H. J. Hall

Phase Transformations, pressure effect on

Pressure Required for Transformation Twinning in Explosively Loaded Low-Carbon Steel

Technical Note

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A series of wedges of 1020 steel (2 1/2 by 6 by 8 in.) were explosively loaded, as shown in Fig. 1. A slab of explosive on the surface of the steel wedge was initiated simultaneously along one edge, producing an essentially two-dimensional oblique shock in the metal. Pressure and density in the metal were measured as a function of distance from the explosive-metal interface by a method described elsewhere.[1] While for pressures below 130 kbars the technique produces accurate results, for greater pressures the presence of two shock waves in the metal[2,3] makes interpretation of the data uncertain. However, the location of the transition in pressure at 130 kbars can be readily identified from the data. The assumption of a single shock in the region above 130 kbars overestimates the pressure computed on a multiple-shock model.

After firing, the wedges were sectioned, lapped, and etched with 2 pct Nital. A photograph of an etched specimen is shown in Fig. 2. The specimens were examined metallographically. The dark region, at the top of the specimen, was heavily banded, Fig. 3, while the lighter area was comparatively free from banding, Fig. 4, the boundary between the two regions being quite abrupt. The very light regions at an angle of about 45 deg to the explosive-metal interface show virtually no banding. The origin of these light regions, which are not Luder's bands, is not yet explained.

The thickness of the heavily banded area was measured and compared with the pressure at the boundary between the heavily and lightly banded regions. The results of these measurements and calculations are given in Table I. For all shots, the pressure at the boundary is approximately the same

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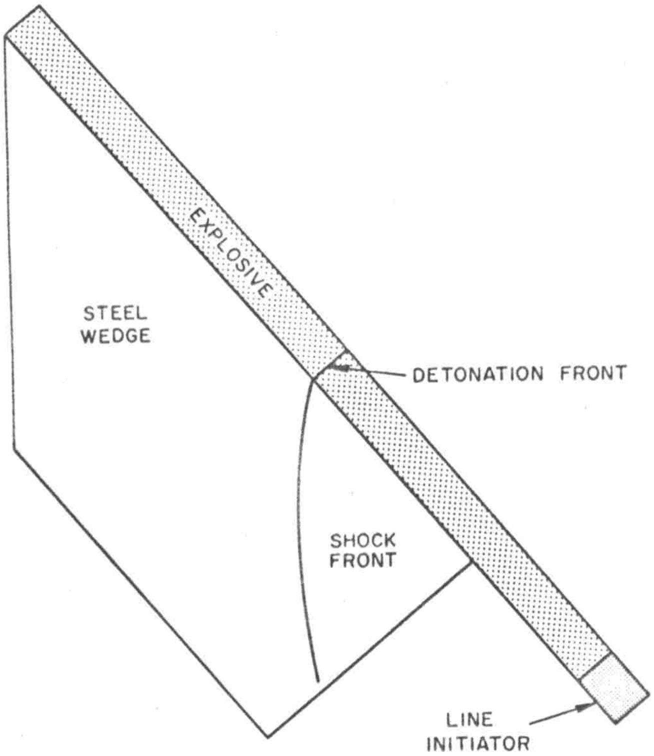

Fig. 1—Diagram of experimental arrangement.

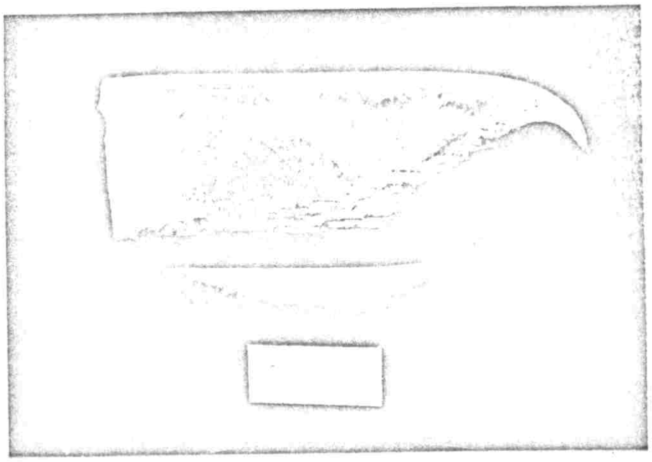

Fig. 2—Section of wedge-shaped steel specimen 2113 after detonation with 25.4 mm of explosive. Etched with 2 pct Nital. X1/2. Reduced approximately 28 pct for reproduction.

and greater than 130 kbars. The value obtained assuming only one shock is close to 150 kbars. The average value for the ratio of thickness of heavily banded region "L" to explosive thickness "D" is approximately constant for all shots, $L/D = 0.54 \pm 0.03$.

Bands in the microstructure of iron, known as Neumann bands, have long been recognized as products of low-pressure shock loading.[4] These Neumann bands have been positively identified as twin bands[5, 6] which form by the usual mechanical twinning mechanism. Similar twin bands are present in the lightly banded areas of the above samples. However, the large and abrupt increase in band density near the interface at a pressure somewhat greater than 130 kbars suggests that the high-density bands are not conventional mechanical twins.

The Hugoniot equation of state[1, 2] of iron at room temperatures exhibits a marked change in slope at about 130 kbars. This has been attributed[2] to a pressure-induced transformation of α iron (b.c.c.) to γ iron (f.c.c.). It is suggested that the high-density banding in the high-pressure region of these specimens was produced by the pressure-induced $\alpha \rightarrow \gamma$ iron transformation, and the reverse $\gamma \rightarrow \alpha$ iron transformation occurring during rarefaction, this transformation occurring by a martensitic (nucleation and shear) transformation instead of the usual nucleation and growth transformation.

As the pressure wave travels through the specimen, portions of each of the crystals transform from their α iron orientation to one of 24 possible related γ iron orientations. * As the pressure re-

*This figure comes from the Bowles' double-shear mechanism of martensite formation involving a (225) habit plane. This is reasonable since the Bowles mechanism also leads directly to twinning in ferrite and austenite.

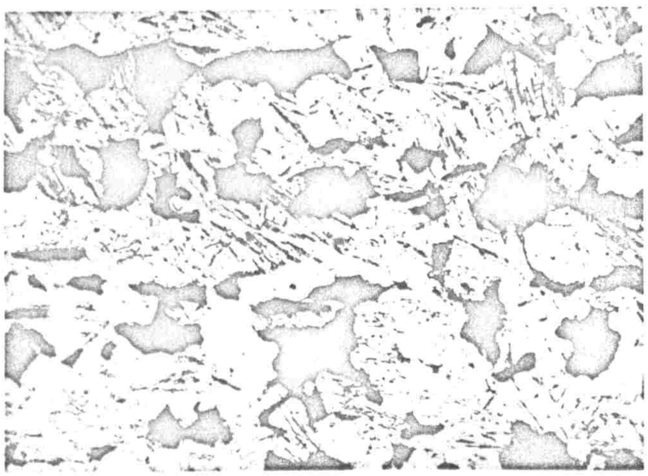

Fig. 3—Heavily banded region of specimen 2113—1mm from metal-explosive interface. Etched with 2 pct Nital. X500. Reduced approximately 25 pct for reproduction.

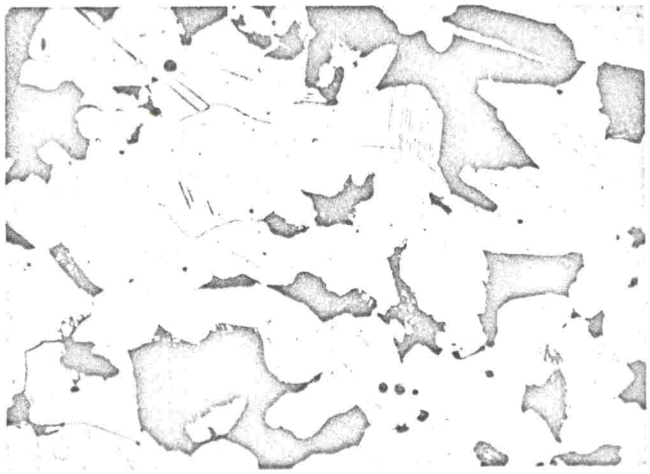

Fig. 4—Lightly banded region of specimen 2113—20 mm from metal-explosive interface. Etched with 2 pct Nital. X500. Reduced approximately 25 pct for reproduction.

Table I. Widths of Profusely "Twinned" Edge Zones and Corresponding Pressures

Shot No.	Explosive Thickness in Mm(D)	Mean Thickness of "Twinned" Zone in Mm(L)	L/D of Twin Zone Boundary	Pressure* at Twin Boundary in Kb	Depth of 130 Kb Point	L/D of 130 Kb Point
1593	12.78	7.0 ± 0.2	0.55 ± 0.02	150	11.3	0.88
1594	12.70	7.0 ± 0.2	0.55 ± 0.02	150	13.2	1.04
1664	24.0	15.0 ± 0.2	0.62 ± 0.01	145	25	1.04
2113	25.4	13.0 ± 0.2	0.51 ± 0.01	155	–	–
2614	25.4	12.5 ± 0.2	0.49 ± 0.01	155	–	–
2141	25.4	13.5 ± 0.2	0.53 ± 0.01	152	26	1.02

*Single shock interpretation

turns to normal the γ iron crystals will transform back to α-iron by means of a second martensite transformation into 24 possible orientations which are related to the γ iron orientations. Some of the newly formed α grains may have transformed from γ iron, by the same shearing movements which produced γ iron from α iron, thereby returning to their initial orientation. In general, however, the new grains will have a different orientation than they had initially. According to the Bowles mechanism all of the α grains with the same orientation will exhibit twin relationships with each other.

The reason that the boundary between the heavily and the lightly banded regions occurs at a pressure greater than the transition pressure of 130 kbars may be due to the nonisothermal nature of the transformation. In such a case the material may not all transform at once but would go through a system of mixed phases.[2] This means that there would be no volume change without increase of pressure, and the volume corresponding to the beginning of the heavily banded region would be at a pressure somewhat higher than 130 kbars, where the transition begins.

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