CLASS 1

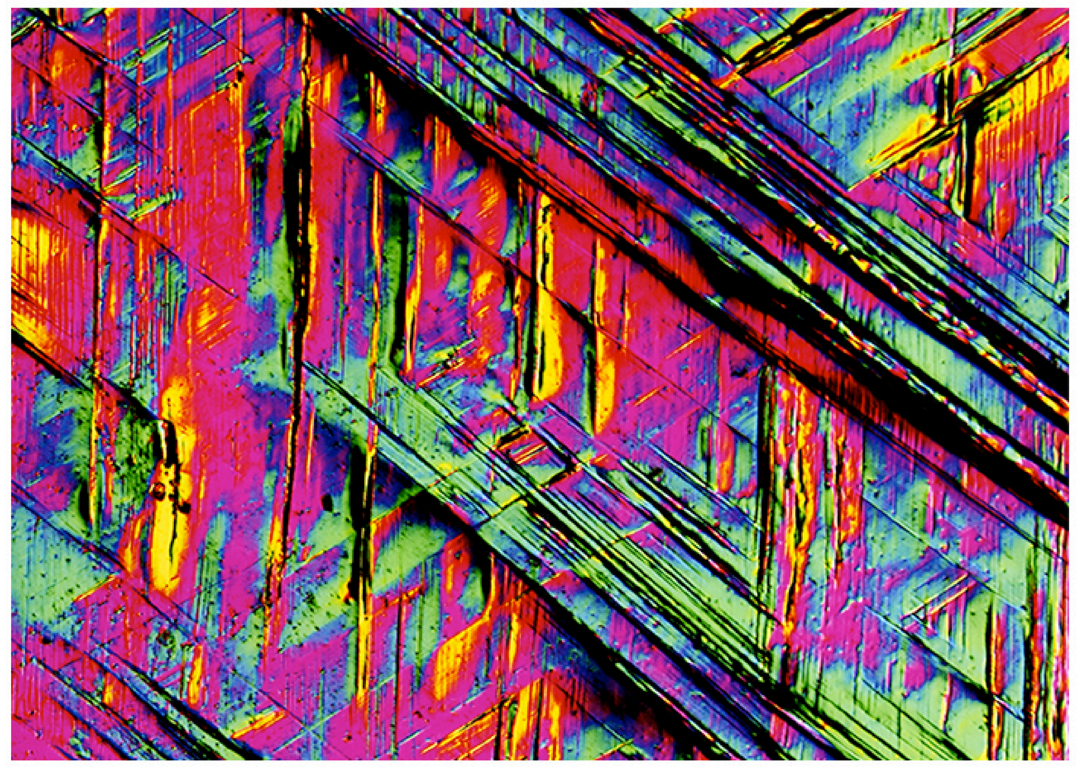
A New Decorative Steel:
Cryo-quenched Fe-Ni-Cr Alloy Single Crystals

Background

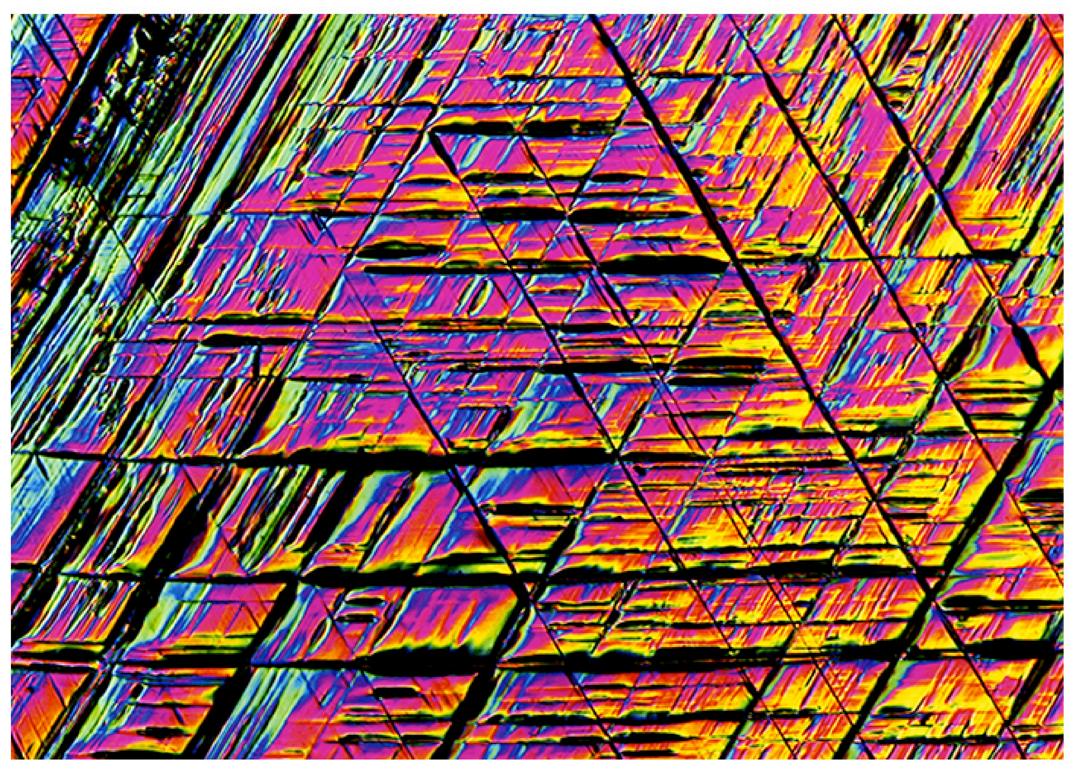
The origin of the first decorative steel (so-called Damascus steel) can be traced back more than two thousand years. The process of producing this steel was based on the use of a material known as wootz steel whose production originated in India - with the material subsequently shipped to Damascus and the Middle East where it was used to manufacture "patterned" swords and other edged weapons of exceptional quality. Sometime around the middle of the 18th century, the original Damascus sword-making process was lost.

More recently, a process known as "pattern welding" has been applied to form decorative steels that are also referred to as Damascus steel - but that, in fact, differ significantly from the ancient Damascus material. Pattern welded steels are produced by first forging different types of steel and iron together followed by repeated folding and forging of the billet to produce multiple layers of the component materials. The resulting decorative pattern arises from contrasting colors of the various "multiple" layers of the forged composite steel.

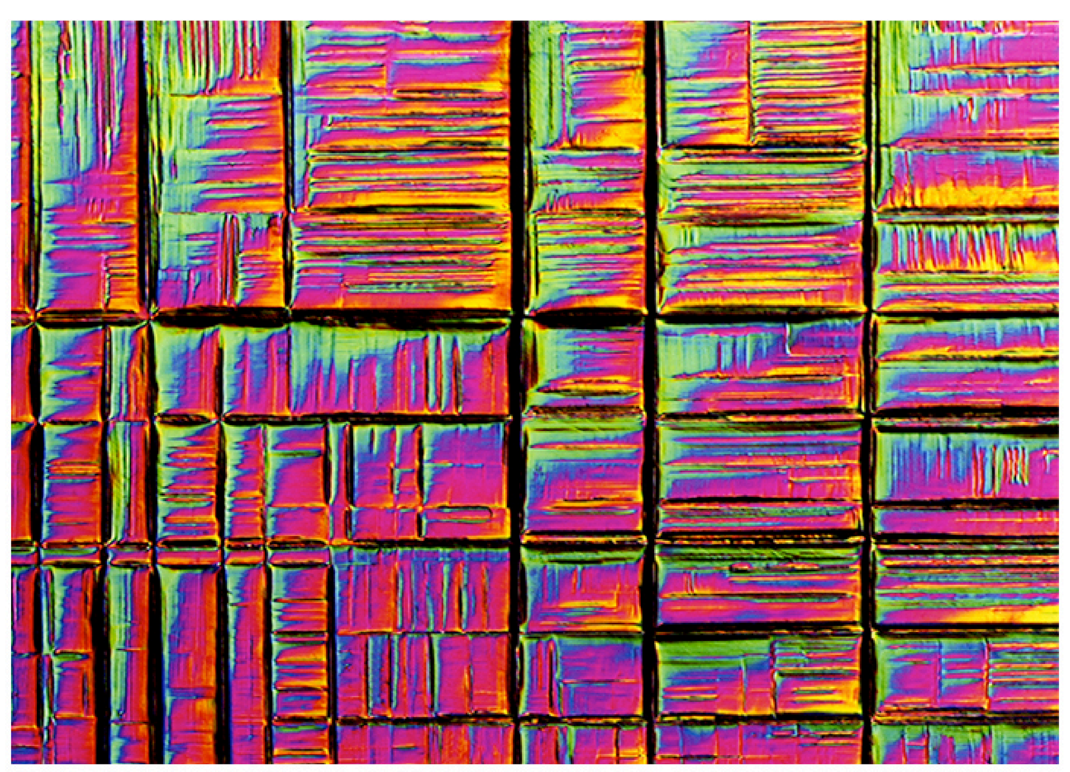
A new decorative steel has been developed as described here that is markedly different from either the original Damascus steel or the more recent "pattern welded" steels. The decorative steels described here are different in terms of: the metallurgical production process, the physical mechanism responsible for producing the decorative pattern, and both the symmetry properties and optical effects that produce the decorative features. This decorative steel is produced by first growing single crystals of a 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy, cutting slices of the material (usually along oriented crystallographic directions), polishing the sample surfaces, and then cryogenically quenching the material through the martensitic phase transition that occurs at -190 K for this composition.



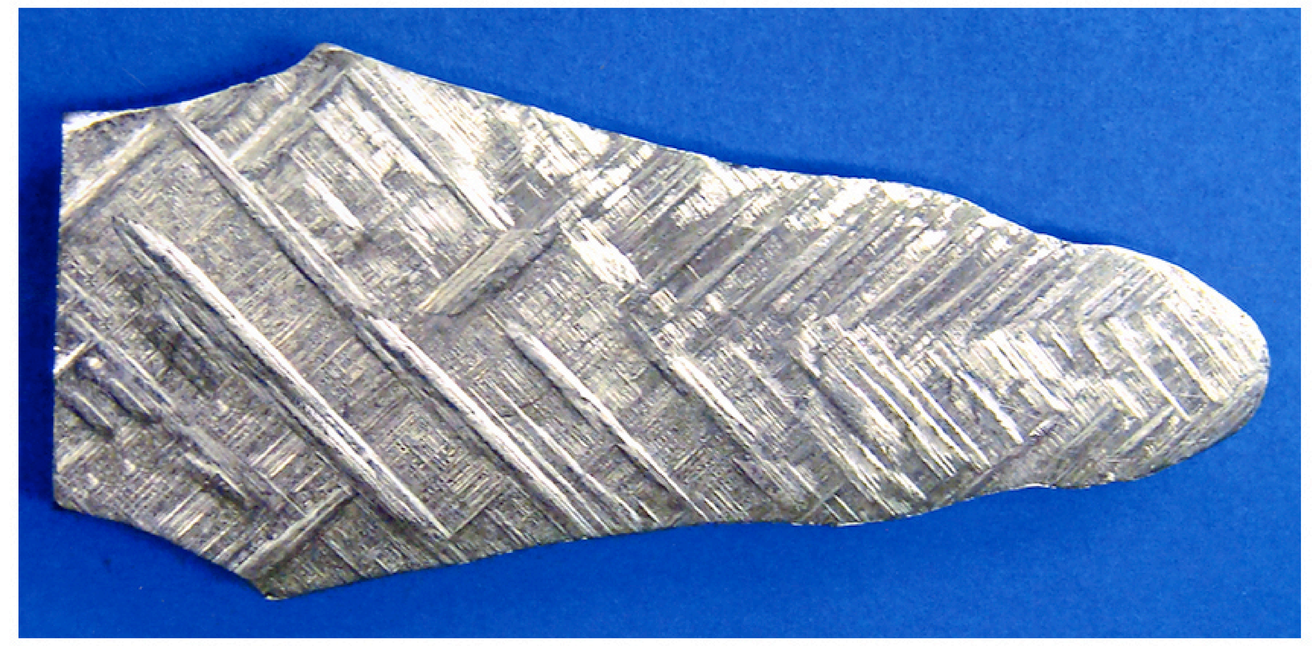
Optical interference contrast micrograph illustrating the symmetry of the decorative pattern formed on a (110) surface of a single crystal 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy (100X magnification).



Optical interference contrast micrograph illustrating the symmetry of the decorative pattern formed on a (111) surface of a single crystal 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy (100X magnification).



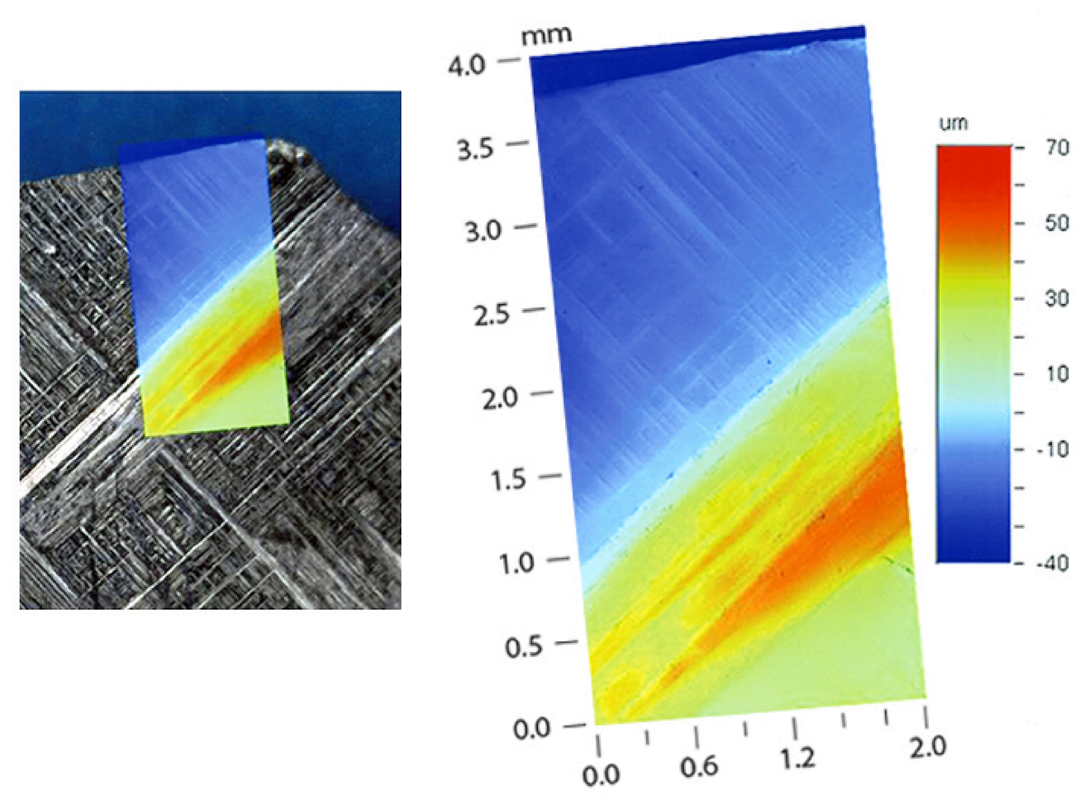
Optical interference contrast micrograph illustrating the symmetry of the decorative pattern formed on a (100) surface of a single crystal 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy (100X magnification).



Example of the decorative pattern formed on a (100) surface of a 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy single crystal. The sample is ~6.0 cm in length.

Sample Preparation

The decorative steels described here are prepared by using Laue back-reflection X-ray methods to orient the 70wt%Fe-15wt%Ni-15%wt%Cr austenitic single crystals. The crystals are then cut using an electric arc discharge machine to expose crystal surfaces that are usually chosen perpendicular to either the [100], [110], or [111] directions of the fcc material – although non-principal orientations can be employed as well to produce different decorative patterns . The crystallographically oriented surfaces are lapped and given a final polish using a colloidal silica suspension. The oriented crystals are then transformed from the austenitic to the martensitic phase by immersion in liquid nitrogen and subsequently returned to room temperature. This phase transition is highly hysteretic. The relatively high relief surface patterns formed by the intersection of the retained austenite lathes with the {110}, (111), and (100) austenitic crystal surfaces are shown here in the form of interference-contrast color micrographs that are ideally suited to revealing the details of the 3-D surface-relief features that result in the decorative effect.



Overlay of optical image with overlayed 3D profile map of a 4x2 mm fragment. The magnitude of the surface relief is determined using optical profilometry (WYKO NT 9800 Veeco Instruments Profilometer). The photographic image was taken with DSLR and 50 mm macro lens. The dimensions of the 2-D scanned area are indicated on the x and y axes and the surface relief is indicated by the accompanying color-coded scale on the right hand side.

Growth of 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy single crystals

Single crystals of the 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy were grown by means of the Czochralski or "crystal pulling" technique. An oriented single-crystal seed was utilized, and the melt from which the crystal was "pulled" was contained in a high-purity alumina crucible. Radio frequency induction heating was employed, and the growth process was carried out using a Varian Multi-purpose crystal growth unit. A growth ambient consisting of purified argon at a pressure slightly in excess of one atmosphere was maintained in the growth chamber during the crystal-pulling and ensuing cool-down operations. In a production setting, single crystals of alloys in this composition range could also be manufactured using the Bridgman growth technique that is currently used to produce high-performance single crystal turbine blades.

Examples of the use of the decorative steel in:
(Top). *The blade of a folding knife made by custom knife maker, Ronald Hewitt, of Adel, Georgia. The bolsters of the knife are titanium and the scales are olive wood.*
(Bottom). *A Western-style belt buckle that incorporates a central medallion of the decorative 70wt%Fe-15wt%Ni-15%wt%Cr austenitic alloy.*

Summary

A new decorative steel with applications spanning cutlery, jewelry, and numerous other similar uses is described. The process for forming this material is unlike that of any of the fabrication methods utilized in making the original Damascus steels or "pattern-welded" (currently so-called "Damascus") steels. The decorative aspect arises from a three-dimensional surface pattern that results from cryogenically quenching polished austenitic alloy single crystals into the martensitic phase that is present below 190 K. No forging operations are involved – the mechanism is entirely based on the metallurgical phase properties of the ternary alloy. The symmetry of the decorative pattern is determined and can be controlled by utilizing the symmetry properties of the alloy single crystal. In addition to using cuts along principal crystallographic directions an effectively infinite number of other cuts can be utilized. Each decorative pattern formed as described here is distinct and unique.

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