

Metallography and Microanalysis of Pattern-welded Composite Steels

Thomas Nizolek, Arlan Benscoter, M. R. Notis

Department of Materials Science and Engineering, Lehigh University, Bethlehem, PA 18015

Throughout history, ferrous composite materials have been created by forge-welding small pieces of metal together. Although this process was difficult, it was often necessitated by the high value of steel or the inability to obtain large single pieces of metal. Early smiths saved their steel scraps and would eventually forge-weld them together to create a new bar of steel. Early examples of pattern-welded steel are found in the sword blades of the Merovingian Franks and the Vikings [1]. The Vikings relied primarily on bog iron for material for their swords, but many of the refined pieces were too small to be useful. The ability to create composite steel blades provided a solution to this problem and also created a better product. As a result of their composite nature, these blades were stronger and less prone to critical failure in battle because crack propagation would be deterred by the lamellar structure of the blade. Secondly, the blades had exceptional cutting ability due to the microscopic serrations created by the different wear rates of the steels. An additional benefit was that composite steel swords displayed a unique patterned appearance due to the different compositions of the original steel scraps. When high carbon steel was combined with low carbon steel and the resulting composite was exposed to a mild acid or prolonged corrosion, the individual layers reacted differently and a pattern was exposed. This appearance not only created unlimited variety and beauty in the blades, but also allowed a bladesmith's customer to verify that a blade was of the highest quality.

Recently there has been renewed interest in pattern-welded steel due to the work of bladesmiths like Rob Hudson, Daryl Meier, and Bill Moran. While it is not as important that knives be made of composite steels now that inexpensive high quality steels are readily available, the beauty and improved resistance to cracking draw the attention of knife connoisseurs worldwide. Although the materials have changed slightly, most pattern-welded steel is still produced using the ancient techniques of the Vikings (Fig. 1). Instead of relying on the different carbon content of the steels to create a pattern, modern smiths usually use a combination of high carbon low alloy steel and low carbon low nickel steel. The striking patterns evident in these modern composite blades are due to the ability of the nickel-bearing layers to resist the etchant (Fig. 2).

A variety of samples composed of W-2 and 203-E steel layers have been studied. They were all made in the traditional manner, the forged products ranging from four layers per centimeter to two hundred layers per centimeter. These samples have been examined to determine the effects of layering and forge-welding on their microstructure. The rate and extent of carbon diffusion through the layers has also been studied. Several of the two hundred layer samples have been further forged to an edge and have been differentially hardened to create a hard edge (60 Rockwell C) while leaving the spine of the sample softer (55 Rockwell C). The hardness differential was created by coating the spine of the knife in an insulating ceramic slurry before quenching - a process similar to the manner in which the Japanese hardened samurai swords. Finally, Charpy impact specimens were machined from samples comprised of a varying number of layers. Impact data were gathered from these samples and the effects of the different number of layers on the material's toughness were observed. The fracture zones have also been examined using scanning electron microscopy.

References:

- [1] C. S. Smith, A History of Metallography, Univ. of Chicago Press, Chicago, 1960



Fig. 1a) Heating a small piece of steel in a coal fire



Fig. 1b) Forging



Fig. 1c) Forging out a pattern-welded steel bar



Fig. 1d) Forge-welding two 64 layer pieces together to create a 128 layer bar



Fig. 2) 64 layer pattern-welded blade made of W-2, 203 E, and iron-nickel meteorite. Wrought iron guard and end cap, with snakewood handle. Forged by Tom Nizolek.