Mechanical and Materials Engineering Division
January 26, 2001

F. Gregg Bemis, Jr., President
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3876 Old Santa Fe Trail
Santa Fe, NM 87505

Subject: ***Southwest Research Institute Project No. 18.04042.01.109***
"Examination of Metal Samples for Evidence of Shock Loading"
Final Report

Dear Mr. Bemis:

This letter constitutes Southwest Research Institute's (SwRI)™ report on the samples you recently submitted for examination.

INTRODUCTION

Two palm-sized metal samples were submitted to SwRI. The client reported these had been torch cut from the broken edges of two different structural steel components that had been fabricated from ~¼-in. thick steel plate. The client also reported that they had been adjacent to one another within the same structure. These are hereinafter identified as Samples F1 and H2, as shown in Figures 1 and 2. SwRI was asked to perform examinations, within a limited budget and timeframe, to form the basis of an opinion either supporting or denying the possibility of fracture due to shock loading, such as might result from detonation.

OBJECTIVE

Our objective was to examine the submitted samples for evidence of shock loading.

PROCEDURE, RESULTS AND DISCUSSION

After cathodic cleaning to remove corrosion products from the fracture surface of Sample H2 (Figure 3), we attempted a direct evaluation of the fracture mechanism by scanning electron microscopy (SEM). This examination proved unfruitful, since the topographic details of the original fracture surface were almost completely corroded away. Nevertheless, the angled geometry of both fracture surfaces, combined with subsequent metallographic observations, clearly indicated fracture by a shearing mechanism due to tensile overload.

We then prepared for metallographic examination a small section you identified as as "Item 1," which had been taken from a corner of Sample F1 by a transverse cut through its fracture surface. Relatively little pre-fracture necking had occurred (Figure 4), and relatively little elongation of the ferrite grains and pearlite colonies comprising the carbon steel microstructure was apparent (Figure 5). Fracture under shock loading conditions is often associated with a localization of shear deformation that arises due to adiabatic conditions. In the present case it was impossible to determine whether a shear band was present at the fracture surface because of the corrosion that had occurred, but the absence of necking suggested its possibility.

Another microstructural feature that can appear as a result of the adiabatic shearing and self-quenching process associated with shock-induced shear localization is that of untempered (“white”) martensite. This is not a prevalent feature in ferrite-pearlite steels because of their sluggish transformation kinetics as compared to the tempered martensites commonly found in the higher carbon and alloy steels. In the present case there were a number of regions near the fracture surface, such as those indicated in Figure 5, whose response to etching suggested that some pearlite colonies may have undergone this process. However, closer examination of these areas by SEM proved otherwise, revealing them to be pearlite colonies merely having an extremely fine interlamellar spacing (Figures 6–8).

A potentially significant feature found in Sample F1 was the occurrence of deformation twinning. Twinned grains like those visible in Figure 9 were scattered along the plate thickness within a few millimeters of the fracture surface. This is a characteristic of extremely high strain rate conditions, assuming the ambient temperature at the time of failure was not cryogenic. In the present case we could not determine whether it resulted from shock loading or was simply the side effect of an unstable, fast-running shear fracture. This uncertainty was due to corrosion damage to the fracture surfaces and our inability to give context to the submitted samples, *i.e.*, to relate them to any surrounding structural damage or to the circumstances under which failure occurred. Further investigation is warranted, probably by experimenting with subsize tensile specimens that could be removed from the samples on hand.

A similar metallographic section taken from Sample H2 exhibited a greater degree of necking and grain elongation away from the shear fracture surface (Figure 10), and deformation twinning was less readily apparent. Again, corrosion made it impossible to determine whether or not a shear band was present at the fracture surface.

For purposes of comparison, an additional metallographic section was taken from each of the two samples (F1 and H2) at locations well away from their fracture surfaces. Both exhibited an equiaxed ferrite-pearlite microstructure typical of a hot-rolled structural steel, with no evidence of deformation twinning in either case.

Conclusions and Recommendations

1. One of the two submitted samples (F1) exhibited deformation twinning and minimal pre-fracture necking. If cryogenic temperatures and running shear fracture can be ruled out, these could be considered evidence of shock loading.

2. The second sample (H2) exhibited neither of the above characteristics of high-strain-rate deformation.

3. The presence or absence of a shear band along both fracture surfaces, which would have helped to confirm or deny the possibility of shock loading, was masked by post-failure corrosion.

4. Additional experiments should be conducted to simulate the range of loading rates over which failure might have occurred. This would enable us to correlate microstructural features found in the submitted samples with those exhibited by samples generated under known conditions. A more detailed proposal can be provided upon your request.

Please feel free to call me at 210-522-3163 if you have any questions or require further assistance.

Sincerely,

Robert W. Warke, Manager
Materials Characterization Section

APPROVED:

James Lankford, Ph.D., Director
Materials Engineering Department

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Hartmann, K.-H., Kunze, H.-D. and Meyer, L. W., “Metallurgical Effects on Impact Loaded Materials,” in *Shock Waves and High-Strain-Rate Phenomena in Metals* (Proceedings of an International Conference on Metallurgical Effects of High-Strain-Rate Deformation and Fabrication), M. A. Meyers and L. E. Murr, eds., Plenum Press, 1980, pp. 325-337.

Meyers, M. A., *Dynamic Behavior of Materials*, John Wiley & Sons, 1994.

Rogers, H. C. and Shastry, C. V., “Material Factors in Adiabatic Shearing in Steels,” in *Shock Waves and High-Strain-Rate Phenomena in Metals* (Proceedings of an International Conference on Metallurgical Effects of High-Strain-Rate Deformation and Fabrication), M. A. Meyers and L. E. Murr, eds., Plenum Press, 1980, pp. 285-298.

(a)

(b)

Figure 1. Overall views of both sides of Sample F1.

(a)

(b)

Figure 2. Overall views of both sides of Sample H2.

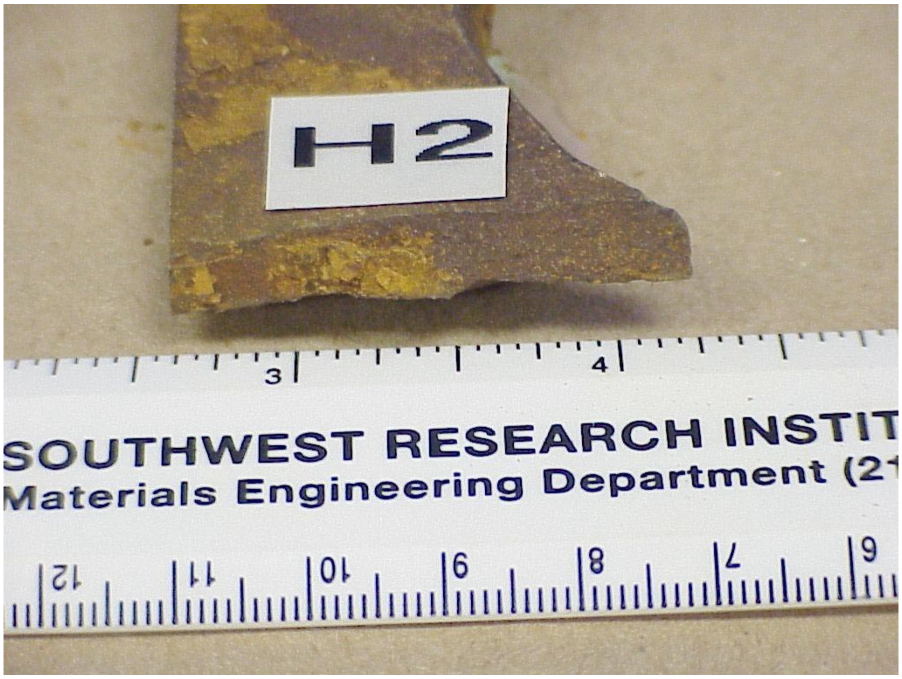

Figure 3. Fracture surface of Sample H2 prior to cathodic cleaning.

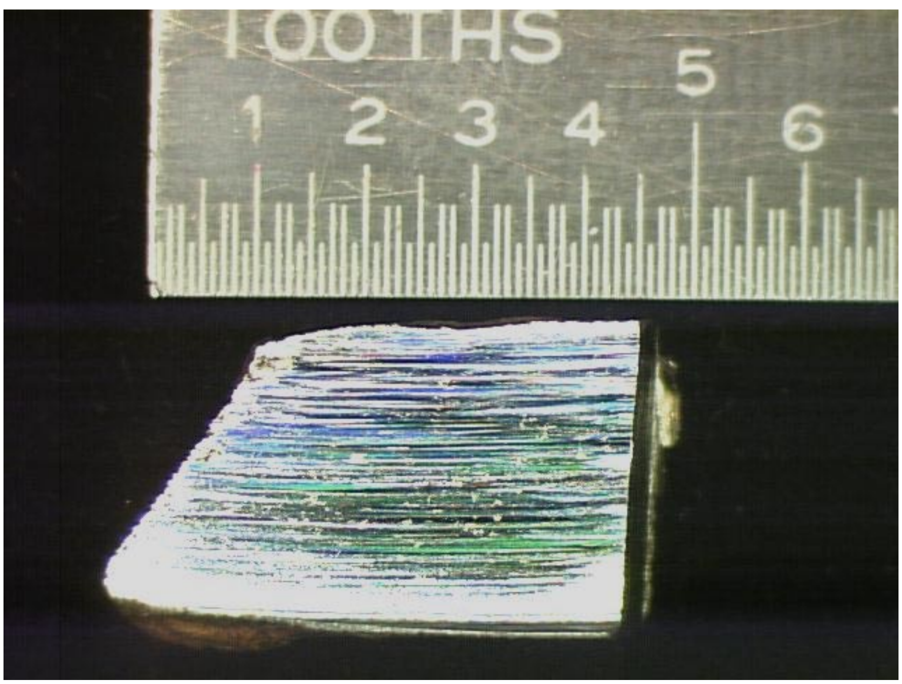

Figure 4. Overall view of section taken from Sample F1, showing minimal pre-fracture necking.

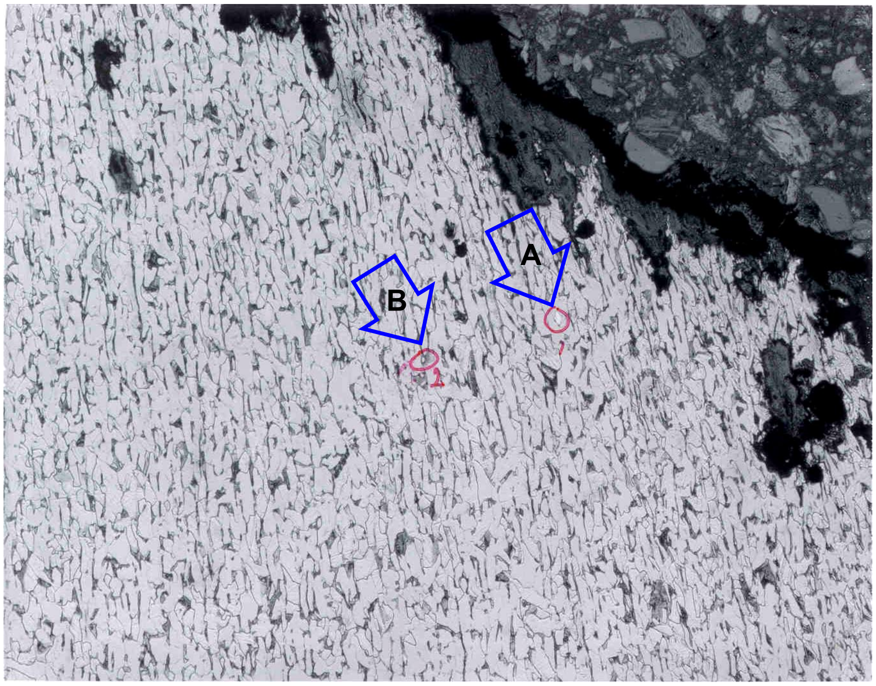

Figure 5. **Optical micrograph showing typical microstructure along fracture surface of Sample F1 (100×).**

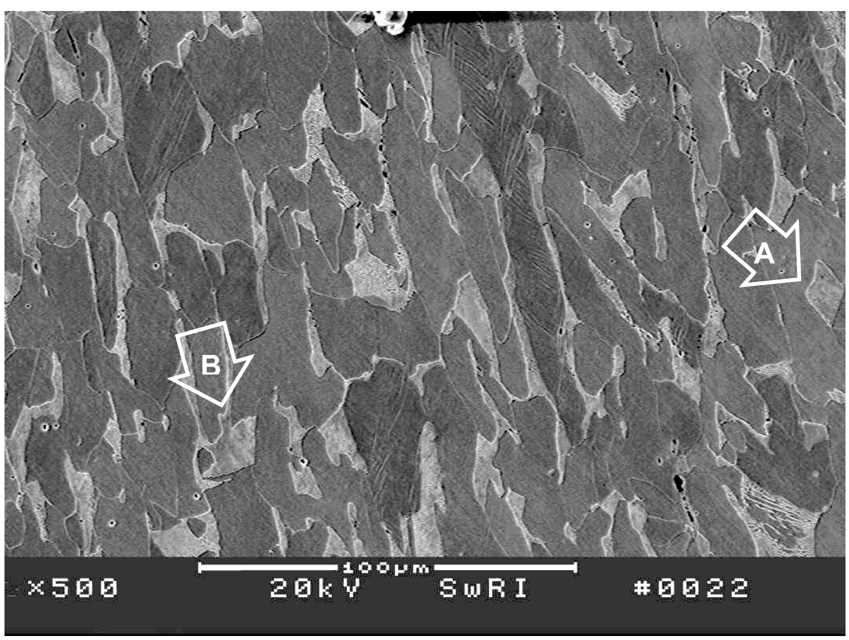

Figure 6. **SEM micrograph showing ferrite-pearlite microstructure of Sample F1, as well as locations 'A' and 'B' in Figure 5.**

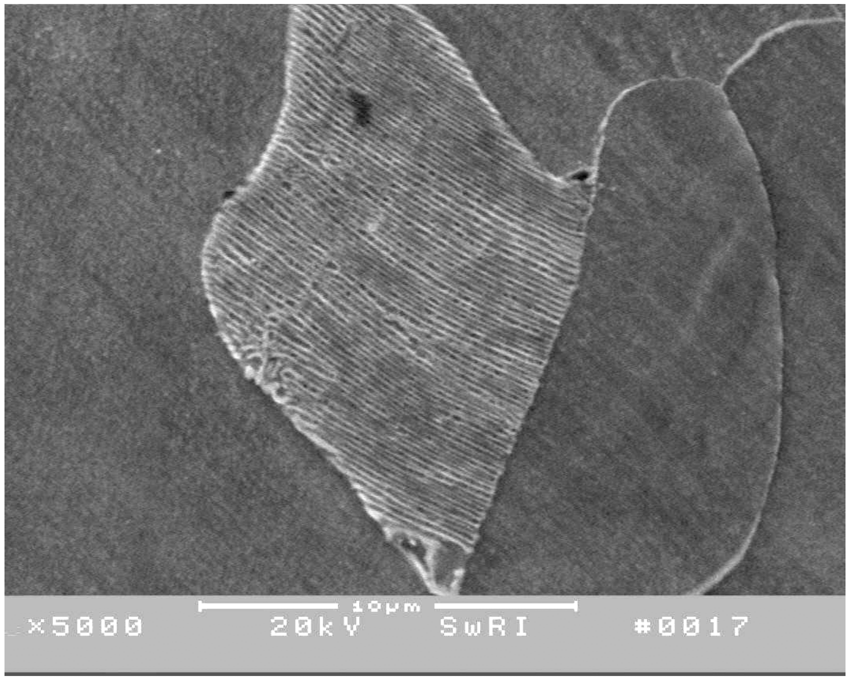

Figure 7. **Highly magnified view showing detail of pearlite colony at location 'A' in Figure 6.**

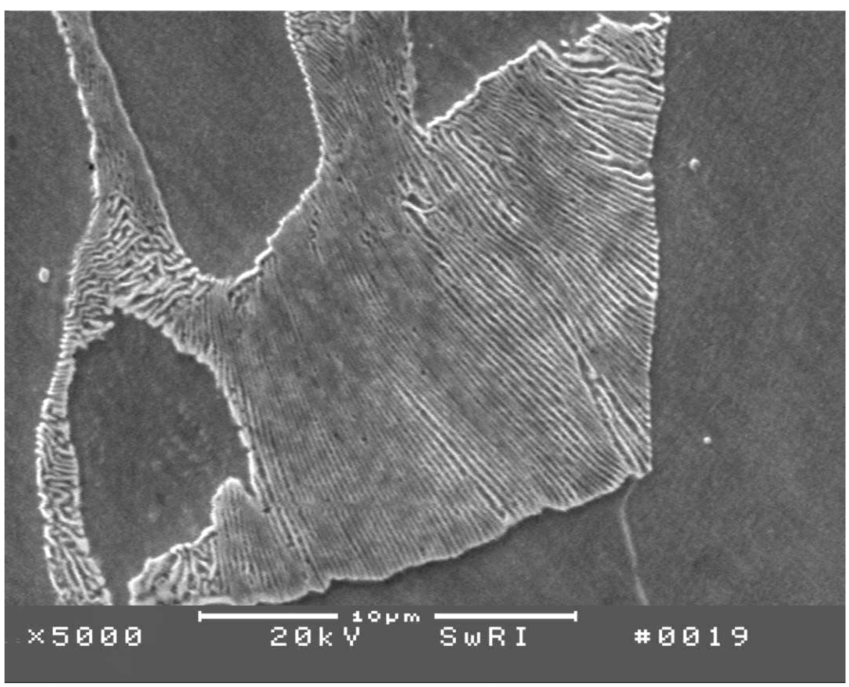

Figure 8. **Highly magnified view showing detail of pearlite colony at location 'B' in Figure 6.**

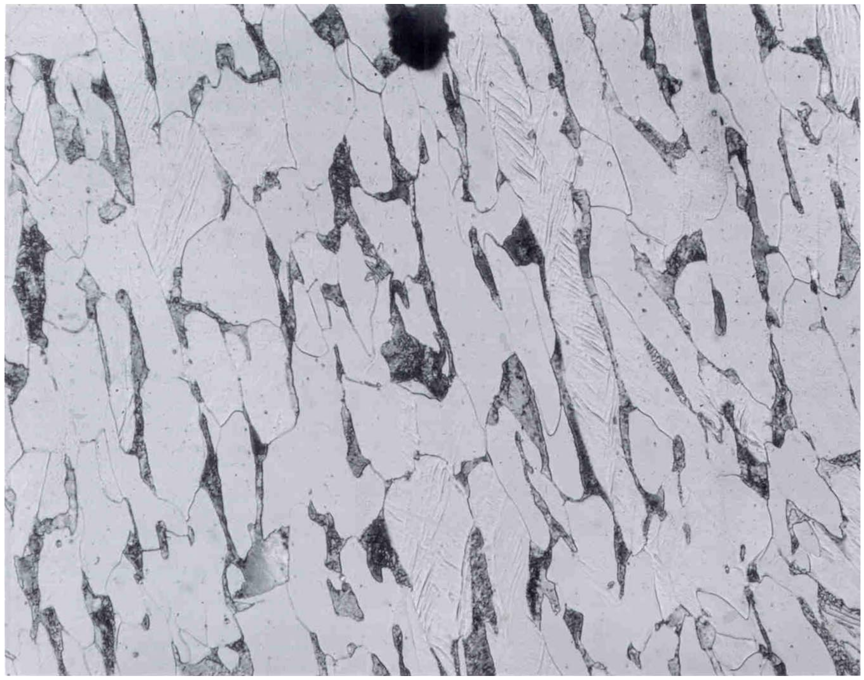

Figure 9. Optical micrograph showing typical evidence of deformation twinning in Sample F1 (500×).

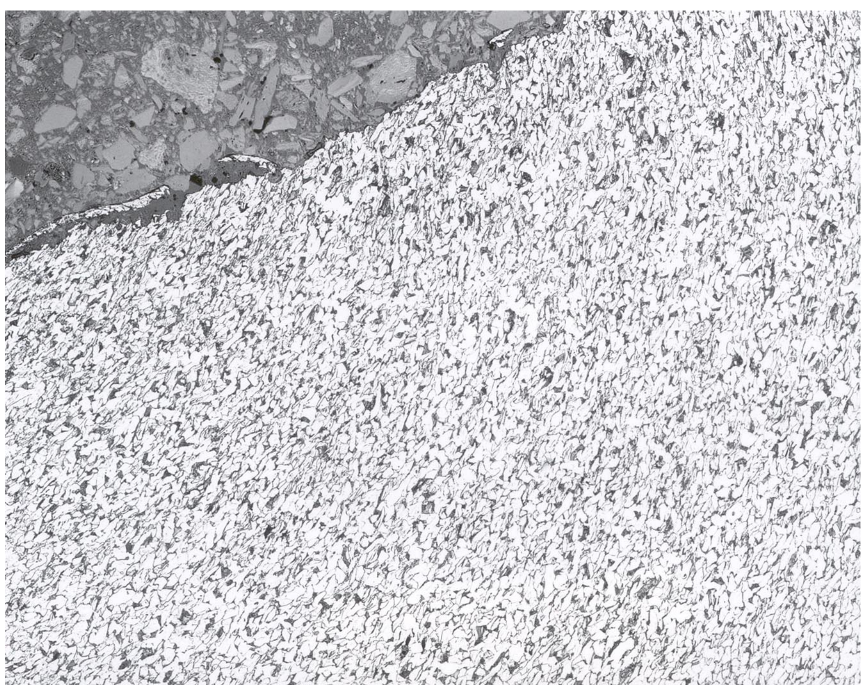

Figure 10. Typical microstructure along fracture surface of Sample H2 (100×).