variety of systems. The results will be published elsewhere.

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Cleavage Patterns Disclose "Toughness" of Metals[1]

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A recent communication in this journal (*1*) called attention to the microscope technique referred to as "fractography," particularly with respect to its usefulness in disclosing subtle structural deformities within crystals relating to their history and mechanism of growth.

Now it is found that the cleavage patterns studied by fractography similarly contain marked features directly related to the "toughness" of the crystal. In the case of engineering materials, particularly metals, "toughness" is a most important property, and one which has escaped satisfactory measurement to date. That is, values for tensile strength were long ago found to be inadequate as a measure of structural stability if the material was stressed nonaxially, such as by bending or by lateral impact, and auxiliary values for ductility, hardness, and impact resistance were subsequently added to specifications. Experience during the recent war, however, emphasized the fact that the true measure for "toughness" still does not stand among any of these values. A phenomenon in point is that in which apparently identical steels used for ship-plate served in a satisfactory manner in one case, but in the other failed suddenly, and often disastrously, in a brittle fashion, indicating some radically inferior property of the metal not yet recognized. Among these experiences are some 4,000 reported failures on welded ships, some 40 of the vessels having broken completely in two.

Recently it has been determined by metallurgists working on the problem, principally under the sponsorship of the U. S. Navy, that this difference in "toughness" can be demonstrated in the laboratory by conducting certain standard tests over a range of temperature—for example, fracturing by impact a series of notched specimens at progressively lowered temperatures. The energy absorbed by the specimen commonly has an acceptably large value when fractured in the high range of ordinary temperatures; but, as the temperature lowers toward and into the freezing range, certain steels rapidly lose their resistance to fracture. The narrow temperature range in which this defection appears is currently referred to as the "transition temperature"; and the phenomenon shows simultaneously as a loss in resistance to propagation of fracture, a failure of the crystal's slip elements to provide the malleability which characterizes good metal, and a change in the macro-appearance of the fracture surface from ductile-fibrous to brittle cleavage.

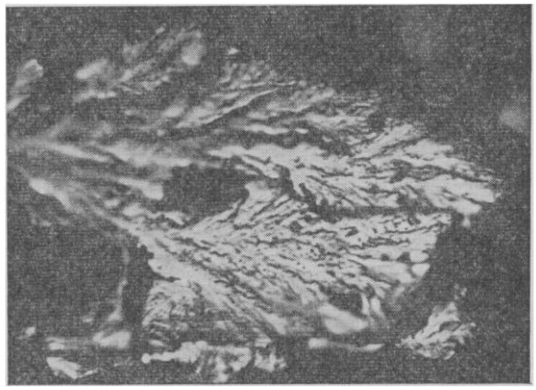

FIG. 1. *Pattern of "toughness."* A cast steel containing 7.70% chromium and 0.10% carbon, air-cooled from 875° C to produce martensite (× 2,000).

In this laboratory the cleavage facets of individual grains within structural steels have been examined at high magnification; and the discovery of a cleavage pattern having marked relationships with "toughness," as determined both by mechanical testing and by actual service, provides the basis for this communication.

The cleavage facet shown in Fig. 1 is in a martensitic structure, which is known to be "tough." The pattern accordingly discloses a rough surface visibly indicating an almost continuous interruption of cleavage traverse.

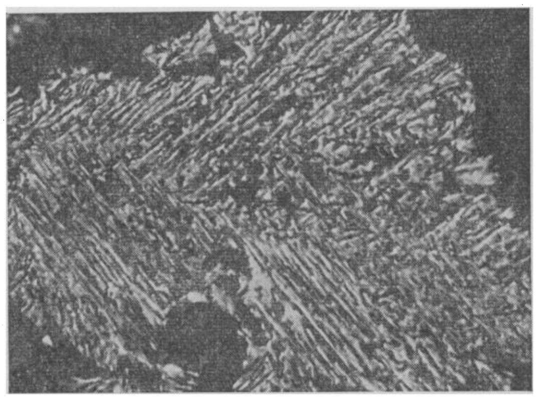

FIG. 2. *Pattern of weakness.* Type 446 stainless steel, containing 26% chromium and 0.15% carbon, water-quenched from 850° C and embrittled by heating for 200 hrs at 475° C (× 850).

Crystallographic markings are absent. The grain size is also small, imposing an additional hindrance by requiring frequent change in the general plane of traverse as the separation proceeds from grain to grain. In this steel, cleavage is therefore resisted both transgranularly and intergranularly.

The fractograph of another chromium-containing steel (Fig. 2) shows a markedly different pattern. This is a

[1] From research conducted in the laboratory of the senior author under contract with the Office of Naval Research.

steel notoriously lacking in "toughness." The cleavage traverse here is relatively flat and uninterrupted across the entire grain; the grain is relatively larger than the preceding, thereby reducing the factor of grain-boundary hindrance; and crystallographic markings, particularly at

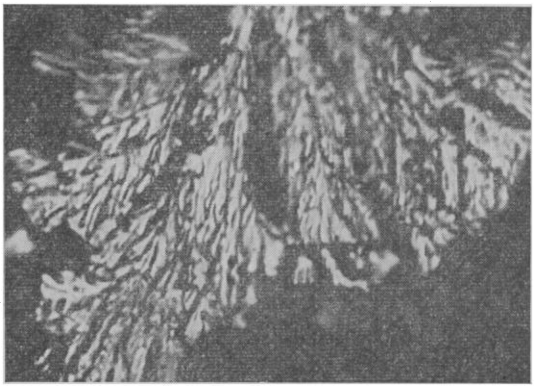

FIG. 3. *Pattern of "toughness."* Standard unalloyed Steel Q from Navy tests, known to be relatively tough for steel of its class (× 1,250).

90°, are in strong evidence. This is accordingly a pattern of cleavability, or weakness—specifically, a low resistance to notch-impact.

Transferring attention now to unalloyed steel, one finds in Figs. 3 and 4 the fractographs of two of the standardized mild steels widely studied with respect to their serviceability for ship-plate. In Fig. 3, Steel Q, which contains 0.22% carbon, 1.13% manganese, and 0.05% silicon, shows a "toughness" pattern suggestive of that shown in Fig. 1. In this case the "toughness"

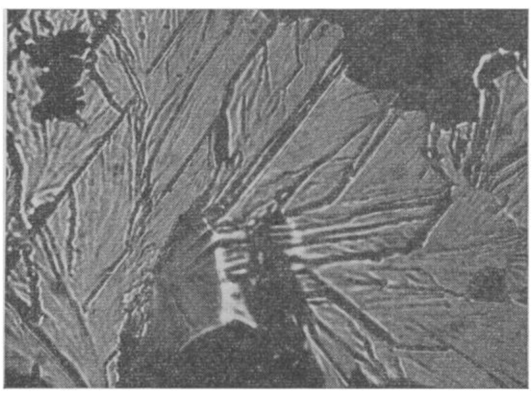

FIG. 4. *Pattern of weakness.* Standard unalloyed Steel E from Navy tests, similar in composition to Steel Q, but known to lack toughness (× 975).

has also been similarly derived, by heat treating in a manner to produce martensite.

In conformity with the information in the fractograph, mechanical testing of this steel in other laboratories has proved it to be "tough" relative to other steels of its kind. A relatively low temperature is required for transition from a tough fracture to a brittle one.

A fractograph of the standard Steel E (Fig. 4) shows a decidedly different pattern, more in keeping with the pattern in Fig. 2. It is similar in composition to Steel Q, except for a manganese content of only 0.33%; but it differs considerably in structure in that its condition is "as-rolled"—hence, not martensitic. The cleavage traverse is flat, expansive, and but little interrupted, and crystallographic markings are much in evidence. In conformity with this fractographic indication of inferior cleavage characteristics, Steel E is known to compare poorly with Steel Q, experiencing transition from tough to brittle cleavage at such relatively high temperatures that it prohibits recommendation for the types of service in question.

These patterns, of course, are strictly comparable only among materials of a defined class. Other fundamental factors—specifically, alloy content—greatly influence strength and toughness; and a pattern for mild steel cannot be compared directly with one for an alloy steel, as a rating of toughness, without taking into account the fundamental difference in atomic cohesion. As will be shown in a report soon to be issued, an alloy steel with an unfavorable cleavage pattern may still show greater toughness than an unalloyed steel with a favorable pattern, simply because the atomic matrix of the alloy steel is more strongly coherent.

Perhaps the principal importance of the evidence stands in its demonstration of an active structural factor within the individual grain which impedes cleavage in one case much more strongly than it does in another, and which therefore accounts for subtle differences, not previously understood, among structural materials of a given class.

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Deposition of Protein in the Liver Following Intravenous Injection of an Amino Acid Mixture (Hydrolyzed Protein) and Glucose[1]

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Although tissue protein is normally synthesized from food protein, there has been no demonstration by direct *in situ* study that this is possible with an amino acid mixture injected intravenously as the sole source of protein food. Chemical and histological evidence was reported from this laboratory (*2*) that protein is deposited in the cytoplasm of protein-depleted hepatic cells by the administration of a high protein diet by mouth. Evidence is presented herewith to show that the same

[1] Aided by a grant from the Commonwealth Fund.