appeal of their custom knives.

As recently described in the *Journal of Alloys and Compounds* (doi:10.1016/j.jallcom.2016.08.327), Lynn A. Boatner of Oak Ridge National Laboratory and his colleagues have discovered a new type of patterned steel. This advance was made accidentally, while working with single crystals of steel containing 70 wt% iron, 15 wt% nickel, and 15 wt% chromium. Instead of heating the material, as they had in past research, the researchers decided to cool the metal by plunging it into liquid nitrogen. When they removed the metal, they noticed a 3D pattern that extended throughout the material.

At very cold temperatures, this steel undergoes a phase transition from the austenitic phase, a face-centered-cubic crystal structure, to the martensitic phase, a tetragonal body-centered crystal. As the material warms to room temperature, only certain domains return to the original austenitic phase. The remaining martensitic phase creates the raised 3D pattern.



(a) A custom knife made with a new type of decorative steel. Credit: Lynn A. Boatner. (b) Optical interference-contrast micrograph showing the symmetry of the (111) face of a cryo-quenched single-crystal 70 wt%Fe-15 wt%Ni-15%wt%Cr alloy. Credit: *Journal of Alloys and Compounds*.

The pattern in the steel reveals the symmetry of the crystallographic orientation of the austenitic phase. Cutting the material along the (111) face of the austenitic phase generates a triangular pattern after cooling, while a rectangular pattern reveals the twofold symmetry of the (110) face. Slicing the steel along random crystallographic orientations creates an effectively infinite variety of patterns, Boatner says.

To work with this metal, bladesmiths first remove metal to create the shape they desire, then they smooth and polish it, and finally plunge it in liquid nitrogen. Polishing the metal after cooling it would remove the raised pattern.

Jeffrey Wadsworth, president and CEO of Battelle Memorial Institute, has researched the metallurgy of both patterned steels and genuine Damascus steels. He says this transformation is unique for solid-state metallurgical transformations and is an innovative way to create a patterned steel.

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