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CHANGE IN CHARPY PROPERTIES OF ALGO-TUF 50B STEEL WITH COLD WORK AND AGEING

BY

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Physical Metallurgy Division

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SUMMARY OF RESULTS

The effect on the Charpy V-notch impact properties of Algo-Tuf 50B steel of cold forming a U-shaped section for an orthotropic-plate deck bridge was investigated. The non-uniform strain of zero to 4.3% involved in the cold forming had much less effect on the impact properties than a 5% uniform strain, but was comparable to that of a 2% uniform strain. Ageing at 500°F after straining had little effect on the properties of this steel at the strain level involved in the cold forming. It was noted that the cold-forming operation was close to a plane strain deformation and a measurement of residual stress in the formed section showed that most of the constraint stress of about half the yield strength remained in the member.

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INTRODUCTION

In design studies for the Northumberland Strait Crossing, an orthotropic-plate deck bridge was considered in which the ribs for the deck were cold-formed U-shaped sections. The plate for the ribs was to be bent to a radius of 4-9/16 in. so the strain through the thickness would vary from zero to over 4% if the plate was about 0.40 in. thick. A question arose as to the effect on the impact properties of the steel of this cold work, possibly coupled with elevated-temperature strain ageing from the heat of welding. A 6-ft length of rib was received for tests. The hot-rolled plate was supplied by Algoma Steel Corporation and cold-formed by Dominion Bridge Company, Limited, using V-dies and a brake.

The desirability of investigating the effect of bending was decided at a committee meeting on the bridge materials involving representatives of The Algoma Steel Corporation, Limited, Dominion Bridge Company, Limited, Northumberland Consultants, Department of Public Works and Department of Energy, Mines and Resources.

MATERIAL AND TESTS

The material in the rib was Algo-Tuf 50B steel, which was found to have the following composition; C 0.15%, Mn 1.01%, Si 0.18%, P. 0.006%, S 0.027%, V 0.06%, Cu 0.27%, Cr 0.35%, Ni 0.33%.

A sketch of the sample rib is shown in Figure 1. Since the length does not change much during the cold bending, the forming operation is approximately a plane strain deformation and a constraint stress of about half the yield strength would be expected to develop along the length of the rib. To determine how much of this stress remained in the rib, the residual stress was measured near the centre of the length at the crown of the bend. Using strain gauges and sectioning, the residual stress was found to be 27,000 psi longitudinal tension on the convex side of the bend and 22,000 psi compression on the concave side. Evidently, most of the constraint stress remains in the member.

In view of the anticipated service stressing of the rib, it was thought that, if a failure were to occur, the most likely crack path would be perpendicular to the length of the rib starting from a surface defect on the bend. For this reason, Charpy impact specimens were taken from the crown of the bend with the notches in the surface of the plate and the length direction of the specimens along the length direction of the rib, which was the rolling direction of the plate. Impact specimens in the rolling direction of the plate usually have the notches perpendicular to the plate surface, so specimens of this type were also taken from the crown of the bend.

To investigate how the effect of the non-uniform strain in the bend would compare with varying amounts of uniform strain, plate tensile specimens were taken from the unstrained sides of the rib. As shown in Figure 1, these were transverse to the rolling direction. They were strained uniformly to 2.0% and 5.0% strain, respectively, before impact specimens were machined from them. These specimens were oriented both in the rolling direction and transverse to it, and were notched in the surface of the plate and perpendicular to it.

Impact specimens from unstrained material in the rib were, of course, taken for comparison. The plate thickness was about 0.390 in. and the Charpy specimen is 0.394 in. square; thus, one dimension of the specimen was slightly undersize. In no case was this dimension less than 0.370 in. and this factor is not thought to have had a significant effect on the results.

Half of the impact specimens of all types were aged at 500°F for 1 hr.

During the course of straining the plate tension specimens, it was found that the transverse yield strength of the plate was about 65,000 psi.

All of the test results are listed in Tables 1 and 2 and visual "best fit" curves for these results are given in Figures 2 to 5.

DISCUSSION OF RESULTS

All longitudinal specimens with notches in the plate surface gave high impact-energy absorption values and are not plotted in the Figures. This high energy absorption was apparently caused by a slight tendency to de-lamination which inhibited crack propagation.

The Charpy test results show considerable scatter, and for this reason it is not considered justifiable to pick particular datum points off the curves shown. Considering the trends of the curves, it is thought that the variable strain from 0 to 4.3%, through the bend region of the plate, had much less effect than that of a 5% uniform strain but was comparable to that of a 2% uniform strain. Ageing at 500°F after straining had little effect on the properties of the steel at the strain level involved in the cold forming.

The transverse impact properties of this plate with notches both in the surface of the plate and perpendicular to it were considerably poorer than in the rolling direction.

ACKNOWLEDGEMENT

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LPT:JAE:lc

TABLE 1

Charpy Impact Results for Materials as Received
Energy Absorbed (ft-lb)

Curve No.	Particulars of Specimen	Room Temp	+40°F	+20°F	O°F	-20°F	-40°F	-60°F	-80°F	-100°F
1	Longitudinal Unstrained Notch, Perpendicular To Plate Surface	92 96	60 52	53 43	32 51	24 25	10 21	10 25		
2	Transverse Unstrained Notch, Perpendicular To Plate Surface	27 26	19 18	16 16	14 15	11 11	10 10	10 7		
3	Longitudinal Unstrained Notch in Plate Surface	204			208			59		144
4	Transverse Unstrained Notch in Plate Surface	34 37	26 25	23 22	16, 24 18, 20	16 14	12 14	11 15		
5	Rolling Direction, Crown of Bend, Notch Perpendicular to Plate Surface	84.5 88	77 85 28	35 25 25	18 32	12 15 18	6 8 8	6 10		
6	Rolling Direction, Crown of Bend, Notch in Plate Surface (Convex)	214			220	240		120		
7	Rolling Direction, Crown of Bend, Notch in Plate Surface (Concave)	197			190	236				
8	Longitudinal, 2% Strain, Notch Perpendicular to Plate Surface	84 84	66, 30 42, 27	30 29	20, 21 45, 30	24 29	15 23	26 14		
9	Rolling Direction, 2% Strain, Notch in Plate Surface	192			218			52	70	63
10	Transverse, 2% Strain, Notch in Plate Surface	31 31	20, 22 21, 24	17, 20 20, 20	15, 17 18, 22	16, 16 18, 20	17, 14 14, 16	12 15	14	14
11	Longitudinal, 5% Strain, Notch Perpendicular to Plate Surface	70, 62 31, 80	35 29	24 20	26, 15 13, 25	19 22	16 14	8 15		
12	Longitudinal, 5% Strain, Notch in Plate Surface	188		214				90	56	48
13	Transverse, 5% Strain, Notch in Plate Surface	28, 28 26	18, 20 15, 22	15, 15 15, 14	16, 14 15, 18	12 14	14 13	16 11	12	10

TABLE 2

Charpy Impact Results for Material Aged 1 Hour at 500°F.
Energy Absorbed (ft-lb)

Curve No.	Particulars of Specimen	Room Temp	+40°F	+20°F	O°F	-20°F	-40°F	-60°F
1	Longitudinal, Unstrained,	96	37	39	40	26	36	14
	Notch Perpendicular to Plate Surface					15	10	
		98	49	38	22	14	11	7
2	Transverse, Unstrained, Notch	26	18	17	14	12	12	8
	Perpendicular to Plate Surface		20					
		27	16	16	13	14	10	10
3	Transverse, Unstrained,	40	32	20	21	16	12	14
	Notch in Plate Surface			18	22			
		37	33	20	16	14	14	12
4	Rolling Direction, Crown of Bend,	83	50	28	20	14	6	
	Notch Perpendicular to Plate Surface	88	56	26	50	20	11	
5	Longitudinal, 2% Strain,	90	50	52	18	22	12	10
	Notch Perpendicular to Plate Surface	85	64	42		9		
		39	28, 36	28, 26	36	20	5	8
6	Longitudinal, 5% Strain,	39	14	10	6	18	10	6
	Notch Perpendicular to Plate Surface		26	14	11	10		
		37	42	26	28	6	6	8
7	Transverse, 2% Strain,	31	24	18	15	16	14	13
	Notch in Plate Surface		22	19	15	13	12	12
		31	22	19	16	14	14	12
8	Transverse, 5% Strain,	20	14	15	12	14	10	8
	Notch in Plate Surface	26	20	10	13	10	10	9
		21	16	12	10	12	10	10

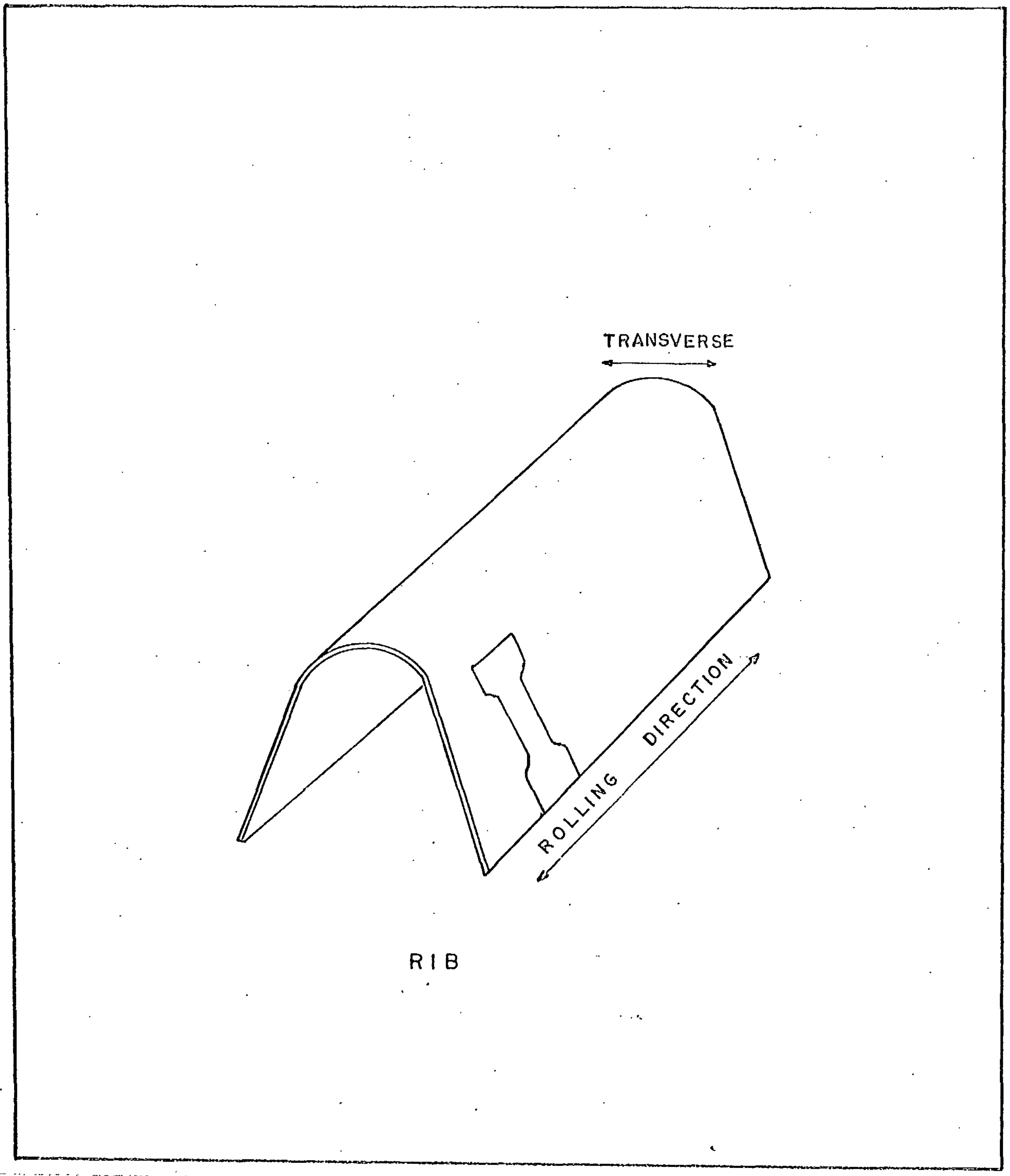

Figure 1. Location of flat tensile specimens.

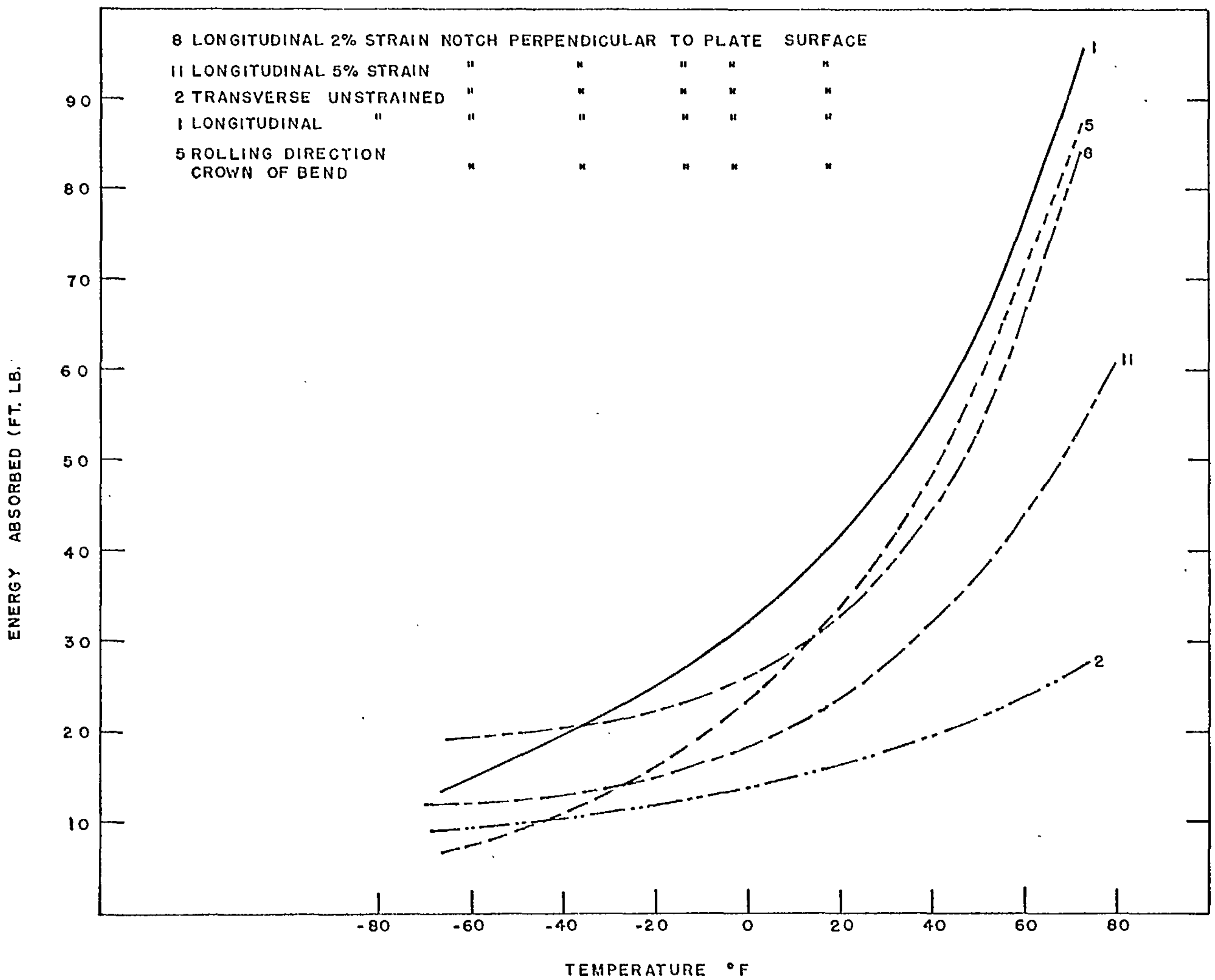

Figure 2. Charpy impact curves. Notch perpendicular to plate surface. Material as received.

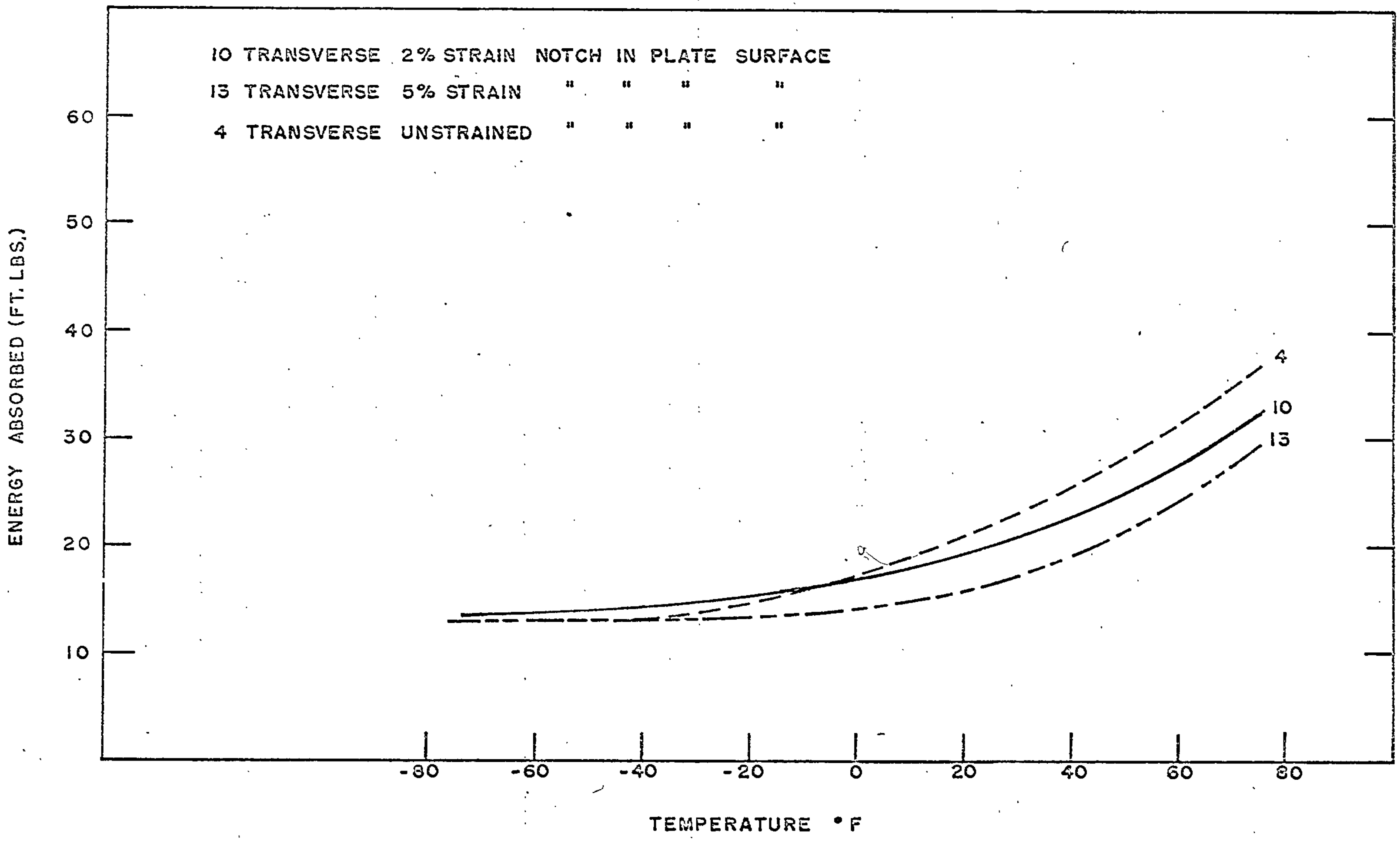

Figure 3. Charpy impact curves. Notch in plate surface.
Material as received.

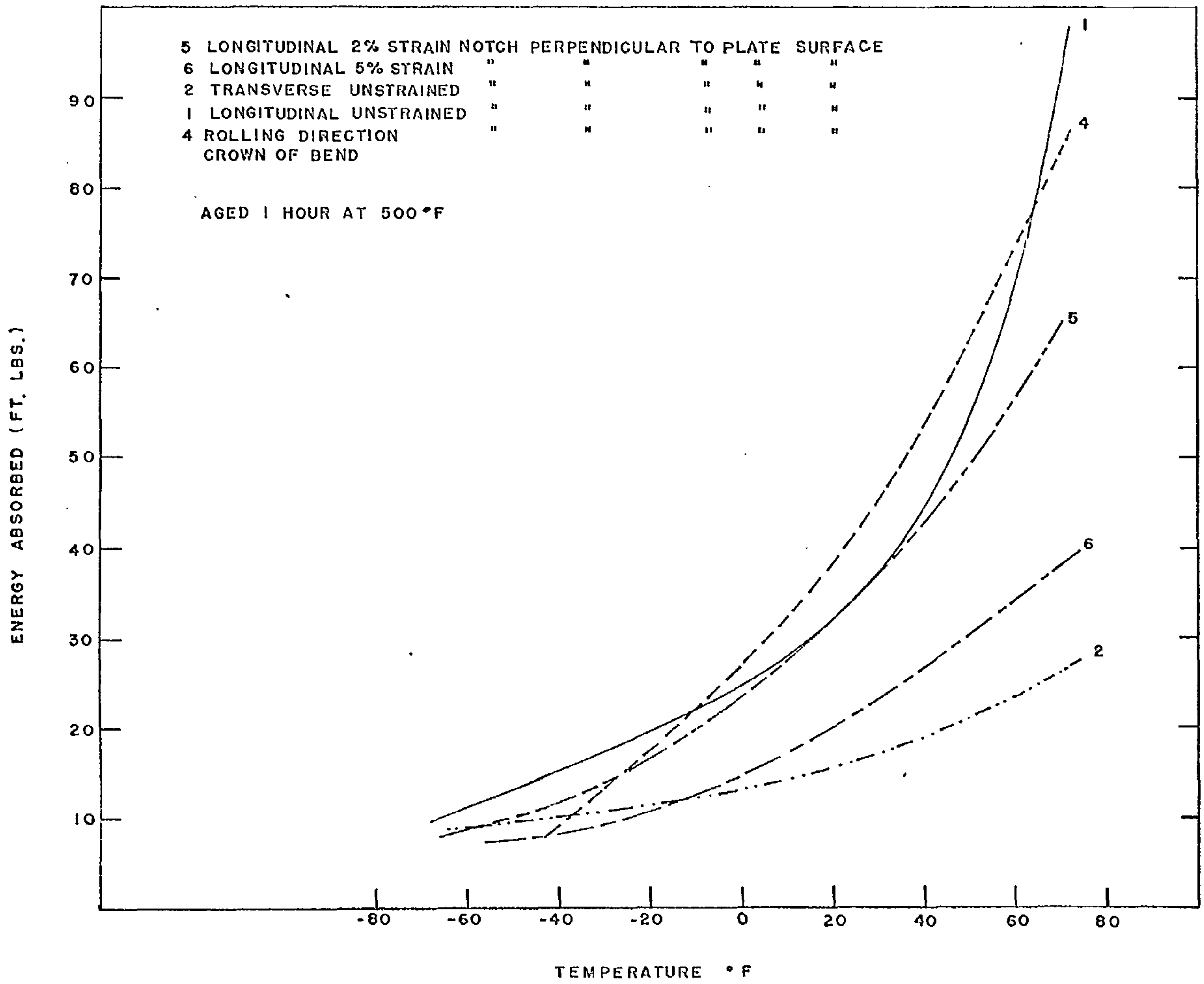

Figure 4. Charpy impact curves. Notch perpendicular to plate surface. Material aged 1 hour at 500°F.

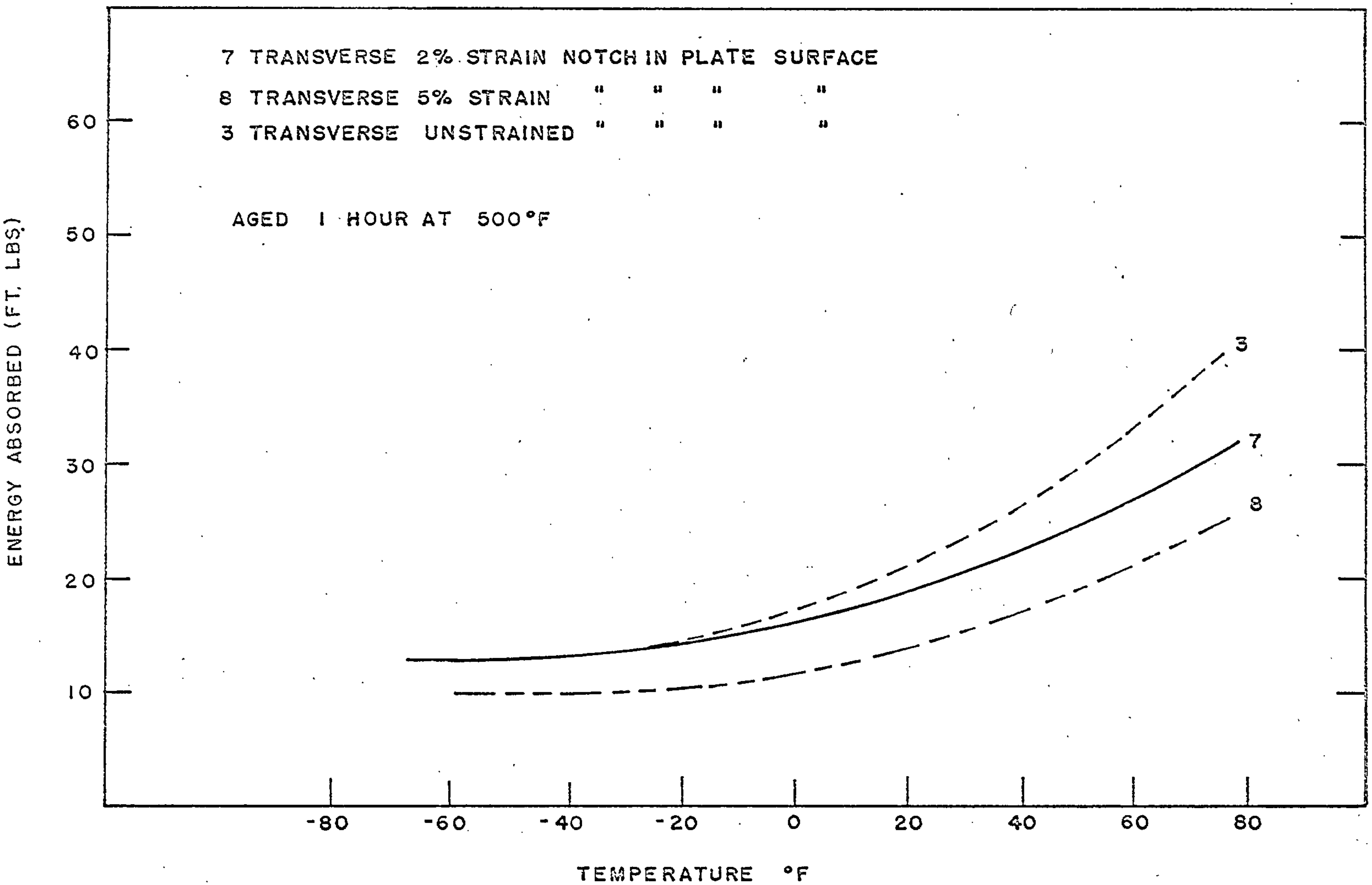

Figure 5. Charpy impact curves. Notch in plate surface. Material aged 1 hour at 500°F.