

GENERAL COMMENT

The non-ferrous alloys and the austenitic steels in commercial use appear to be no worse in their combination of strength and toughness (however these properties are evaluated) at subnormal temperatures than they are at room temperature.

Ferritic steels and irons, likewise, appear to be no worse engineering materials at subnormal temperatures when strength and toughness are evaluated by usual static methods upon unnotched specimens; indeed the increased strength due to decrease in temperature is accompanied by less loss of ductility than when comparable increase in strength is produced by other means at the command of the metallurgist. But when these ferritic materials are required to deform at low temperatures under conditions of restraint against deformation, as in the presence of a notch, or when the force is applied with extreme rapidity, some of them show extreme brittleness, fracturing without deformation rather than showing plasticity. Without a notch, or some equivalent localization of stress, they are tough at any temperature; with the notch, they are brittle at some sufficiently low temperature. More accurately, they become "notch-brittle" at some "transition temperature."

Commercial use of ferritic materials, like some structural bessemer steels and ordinary rail steels, which are notch-brittle at ordinary temperature, shows that even notch-brittle materials need not be barred from all engineering uses, and if all notches or other "stress-raisers" could be avoided, they might not be unsafe for any use. But notches cannot be avoided in much engineering practice,

so the development of steels of high notch-toughness at whatever low temperature the service demands, has been made necessary.

Proper melting and deoxidation practice and proper heat-treatment (usually a simple one like normalizing) for the production of fine-grained low-carbon steels allow these steels to be given considerable notch-toughness at least down to the lowest natural winter temperatures. But these steels, though tough, are not especially strong. To get a better combination of strength and toughness, and particularly to get the best combination at lower, artificially produced temperatures, not only grain-size control but also alloying, and perhaps more complex heat-treatments (double normalizing and drawing, quenching and tempering) have to be resorted to. When, as is often the case in the structures that must operate at low temperatures, quenching and tempering cannot be used, or when the mass precludes proper hardening on quenching, the alloying needs to be such that normalizing will serve.

A variety of mild-alloy steels has been developed in which certain alloying elements are used that go wholly into the ferrite, like Ni and Cu, or that, when the carbon is not too high, go at least partly into the ferrite, like Cr and Mo. In the case of Ni, that may be the only alloying element; the others generally, and Ni very commonly, are used in combination. For the very lowest temperatures, generous amounts of Ni appear indispensable.

Whatever the chemical composition of the steel, its low-temperature notch-

toughness appears to be vastly improved when the steel is fine-grained in its actual condition of use, whether the grain size is made refined through the deoxidation practise or by heat-treatment. This apparent correlation of grain size and low-temperature notch-toughness is, however, only a first approach to the truth, because, as Herty and McBride (14) and other investigators have shown, some fine-grained steels that have been overheated become notch-brittle, even though there has been no grain growth.

Moreover, heat-treatments that do not affect the microstructure at all, such as low-temperature draws, or stress-relief anneals, may profoundly affect the low-temperature notch-toughness. Nor do all supposedly like steels respond similarly to such treatments. The conclusions seem inescapable that solution and precipitation of nonmetallics, or of particular metallic compounds (probably usually of submicroscopic size and hence not amenable to direct demonstration of their presence or absence), must be going on and that the usual methods of making a steel fine-grained tend to create desirable conditions of the nonmetallics. The non-metallics rather than the grain size, may be the primary factor.

Thus the methods of control now used may only be indirect in their action. Perhaps some day there may arise a sufficient understanding of the real mechanism to make control more certain.

That control is not yet very certain

is indicated by the comments of Armstrong and Gagnebin (33) who remark that "the present state of the art does not permit use of composition, grain size, and heat-treatment as criteria for resistance to impact, which indicates the advisability of subjecting each lot to test, particularly when service involves temperatures below -100°F. "

In discussion of Armstrong and Gagnebin's paper, Rosenberg remarks that "impact tests secured on a single heat of steel are more or less peculiar to that individual heat, and will not necessarily be duplicated by another heat of the same type of steel. Individual heats apparently have what may be termed an 'inherent' resistance to impact within certain limits, and this is dependent upon factors not at present recognized. . . . The practice of evaluating the impact resistance of any material, particularly at low temperature, from the results of even a comprehensive series of tests upon an individual heat of that material may lead to erroneous conclusions."

The transition temperature, at which the type of fracture of a notched-bar specimen of a steel shifts from tough to brittle, is plainly a criterion through which differences not otherwise obvious might be made evident; so, low-temperature notched-bar testing might be a useful tool in the constant search for the underlying causes of the "inherent individuality" of a particular heat of steel, even though that heat might not be destined for low-temperature service.