For 1020 steel, shot peening markedly reduced the temperature of transition from ductile to brittle failure, as measured by slow bend tests of notched specimens.

Effect of Shot Peening on the Brittle Transition Temperature

ONE of the useful properties of many metals is their ability to deform permanently before fracture. This is referred to as ductility, and the opposite behavior is called brittleness. These are not intrinsic properties; under suitable conditions a metal may pass from one state to the other. Unfortunately there is no single test or measurement that will uniquely determine this composite property. The condition of mechanical stability is defined by the following parameters: *(a)* composition and structure of the material, *(b)* state of stress (triaxiality), *(c)* strain rate, and *(d)* testing temperature. Because of the dependence on strain rate, ductility (or brittleness) is a dynamic property of the material.

One effective experimental evaluation is to determine the conditions under which the metal will pass from a ductile to brittle behavior. For ferritic steels this demarcation is well defined. The usual experimental technique in studying a given metal is to keep the triaxiality and strain rate constant and to determine the temperature where the metal will become brittle. This temperature is called the brittle transition temperature, corresponding to the given triaxiality and strain rate.

Specimens — In the present study the effects of shot peening on the transition temperature of a mild steel were investigated. A bar of 1020 steel (0.20% C, 0.37% Mn, 0.009% P, 0.028% S) was cut into pieces 6 in. long and fully annealed at 1650° F. for 1 hr. After the surface scale was removed, a semicircular notch ¼ in. deep with ⅛-in. radius was milled in the center of one side (Fig. 1). The specimens were then divided at random into three batches: One batch was used as control specimens, the second batch was shot-peened to an intensity of 0.013 on the Almen gage No. A2 and tested in that condition, and the third batch was shot-peened to the same intensity as the second, then stress relieved at 450° F. and subsequently tested.

Testing Procedure — A detailed description of the apparatus and the experimental technique has been given previously,* and only a brief outline is included here. The testing equipment is designed to load a specimen in simple bending at a given uniform speed and temperature and to supply a load-deflection record of the test. Electric strain gages (AB-7, SR-4) connected in a bridge circuit are used to measure both the load and deflection. The integral parts of the apparatus include the loading machine with strain gages, the thermocouple and millivoltmeter, stop watch, electronic recorder and a still camera.

The loading device is a lever system which

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*"De Forest Brittle Temperature Research", by P. R. Shepler, *Welding Journal, Research Supplement*, V. 25, No. 6, June 1946, p. 321s to 332s; "The Effect of Welding Technique in the Brittle Transition Temperature", by N. Grossman and P. R. Shepler, *Welding Journal, Research Supplement*, V. 26, 1947, p. 321s.

transmits the load to the specimen resting on a suitable support. The support, specimen and electric strain gages are housed in a subzero test cabinet which can be cooled to −100° F. by forced circulation of dry ice; the specimen can be further cooled by pouring liquid nitrogen around it.

An a-c. bridge system is employed whereby a 5500-c.p.s. voltage is introduced into the load bridge and the deflection bridge, with the resulting unbalance from loading or deflecting detected, amplified and transmitted to a 3FPI tube. A record is made with a still camera. The load bridge and the deflection bridge contain an AB-7, SR-4 strain gage in each of the four arms.

The notched test specimens were freely supported on knife edges 5½ in. apart with the notch in the middle of one side perpendicular to the longitudinal axis. The load was applied in the center of the bar on the side opposite the notch.

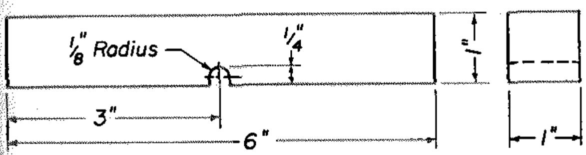


Fig. 1—Dimensions of the Test Specimen

The specimen was first cooled to a temperature that was estimated to be slightly above the transition temperature. If the load-deflection record showed a departure from linearity when the load was applied at a constant deflection rate at this temperature, it was an indication that yielding had occurred and that the specimen was still in the ductile condition. The test was then stopped and the same procedure was repeated at a lower temperature. This "probing" was continued until the first specimen failed with a very slight amount of yielding. A new specimen was then tested at the same speed but at a lower temperature to eliminate the possible effects of the cold working of the first or probing specimen. This procedure was repeated until the exact transition temperature was determined.

If the first test had shown a brittle failure, the second specimen would have been tested at a higher temperature. The advantage of starting above the transition temperature is that the first specimen can be used for several trials before it fails.

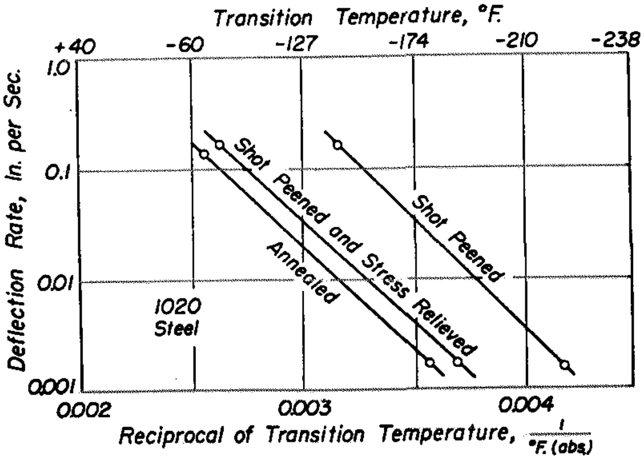


Fig. 2—Transition Temperature Versus Deflection Rate for Slow Bend Tests of Notched Specimens

The transition temperature determined in this way is the highest temperature, at a constant strain rate, for which the metal ceases all macroscopic ductile behavior as revealed by the load-deflection curve.

Discussion of Results

It has been known for some time that, with a given metal and system of constraint, a straight line is obtained when the logarithm of deflection velocity is plotted against the reciprocal of absolute temperature of transition. This property was utilized in the present investigation. The plotted curves in Fig. 2 indicate that shot peening made the steel more ductile, as reflected by a decrease in the brittle transition temperature. This decrease was most drastic on the shot-peened specimens tested

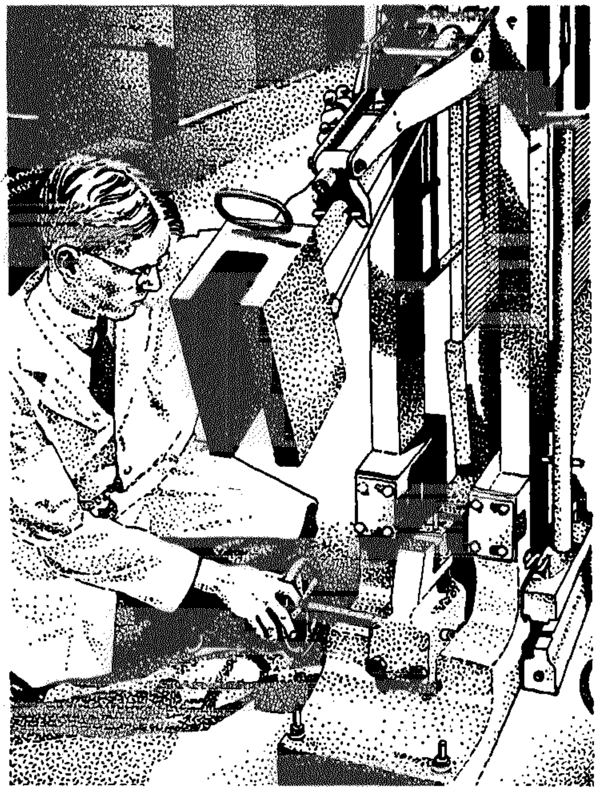
Table I—Results of Experiments on 1020 Steel

	ANNEALED ONLY		SHOT PEENED		SHOT PEENED AND STRESS RELIEVED AT 450° F.	
Transition temp.	−70° F.	−180° F.	−145° F.	−220° F.	−80° F.	−190° F.
Deflection rate*	0.137	0.00171	0.164	0.00170	0.164	0.00150
Surface roughness	19 micro-in.		70 to 85 micro-in.		70 to 85 micro-in.	
Monotron hardness						
Average	25.5 kg. (8)†		26.5 kg. (10)		28.0 kg. (11)	
Range	25.0 to 26.4		25.0 to 29.8		26.5 to 32.0	
Rockwell superficial hardness						
Average	30T-46.3 (6)†		30T-50.0 (7)		30T-49.9 (7)	
Range	38 to 50		44 to 55		47 to 54	

*Deflection rate in in. per sec. †Figures in parentheses designate total number of readings, of which the average is given.

without any subsequent heat treatment; specimens stress relieved *after* shot peening were not so markedly affected. For a deflection rate of 0.10 in. per second the transition temperature was about −80° F. for the annealed specimens, −150° F. for the shot-peened test bars, and −95° F. for the specimens shot-peened and subsequently stress relieved at 450° F.

According to our present state of knowledge, fracture starts just below the surface where the highest triaxiality exists — in these specimens, at the root of the notch. Evidently the fracture did commence at the layer where the metal was cold worked due to peening. Two conclusions may be tentatively drawn: *(a)* Shot peening introduces a highly compressed surface layer, and if fracture is to initiate within this layer, the transition temperature of the part is decreased — indicating that the metal is in a more ductile state as a result of peening; *(b)* stress relieving of the specimens after shot peening removes most of these effects.



To get some possible correlation with other mechanical properties, the hardness of the surface was measured. Care had to be exercised, however, to insure that only the topmost metal layer was considered and evaluated. The Vickers hardness tester is not suitable because it requires a well-defined, sharp indentation, not readily obtained on a peened surface. The Monotron hardness tester, based on the principle that the required load (in kilograms) to penetrate a given constant depth (0.0018 in.) is the measure of hardness, was well adapted to the shot-peened specimens. As a qualitative check the Rockwell 30-T hardness was also determined. The data obtained reveal no correlation between hardness and transition temperature. Although heating the shot-peened specimens to 450° F. markedly influenced the value of the transition temperature, it scarcely affected the hardness, as indicated in the lower part of Table I.

Shot peening introduces compressive stresses into the surface layer. It has been estimated that the depth of the stressed layer, as revealed by X-ray diffraction patterns, is about 0.006 in. for a steel and peening intensity comparable with those reported here.* During the present investigation two other methods were tried to establish the depth of the hardened layer, as well as to gain a quantitative estimate of the degree of cold working introduced by the peening operation.

Several shot-peened test bars were placed on the surface grinder and with the aid of sine-bars the specimens were tilted a small angle and the shot-peened surface ground to a depth of about 0.1 in. through a horizontal distance of about 2½ in. This gave a 25-fold "vertical magnification". The surfaces were then prepared for metallographic examination. It was hoped that the distorted grains close to the surface would be well differentiated from those unaffected by the cold working and that the demarcation zone would give positive information as to the depth of penetration. Unfortunately this approach did not yield the results that were significant.

Another method was then tried: By the use of the Bierbaum Microcharacter several sharp scratches were made on the tapered surfaces with a diamond indenter and a known load. However, this method was not sensitive enough to differentiate the cold worked and unaffected portions.

Summary

Shot peening of annealed 1020 steel markedly decreased the temperature of transition from ductile to brittle failure under the given conditions. Stress relieving at 450° F. increased the transition temperature of the shot-peened specimens nearly to the value for the original annealed steel. No correlation could be observed between surface hardness and change in ductility.

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*"The Effect of Shot Blasting and Its Bearing on Fatigue", by J. M. Lessells and W. M. Murray, *Proceedings*, American Society for Testing Materials, V. 41, 1941.