CANADA

THE DOUBLE-NOTCHED (V-V) BAR TENSION-BENDING TEST

T. W. WLODEK
PHYSICAL METALLURGY DIVISION

DEPARTMENT OF MINES AND TECHNICAL SURVEYS, OTTAWA

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The Double-Notched (V-V) Bar Tension-Bending Test*

By T. W. WLODEK†

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Summary

During recent studies concerning the effects that various surface treatments, surface imperfections, locked-in residual stresses and metallurgical and geometrical notches have upon the mechanical behaviour of metals, and, in particular, upon their tension-bending characteristics under impact loads, it became apparent that specially developed methods and samples would be of great assistance in determining the desired data. This paper describes and discusses a number of different types of double-notched tension-bending impact samples which have been considered and examined for this purpose.

The types most suitable for exploratory investigations are proposed for application in the study of the behaviour of metals, their welds, and, in particular, their surfaces, when subjected to various notch-severities, surface imperfections, strain rates, temperatures, and constrained states of stress (i.e. the relations of the three principal stresses).

It is expected that the proposed double-notched tension-bending samples and the proposed test methods will also contribute toward further understanding of the cold brittle behaviour and the notch-sensitivities of metals.

The possibilities of introducing the so-called impact notch-sensitivity index and relative impact notch sensitivity of metals are discussed.

Data obtained on double-notched (V-V) square and flat impact samples are also discussed. The tension-bending characteristics of as-cast, as-rolled, and as-machined surfaces are examined and analyzed.

* * *

Introduction

THE recording and analysing of the impact energy required to break notched or unnotched samples, and the visual observation of shape and type of fracture obtained on broken surfaces, are old and popular arts currently employed in the testing of metal.

Impact tests are widely used, at present, for the experimental study on the mechanism of the transition of metals from ductility to brittleness. The majority of these investigations and experiments are being done on iron and steel, i.e. on ferrous materials, because of the industrial importance of these metals and their susceptibility to this transition.

In notched impact test specimens of ferrous materials, a change in fracture appearance from a ductile to a crystalline (brittle) fracture occurs over a certain temperature range as the testing temperature is lowered. A drop in energy values also occurs over this temperature range. The temperature at some arbitrary point within this range has been called the transition temperature.

The generally accepted explanation of the fundamentals of the ductile-brittle transition mechanism in metals is based on the phenomena of "locked dislocations" resulting from impurities (1, 2, 3, 4), and internal micro-stresses (5, 6), and the release of these dislocations under stress and correlated activation energies.

The list of standard notched impact test samples, standard impact machines, and test methods employed is at present well established and accepted for general use in engineering design and metallurgical research (7) (8). For conventional impact testing, Charpy or Izod type impact testing machines are usually employed. Both of these machines employ a heavy pendulum that swings down from an elevated position to strike the specimen. The Charpy type machine uses a notched test specimen freely supported at both ends as a simple horizontal beam which under test is struck at mid-span immediately behind the notch. The Izod type machine uses a notched test specimen which is fixed vertically at one end as a cantilever beam and struck at the other, the specimen being struck on the side which is notched. During impact tests, the energy required to break the sample, the testing temperature, and the shape and appearance of the fracture, are all recorded. Later in this paper, a system is proposed for describing and recording the fracture (Table XII gives details).

Impact test specimens and test methods can be segregated into a few groups according to shape, dimension and type of notch, preparation and surface finish, and, also, according to the type of load applied (i.e. bending, tension-bending or simple tension under impact or slow loading conditions). In general, it can be stated that the test data obtained from notched impact bars are not readily interpreted and analysed.

In addition to the standard impact test methods, samples and machines mentioned above, a number of supplementary impact (9) and slow-loading test samples and methods have been employed in connection with the study of problems of brittle fracture of metals under service conditions, with particular reference to ferrous materials (9, 10, 11, 12, 13, 14, 15). These standard and supplementary testing methods are very useful for studying the mechanism of brittle fracture and the effects of melting and refining, heat treatment, cold work, welding and structural shape on the brittle characteristics of metals.

The list of supplementary samples and test methods used to study the brittle behaviour of metals is quite extensive, but for illustration purposes a few typical samples are mentioned below.

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†Senior Scientific Officer, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Examples of the slow-loading type of test are the M.I.T. Slow Bend Test (10), recommended for structural steel tests by C. W. MacGregor and N. Grossman and the U.S. Navy Tear Test (11), recommended by N. A. Kahn and E. A. Imbembo for steel plates in ship structures.

For ductility tests of welded structures, the Kinzel type notched slow-bend specimen, with longitudinal weld bead, is widely used (12).

The drop-weight impact test and the explosion test, both employing a hard surfacing type weld as crack initiator, represent another type in this field. These tests were developed by P. P. Puzak, M. E. Schuster, and W. S. Pellini (13).

Schnadt (14, 15, 18) recently introduced an interesting type of impact sample, designed to be tested in the Charpy impact machine. The sample contains a closely fitted, hardened, cylindrical steel pin in its compression side, for the purpose of eliminating the portion of the sample which is compressed during the test.

In this paper some newly developed tension-bending impact test specimens are introduced. With conventional impact specimens, the energy of tension-deformation is recorded together with the energy of compression - deformation. These newly developed impact specimens are designed in such a manner that the energy recorded will be composed mostly of the energy of tension-deformation. These specimens are notched on the compression side, so that all the material in the breaking section is exposed to tension-bending stresses when undergoing test.

It is suggested that these specimens, which may be notched or unnotched on the tension side may be used to examine the ductile-brittle transition characteristics of metals in general, and to determine the effects of various surface conditions on these characteristics. It is also suggested that tension-bending samples of this type, without notches on the tension side, would provide uniform cross-sections and more regularly distributed tension stresses, with possibilities of direct measurement of the magnitude and direction of principal surface strains. It is expected that data obtained from these newly developed test specimens will provide more direct numerical information for a series of proposed fundamental equations on basic relations between transition temperature, strain rate, and probability of brittle fracture, as well as other information on the theory of the fracture of metals (1, 2, 3, 4).

In describing these tension-bending specimens, the notch on the compression side is referred to as the supporting notch, while that on the tension side is called the breaking notch.

Interesting features of double-notched impact and slow-bend tests are illustrated throughout this paper.

The brittle transition of industrial metals is investigated by impact tests in which the following are recorded, at temperatures below, at, and above the observed brittle transition; (a) the energy required to break the sample of these metals, (b) the fracture appearance, and (c) changes in the fracture dimensions. The ductile-brittle transition characteristics of metal surfaces, and the effects of various surface treatments, can be examined by the proposed double-notched type of impact samples, without breaking notches.

Double-Notched Impact Sample (V-V)

The double-notched impact test sample introduced in this paper is designed to be tested in an Izod type impact machine. The apparatus, with wedged type support and the proposed double-notched tension-bending sample, records mainly the energy used for tension-breaking of the sample. The modified apparatus, the double-notched sample, and the proposed method of tension-bending testing, should all contribute toward further clarification of metallurgical criteria associated with the brittle behaviour and cold brittle transition characteristics of metals, their welds and their surfaces, and may possibly simplify the methods that are in use at the present time. In the conventional Izod type of impact testing machine, the pendulum strikes the cantilever-beam notched bar at the upper end, while the lower end of the sample is gripped rigidly up to the centre of the notch. In the improved version of apparatus used for impact tension-bending, a specially designed wedged-support for a new type of double-notched sample, also with a heavy swinging pendulum, is employed. The basic difference between these two types of tests is in the way test samples are supported. The basic shape of this double-notched impact sample, together with the wedged type grips used to locate the sample in the standard impact machine, is shown in Figure 1a. Some possible modifications of this shape are shown in Figures 2 to 7. The dimensions of these modified samples are contained in Tables I and II.

From these above-mentioned samples, the following were chosen for exploratory studies and experiments:

1. Types A-V and C-V, with three breaking notches 2 mm deep and of 0.25 mm radius.

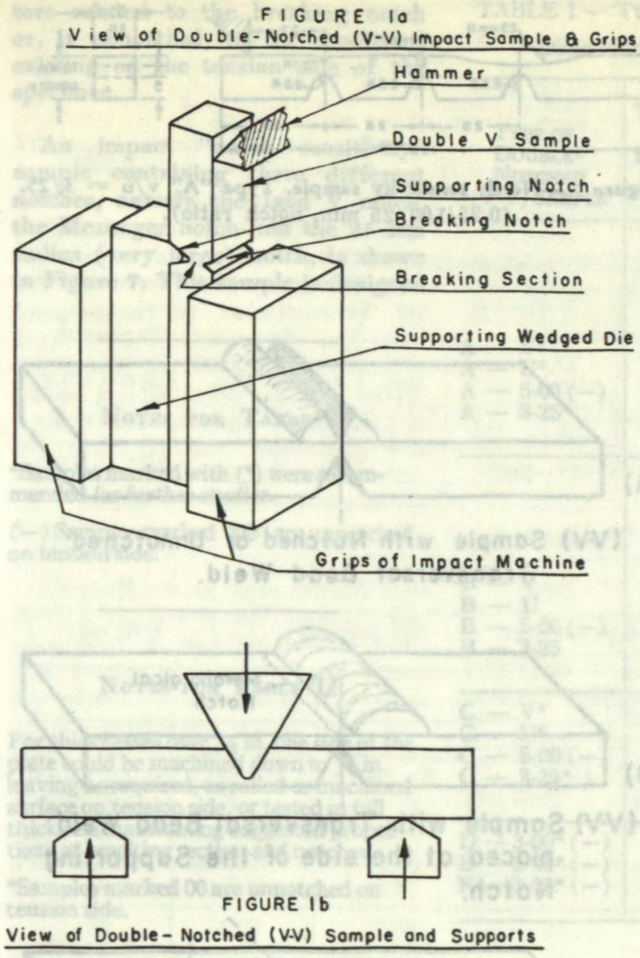
2. Types A-U and C-U, with three breaking notches 2 mm deep and of 1 mm radius.

3. Types A-3-25 and C-3-25, with no breaking notches but with large 25 mm or 1-in. ½-in., ¼-in. and ⅛-in. radius notched undercuts; or, alternatively, without undercut if it is desired to examine the surface in the as-rolled, forged or as-cast conditions. In all these types of samples, a 45° supporting notch with 2.5 mm radius is employed.

4. Types D-3-00 and F-3-00, the unnotched types, with no breaking notch, with a 7 mm deep 45° supporting notch with 2.5 mm radius. This type of sample is employed for studying the effects of different surface treatments and surface conditions in general.

The double-notched impact samples could also be used in non-standard dimensions, e.g. below 10 x 10 mm square cross-sections for small structural elements, or, above this standard size, up to about 30 x 30 mm square cross-sections, for examining larger structural elements.

The general shape of double-notched impact samples recommended for ductility tests of steel plates and welded structures is shown in Figure 6. Dimensions of various examples of double-notched flat impact samples, recommended for this purpose, are given in Table II. Double-notched flat impact samples could be used with breaking notches, as shown in Figure 6 and Table II,



Figures 1*a* and 1*b*.

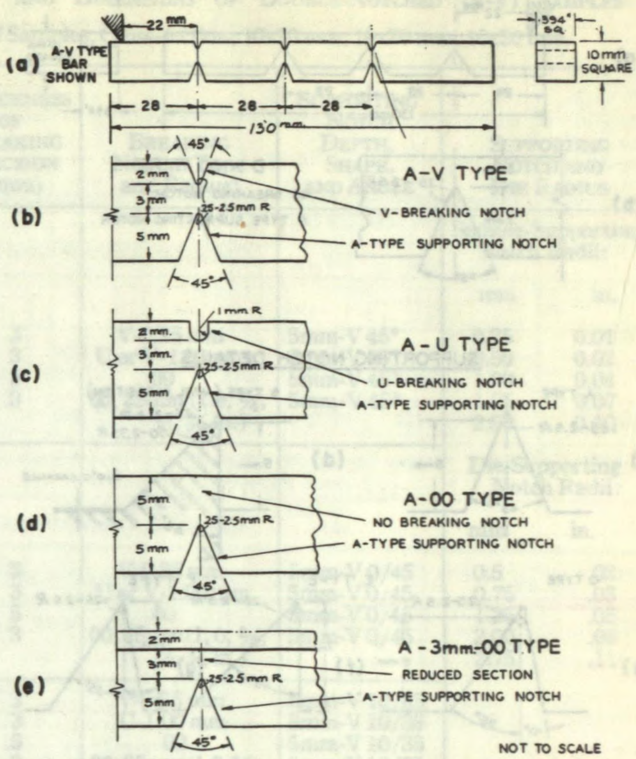


Figure 2.—Details of Type "A" double-notched (V-V) impact samples.

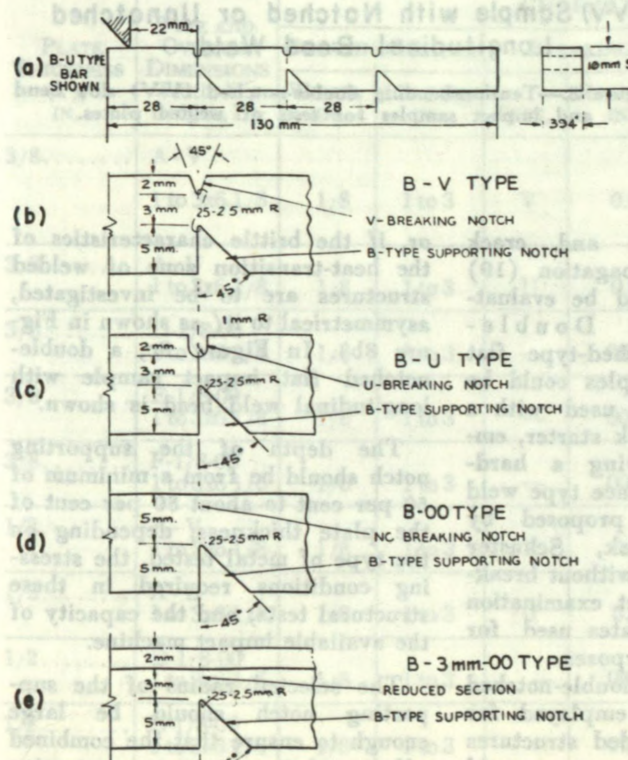
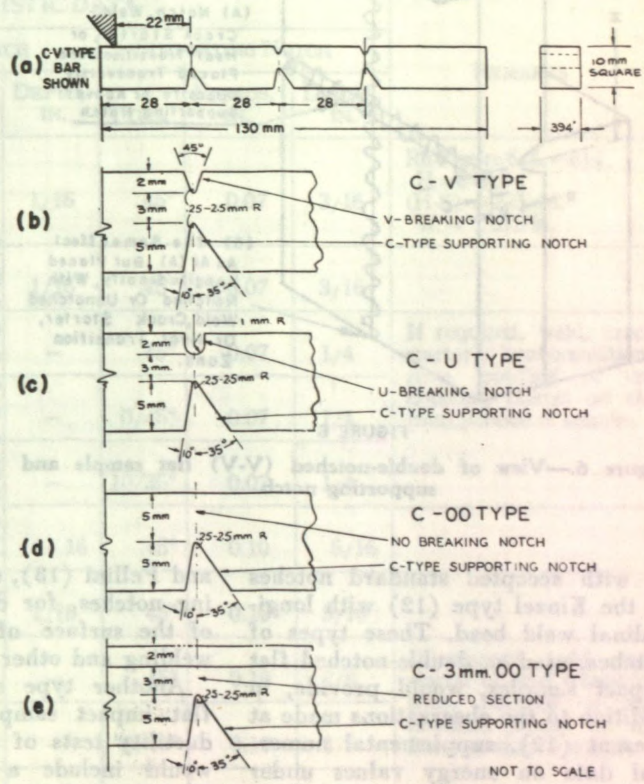


Figure 3.—Details of Type "B" double-notched (V-V) impact samples.



Fgiure 4.—Details of Type "C" double-notched (V-V) impact samples.

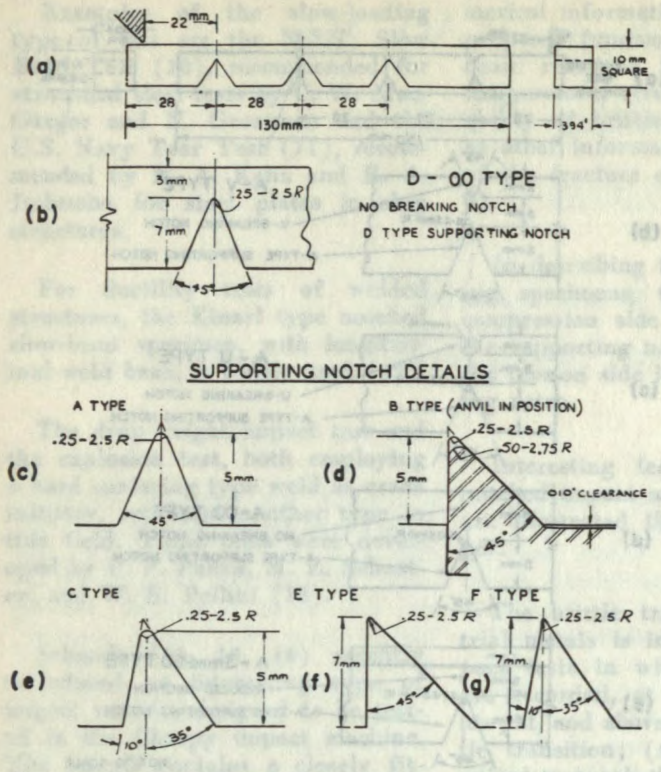


Figure 5.—Details of Type "D" double-notched (V-V) impact samples, and supporting notch details (all tpyes).

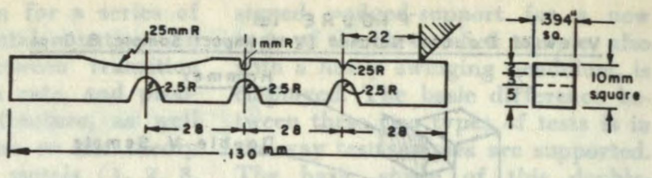


Figure 7.—Notch sensitivity sample, Type "A" v/u = 3/25. (0.25/1.00/25 mm. notch ratio).

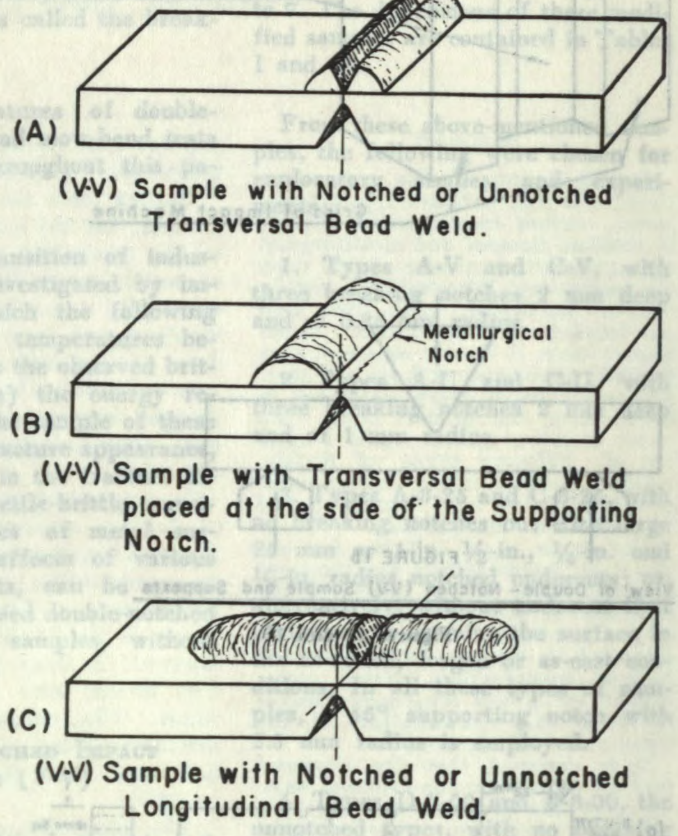


Figure 8.—Tension-bending double-notched (V-V) slow bend and impact samples for tests of welded plates.

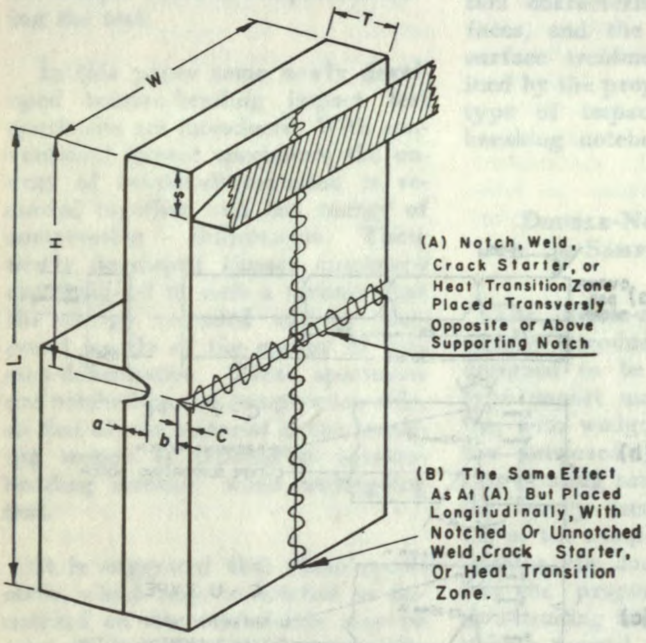


FIGURE 6

Figure 6.—View of double-notched (V-V) flat sample and supporting notch.

or with accepted standard notches of the Kinzel type (12) with longitudinal weld bead. These types of notches, used on double-notched flat impact samples, would provide, in addition to the observations made at present (12), supplemental numerical data on energy values under various load rates. From these data, the energy required for crack initiation and crack propagation (19) could be evaluated. Double-notched-type flat samples could be also used with a crack starter, employing a hard-surface type weld as proposed by Puzak, Schuster and Pellini (13), or, without breaking notches, for direct examination of the surface of plates used for welding and other purposes.

Another type of double-notched flat impact sample employed for ductility tests of welded structures would include a transverse weld bead located opposite the supporting notch (as shown in Figure 8a), or, if the brittle characteristics of the heat-transition zone of welded structures are to be investigated, asymmetrical to it(as shown in Figure 8b). In Figure 8c, a double-notched flat impact sample with longitudinal weld bead is shown.

The depth of the supporting notch should be from a minimum of 50 per cent to about 80 per cent of the plate thickness, depending on the type of metal tested, the stressing conditions required in these structural tests, and the capacity of the available impact machine.

The selected radius of the supporting notch should be large enough to ensure that the combined effects of its stress concentration factor and corresponding strain rates are less effective than the factors related to the breaking notch or, if unnotched, to the conditions existing on the tension side of the specimen.

An impact "notch sensitivity" sample containing three different notches, namely the Izod V notch, the Mesnager notch and the 25 mm radius (very large) notch, is shown in Figure 7. This sample is designed

TABLE I — Type and Dimensions of Double-Notched (V-V) Samples

Dimensions of Samples; Cross-section; 10x10 mm; 10x20 mm; 10x30 mm.

Type of Double-Notched (V-V) Sample	Thickness of Breaking Section (mm)	Breaking Notch (Type and Radius)	Supporting Notch Depth, Shape, and Angle	Supporting Notch and Die Radius	
				Sample-Supporting Notch Radii:	
				mm	in.
A — V*	3	V-0.25 mm	5mm-V 45°	0.25	0.01
A — U*	3	U or V-1.00 mm	5mm-V 45°	0.50	0.02
A — 5-00 (–)	5	00	5mm-V 45°	1.00	0.04
A — 3-25*	3	00, 25mm (1.0, ¾, ½, ¼ in.)	5mm-V 45°	1.75	0.07
				2.50	0.10
				Die-Supporting Notch Radii:	
				mm	in.
B — V	3	V-0.25 mm	5mm-V 0/45	0.5	.02
B — U	3	U or V-1.00 mm	5mm-V 0/45	0.75	.03
B — 5-00 (–)	5	00	5mm-V 0/45	1.25	.05
B — 3-25	3	00, 25mm (1, 0, ¾, ½, ¼ in.)	5mm-V 0/45	2.00	.08
				2.75	.11
C — V*	3	V-0.25 mm	5mm-V 10/35		
C — U*.	3	U-1.00 mm	5mm-V 10/35		
C — 5-00 (–)	5	00	5mm-V 10/35		
C — 3-25*	3	00, 25mm (1.0, ¾, ½, ¼ in.)	5mm-V 10/35		
D — 3-00* (–)	3	00	7mm-V 45		
E — 3-00* (–)	3	00	7mm-V 0/45		
F — 3-00* (–)	3	00	7mm-V 10/35		

Notes for Table I

*Samples marked with (*) were recommended for further studies.

(–) Samples marked "00" are unnotched on tension side.

Notes for Table II

For thicknesses over ½ in. one side of the plate could be machined down to ½ in. leaving as required, as rolled or machined surface on tension side, or tested in full thickness maintaining suggested proportions of breaking section and notches.

*Samples marked 00 are unnotched on tension side.

TABLE II — Type and Dimensions of Double-Notched (V-V) Flat (Plate) Samples

Plate Thickness (T), in.	Type and Overall Dimensions Width, W; Length, L)	Characteristic Data								Remarks
		Breaking Section		Breaking Notch			Supporting Notch			
		Width, in.	Length, in.	Type,	Radius, in.	Depth, in.	Type,	Radius, in.	Depth, in.	
3/8.......	A - V 1 to 3x6 1/8	1/8	1 to 3	V	0.01	1/16	45°	0.07	3/16	Re Figure 6: L = 6⅛, H = 2-5/8 (H-S) = 2-5/16, W = 1 to 3 in.
3/8.......	A - U 1 to 3x6 1/8	1/8	1 to 3	U	0.04	1/16	45°	0.07	3/16	
3/8.......	D-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	45°	0.07	1/4	If required, weld, crack starter or heat transition zone, notched or unnotched, placed on the front portion of sample.
3/8.......	E-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	0/45°	0.07	1/4	
3/8.......	F-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	10/35°	0.07	1/4	
1/2.......	A - V 1 to 3x6 1/8	1/8	1 to 3	V	0.01	1.16	45°	0.10	5/16	
1/2.......	A - U 1 to 3x6 1/8	1/8	1 to 3	U	0.04	1/16	45°	0.10	5/16	
1/2.......	D-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	45°	0.10	3/8	If required, weld crack starter or heat transition zone, notched or unnotched, placed on the front portion of sample
1/2.......	E-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	0/45°	0.10	3/8	
1/2.......	F-1/8-00 1 to 3x6 1/8	1/8	1 to 3	—	00*	–	10/35°	0.10	3/8	

TABLE III — (a) CHEMICAL COMPOSITION OF STEEL (%)

STEEL	CARBON	MANGANESE	PHOSPHORUS	SULPHUR	SILICON	CHROMIUM	NICKEL	Boron
SAE 1085	0.87	0.24	0.021	0.020	0.17			
SAE 1045	0.43	0.71	0.015	0.016	0.21			
SAE 2315	0.12	0.54	0.013	0.012	0.20	1.49	3.60	
Constructional Alloy Steel	0.16	0.75	0.021	0.027	0.24	0.55	0.82	0.005*

*Used for welded samples shown in Figure 12.

(b) CHEMICAL COMPOSITION LIMITS OF ALUMINUM ALLOYS (%)

ALLOY	CU		FE	MG		MN	SI	TI	ZN		CR		OTHER ELEMENTS	
	MAX.	MIN.	MAX.	MAX.	MIN.	MAX.	MAX.	MAX.	MAX.	MIN.	MAX.	MIN.	EACH	TOTAL
Alcan 75S	2.0	1.2	0.7	2.9	2.1	0.3	0.5	0.2	6.1	5.1	0.4	0.18	0.05	0.15
Alcan 350	0.15	—	0.3	10.6	9.5	0.1	0.2	0.2	—	—	—	—	0.05	0.15

(c) CHEMICAL COMPOSITION OF MAGNESIUM ALLOY (%)

ALLOY	AL	ZN	MN	NI	FE
AZ80	7.5 — 8.5	0.30 — 0.70	0.15 — 0.40	0.01 max	0.03 max

TABLE IV — MECHANICAL PROPERTIES

	ULTIMATE STRESS, kpsi	0.2= PROOF STRESS, psi	ELONGATION, 4 x dia. (%)	ELONGATION, 5 x dia. (%)	REDUCTION IN AREA, (%)	ROCKWELL B HARDNESS
Alcan 75S-T6	93.2	N.D.	8.0	6.5	15.7	90
Magnesium AZ80-F (Extruded)	50.3	39.3	4.8	6.4	N.D.	32
Commercial bronze (drawn)	70.5	41.8	35.1	32.9	80.5	80
Commercial yellow brass	73.6	53.6	20.0	17.3	59.0	74
Copper (hard drawn)	44.5	44.5	20.0	15.2	66.5	41
SAE 1085, as rolled, plant annealed	87.1	45.2	24.8	23.8	43.3	88
SAE 1085, laboratory annealed	102.0	46.7	20.0	16.2	29.0	90
SAE 1045	93.1	65.7	29.6	26.4	24.9	87
SAE 2315	135.5	74.0	16.4	14.2	32.6	88
Constructional alloy steel	114.3	105.7	—	—	51.9	98

N.D. = Not determined.

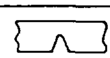
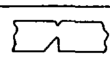
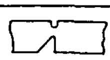
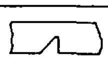
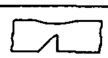
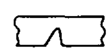
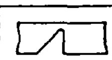
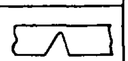
Type of Sample	Breaking Notch (type and radius)	Supporting Notch, radius:0.25 mm Depth and shape	Average Impact Energy (ft-lb sample)	Average Fracture Deformation of: leading edge, trailing edge, supporting edge	Remarks
A - V	V - 0.25 mm	5mm V 45°	2.5	A X 2 -.000 -.000 +.002	
A - U	U - 1.00 mm	5mm V 45°	25.0	A X 1 -.020 -.005 +.039	
A - 5-00	00	5mm V 45°	113.0	A X 1 -.035 -.015 +.035	
A - 3-25	25mm	5mm V 45°	33.0	A C C M -.033 -.012 +.048	
B - V	V - 0.25 mm	5mm V 0/45°	3.0	A X 2 -.002 -.000 +.003	
B - U	U - 1.00 mm	5mm V 0/45°	25.0	A -M X 2 -.024 -.004 +.030	
B -5-00	00	5mm V 0/45°	105.0	A -M X 1 -.044 -.015 +.092	
B - 3-25	25mm	5mm V 0/45°	31.0	A -M X 1 -.024 -.012 +.040	
C - V	V - 0.25 mm	5mm V 10/35	3.0	A X 2 -.002 -.000 +.002	
C - U	U - 1.00 mm	5mm V 10/35	27.0	A -M X 2 -.024 -.006 +.037	
C - 5-00	00	5mm V 10/35	100.0	A -M X 1 -.042 -.014 +.090	
C - 3-25	25 mm	5mm V 10/35	31.0	A X 1 -.026 -.014 +.042	
D - 3-00	00	7mm V 45°	20.5	A X 1 -.013 -.010 +.020	
E - 3-00	00	7mm V 0/45°	24.8	A X 1 -.014 -.007 +.024	
F - 3-00	00	7mm V 10/35	17.5	A X 2 -.011 -.008 +.022	

Table V.—Tension-bending values of various double-notched (V-V) samples, SAE 1085 steel, ½-inch square, as rolled (plant annealed).

to provide a notch sensitivity index for 0.25/1.00/25 mm or other notch ratios at different temperatures.

Double-Notched Tension-Bending Impact Tests

In order to select the most suitable type and shape of double-notched tension-bending impact samples to be recommended for further exploratory tests and studies, a set of samples as listed in Table I was prepared and tested. SAE 1085 steel, ½-in. square, in the plant-annealed condition, was used for these comparison tests. The results obtained are listed in Table V.

On the basis of these results, type A-V, A-U, A-3-25 and D-3-00 samples were selected for further tests. The results of an investigation into the effect of increasing the radius of the supporting notch from 0.25 mm (0.01 in.) to 2.5 mm (0.1 in.) are shown in Tables VI, VII and VIII and Figures 9, 10 and 11. Steel SAE 1085, aluminum alloy 75S-T6, and magnesium alloy AZ80-F were used in these tests.

Type D-3-00 samples, with 0.25 and 2.5 mm radius supporting notches, were used to study the impact tension-bending characteristics of SAE 1085 steel with machined and unmachined (as-rolled) surfaces.

These tests were carried out at temperatures extending above and below the brittle to ductile transition temperature. The testing temperatures ranged from —70°F to +284°F. The results obtained in this series of tests are shown in Tables IX and X.

The data shown in Table IX were obtained on type D-3-00 samples with a sharp 0.25 mm (0.01 in.) radius supporting notch. In these tests, very likely, the notch-severity of the sharp supporting notch was the limiting factor, and therefore the tension-bending impact characteristic of the surface was not properly revealed. In order to reveal the natural impact characteristic of machined and as-rolled surfaces under examination, the radius of the supporting notch was increased from 0.25 mm to 2.5 mm.

The data obtained with a 2.5 mm radius supporting notch are given in Table X. This change, which was based on the test data shown in Table VI and Figure 9, removed the possible limitations imposed by the 0.25 mm radius notch.

The average impact-notch-sensitivity indices, both actual and relative, determined for SAE 1085 steel, SAE 1045 steel, 75S-T6 aluminum alloy, an extruded AZ80-F magnesium alloy, and other metals, are shown and defined in Table XI. These values were obtained at room temperature. The chemical composition and mechanical properties of the alloys used to illustrate the impact notch-sensitivity indices are given in Tables III and IV.

During tension-bending impact loading, the upper portion of the test sample bears on the wedged support held in the supporting notch, and the portion of the sample in contact with this support is exposed to large compression stress-

SAMPLE	DOUBLE - NOTCHED (VV)				IZOD TYPE (SQUARE)		
	A - V	A - U	A - 3 - 25	D - 3 - 00			
Supporting Notch, 0.01 in. Radius (Breaking energy in ft-lb)	1.2	5.0	19.5	15.1	1.8	5.7	141.8
Change in (Leading Edge	.000	-.005	-.013	-.008	-.001	-.005	-.055
Change in (Trailing Edge	.000	-.002	-.006	-.004	-	-	-
Change in (Supporting Edge	.000	+.002	+.025	+.015	.000	+.004	+.065
Fracture	AX2	AX2	AX1	AX2	AX2	AX2	A 1/2M-1/2MX1
Supporting Notch, 0.02 in. radius	1.0	4.4	28.7	18.5			
Supporting Notch, 0.04 in. radius	1.7	5.4	29.8	22.8	CHARPY TYPE		
Supporting Notch, 0.07 in. radius	1.9	4.5	34.2	28.1			
Supporting Notch, 0.10 in. radius	2.5	6.1	37.4	39.4	2.1	6.5	181.6
Change in (Leading Edge	-.001	-.004	-.021	-.018	.000	-.003	-.055
Change in (Trailing Edge	-.001	-.002	-.009	-.015	-	-	-
Change in (Supporting Edge	+.002	+.003	+.040	+.035	.000	+.003	+.086
Fracture	AX2	AX2	AX1	AX1	AX2	AX2	A 1/2M-1/2MX1

Table VI.—Dougle-notched (V-V) Izod and Mesnager impact data, SAE 1085 laboratory annealed steel.
(Average of six tests).

SAMPLE	DOUBLE - NOTCHED (VV)				IZOD TYPE SQUARE		
	A — V	A - U	A - 3 - 25	D - 3 - 00			
Supporting Notch, 0.01 in. radius Breaking energy in ft-lb	4.0	7.0	8.1	8.5	4.8	7.0	30.1
Fracture	BCM1	BCM1	ACM1	AM1	AMX1	AMX1	BM1
Supporting Notch, 0.02 in. radius	4.0	6.7	11.2	9.0			
Supporting Notch, 0.04 in. radius	4.0	7.0	8.9	8.5	CHARPY TYPE		
Supporting Notch, 0.07 in. radius	3.5	5.7	9.5	9.7			
Supporting Notch, 0.10 in. radius	4.0	6.5	18.3	11.0	5.0	9.0	49.7
Fracture	ACM1	BM1	ACM1	AM1	AMX1	AMX1	BM1

Table VII.—Double-notched (V-V) Izod and Mesnager impact data, aluminum alloy 755-T6.
(Average of six tests. Breaking energy in foot-pounds).

SAMPLE	DOUBLE - NOTCHED (VV)				IZOD TYPE (SQUARE)		
	A - V	A - U	A - 3 - 25	D - 3 - 00			
Supporting Notch, 0.01 in. radius (Breaking energy in ft-lb)	1.8	2.4	6.3	5.7	1.6	2.8	11.5
Fracture	CM1	CM1	BM1	AM1	A-MX1	A-MX1	AM1
Supporting Notch, 0.02 in. radius	1.2	2.0	6.4	6.6			
Supporting Notch, 0.04 in. radius	1.2	1.9	6.7	5.6	CHARPY TYPE		
Supporting Notch, 0.07 in. radius	1.5	2.0	6.3	7.7			
Supporting Notch, 0.10 in. radius	1.8	3.2	7.1	11.0	2.1	3.1	22.0
Fracture	BM1	AM1	BM1	AM1	A-MX1	A-MX1	AM1

Table VIII.—Double-notched (V-V) Izod and Mesnager impact data, magnesium alloy AZ80-F (extruded).
(Average of six tests. Breaking energy in foot-pounds).

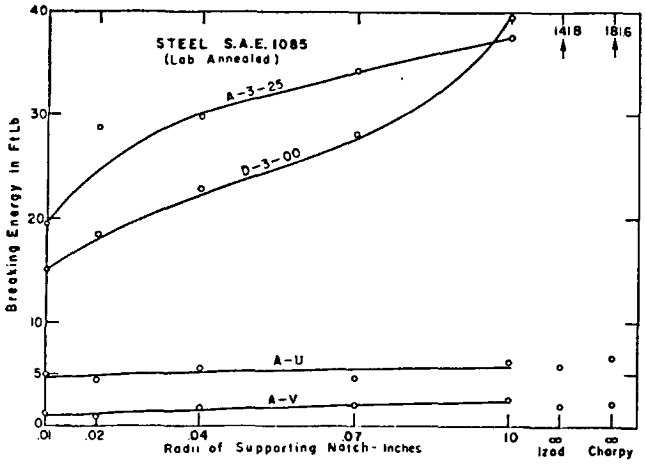


Figure 9.—Breaking energy *vs.* supporting notch radius, for SAE 1085 steel.

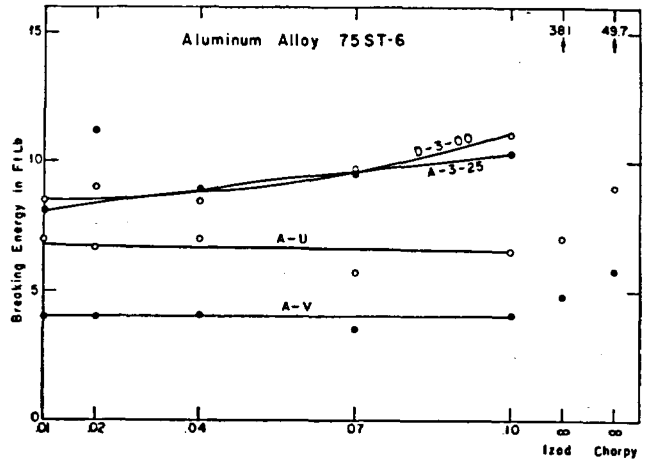


Figure 10.—Breaking energy *vs.* supporting notch radius, for aluminum alloy 75ST-6.

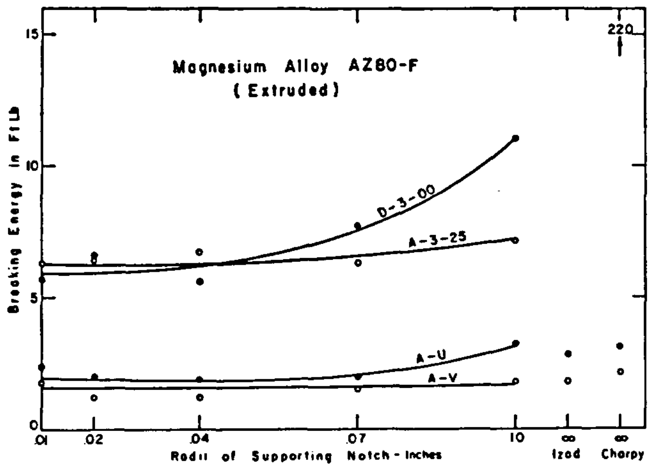


Figure 11.—Breaking energy *vs.* supporting notch radius, for magnesium alloy AZ 80-F (extruded).

es. These compression stresses cause a local mushrooming, which was recorded as expansion of the supporting edge in Tables V, VI, IX and X, during the preliminary tests. This expansion was found to be almost negligible below the ductility transition temperature, and this is helpful and desirable in determination of this transition. Since the energy required for plastic compression deformation is recorded together with the tension breaking energy, the supporting notches were designed with a view to keeping the amount of compression deformation to a minimum.

Discussion of Test Results

Results obtained on Type A, B and C double-notched samples (see Table V) show that the effect of the change in the supporting notch angle from 45° to 0/45 and 10/35° is relatively small. This also applies for sample types D, E and F.

The effect of the changes in the severity of breaking notches from 0.25 mm radius (0.01 in.) to 1.0 mm radius (0.04 in.) was just as would be expected, i.e., a corresponding increase in breaking energy is recorded with the reduction of notch severity. Similarly, the unnotched samples yielded correspondingly higher impact values.

Data given in Table VI show that with double-notched impact samples, types A-V and A-U, of SAE 1085 steel, laboratory annealed, an increase in supporting notch radius from 0.25 mm (0.01 in.) to 1.75 mm (0.07 in.) does not appreciably affect the breaking energy required. However, a further increase of the radius from 1.75 mm (0.07 in.) to 2.5 mm (0.1 in.) has a more pronounced effect. The following two factors might contribute to this effect: first, a larger radius extends the volume of metal exposed to plastic deformation and hence raises the required breaking energy, and secondly, the increased radius of the supporting notch results in a reduction in stress concentration. It is obvious that in samples A-V and A-U the break occurs at the breaking notch first, and the notch severity of the breaking notch is the governing factor with these types of samples. In samples A-3-25 and D-3-00, the effect of increasing the radius of the supporting notch is more pronounced because, with, respectively, a large 25 mm (1 in.) radius breaking notch, or with no breaking notch, the severity of the supporting notch might be the limiting factor.

Similar observations can be made concerning the data in Tables VII and VIII. However, probably because of the shear character of the fractures recorded for these aluminum and magnesium alloys, this effect appears less pronounced.

Close analysis of the test data given in Tables VI, VII and VIII indicates that the 2.5 mm (0.1 in.) radius supporting notch, and in some cases the 1.75 mm (0.07 in.) (see Table II) radius supporting notch, should be recommended for the double-notched tension-bending impact and slow-bend tests. (Fig. 1b).

Examination of the tension-bending impact characteristics of as-machined and as-rolled surfaces, as shown in Tables IX and X for the D-3-00 sample with 0.25 mm and 2.5 mm radius supporting notches, reveals that under these conditions the brittle transition of the as-rolled surface and that of the as-machined surface are not much different, for the SAE 1085 steel.

Since surface finish has a very pronounced effect on the endurance and the fatigue limit of metals, it would be interesting to study the relationship between the tension-bending brittle transition characteristics of metal surfaces (16). Further studies in this field should be encouraging and may lead to better understanding of the effect of surface conditions on the brittle characteristics and the behaviour under fatigue conditions.

TABLE IX — TENSION-BENDING CHARACTERISTICS

Sample: D-3-00; supporting notch, 0.25 mm (0.01 in.) 1085 Steel ½ sq. as-rolled (plant annealed)

Test Temp. (°F.)	Machined Surface: Average Energy (Ft-lb) (notch)	Machined Surface: Type of Fracture	Machined Surface: Deformation of Leading edge Trailing edge Supporting edge, inch	Unmachined Surface: Average Energy (Ft-lb) (notch)	Unmachined Surface: Type of Fracture	Unmachined Surface: Deformation of Leading Edge Trailing edge Supporting edge, inch
−76 (−60°C)	3.1	AX2	−.001 (0.25%) .000 .000	3.3	AX2	−.001 (0.25%) .000 .000
−4 (−20°C)	3.5	AX2	−.003 (0.75%) .000 .000	3.6	AX2	−.002 (0.50%) .000 .000
68 (+20°C)	7.3	AX2	−.006 (1.5%) −.004 (1.0%) +.004 (1.0%)	7.0	AX2	−.005 (1.3%) −.001 (0.25%) +.002 (0.50%)
104 (+40°C)	8.6	AX2	−.006 (1.5%) −.004 (1.0%) +.006 (1.5%)	8.6	AX1	−.007 (1.7%) −.004 (1.0%) +.009 (2.3%)
140 (+60°C)	11.1	AX1	−.009 (2.3%) −.005 (1.3%) +.012 (3.0%)	11.0	AX1	—.009 (2.3%) −.005 (1.3%) +.013 (3.5%)
176 (+80°C)	15.0	A 1.4 MI ¾ X 1	−.015 (3.7%) −.008 (2.0%) +.019 (4.7%)	16.0	AC 2/3 MI 1/3 X 1	−.017 (4.3%) −.007 (1.7%) +.020 (5.0%)
212 (+100°C)	20.5	AC ¾ MI ¼ X 1	−.015 (3.7%) −.008 (2.0%) +.024 (6.0%)	22.6	ACMI	−.021 (5.3%) −.008 (2.0%) +.028 (7.0%)
284 (+140°C)	23.7	ACM1	−.021 (5.1%) −.008 (2.0%) +.033 (8.2%)	21.2	ACM1	−.021 (5.3%) −.007 (1.7%) +.027 (6.7%)

Testing results for impact testing would not be complete if they did not contain data on range of impact energy transition, fracture-transition, and ductility-transition.

Impact energy transition temperature for tension-bending impact tests may be obtained from examination of the values of energy required to break one test section, in foot-pounds, recorded for a selected range of testing temperatures.

The fracture transition temperature range is determined from visual observations of the fractured surface, employing the proposed table of fractured impact samples (see Table XII) set up for the purpose of simplification and standardization of the tests.

Examples of application for the fracture table are shown in Tables V to X. The proposed fracture Table XII could be applied to the majority of impact fractures. In cases where unusual and irregular fractures are encountered, additional descriptions and photographic methods could be applied.

TABLE XI — AVERAGE NOTCH SENSITIVITY FACTORS AT ROOM TEMPERATURE

For selected notch combination 0.25/1.00/25.0 mm

	Material	Direct Notch Sensitivity Factor Ratio of Energy Absorbed. in ft-lb (Supporting Notch Radius, 0.1 in). V notch: A-V	U notch: A-U	25 mm notch: A-3-25	Relative Notch Sensitivity Factor. Ratio of: A-V/A-U/A-3-25 over A-V
1	SAE 1045	20.0	29.0	57.0	1/1.5/2.9
2	SAE 1085 (lab annealed)	2.5	6.1	37.4	1/2.5/15.0
3	SAE 2315	11.0	23.0	42.8	1/2.1/3.9
4	75ST (Alcan)	4.0	6.5	10.3	1/1.6/2.6
5	Alum. Casting Alloy .. Alcan 350-W	5.0	7.0	19.6	1/1.4/3.9
6	Magnesium Alloy AZ80-F (extruded)	1.8	3.2	7.1	1/1.8/3.9
7	Copper (hard drawn)	10.0	11.5	19.5	1/1.2/2.0
8	Commercial Yellow Brass (drawn)	4.5	8.5	25.5	1/1.9/5.7
9	Commercial Bronze (drawn)	12.0	16.5	35.0	1/1.4/2.9

TABLE X — Tension-Bending Characteristics

Sample: D-3-00; Supporting Notch 2.5 mm (0.10 in.) SAE 1085 Steel, ½ in. sq. (laboratory annealed)

	Machined Surface			Unmachined Surface		
Test Temp. (°F.)	Average Energy (Ft-lb) (Notch)	Type of Fracture	Deformation of Leading edge Trailing edge Supporting edge, inch	Average Energy (Ft-lb) (Notch)	Type of Fracture	Deformation of Leading edge Trailing edge Supporting edge, inch
−76 (−60°C)	4.7	AX3	−.002 −.002 +.002	3.5	AX3	−.002 −.002 +.002
−40 (−40°C)	10.7	AX2	−.007 −.006 +.005	7.2	AX2	−.002 −.002 +.002
−4 (−20°C)	22.7	AX2	−.008 −.008 +.012	18.0	AX2	−.008 −.006 +.012
32 (0°C)	21.0	AX2	−.010 −.009 +.017	29.6	AX1	−.015 −.014 +.027
68 (+20°C)	34.4	AX2	−.015 −.013 +.035	35.5	AX1	−.017 −.015 +.033
104 (+40°C)	32.0	AX1	−.016 −.016 +0.30	28.7	AX1	−.012 −.012 +.026
140 (+60°C)	30.9	AX1	−.014 −.014 +.029	26.0	AX1	−.014 −.014 +.027
176 (+80°C)	29.7	AX1	−.015 −.014 +.028	32.0	AX1	−.017 −.015 +.027
212 (+100°C)	34.5	CCM1	−.022 −.018 +.034	33.0	AX1 CCM1	−.016 −.015 +.034
248 (+120°C)	35.8	CCM1	−.022 −.016 +.032	30.0	CCM1	−.020 −.013 +.030
284 (+140°C)	31.8	CCM1	−.020 −.015 +.032	34.5	CCM1	−.021 −.013 +.030

The ductility-transition-temperature range can be set up by using percentage figures taken from the transversal contraction of the cross-section for the samples, measured at the bottom of the breaking notch (leading edge).

In order to obtain a complete picture of the characteristics of plastic deformation taking place during tension-bending loading in the first groups of tests (Tables V to X), the transverse contraction at the bottom of the supporting notch (trailing edge) was also recorded. The presence of this contraction is a direct indication of the existence of tension strain at the bottom of the supporting notch, and indicates, also, that the whole breaking section was exposed to tension strain.

General Discussion

The proposed double-notched impact samples provide, for practical metallurgical and mechanical testing, a wide range in severities of stress concentration factors and in rates of straining (Figure 17).

The tri-axiality of loading of double-notched samples can be regulated by increasing the width of the sample in the breaking method area, by variations in the transverse dimensions of breaking and supporting notches, and by variations in the thickness of the test section. The rate of straining, accentuated by sharpness of notches, is regulated by the height from which the hammer is dropped and by the dimensional relations between sample and hammer (Figure 17).

The dimensions and shapes of double-notched impact samples are listed in Tables I and II and are shown in Figures 2 to 7. A wide variety of further modifications of double-notched impact samples could be applied to suit other particular requirements.

In the initial stage of this exploratory work, three shapes of supporting notches were included. A 45° type was selected as a supporting notch with a 22.5/22.5° position from the horizontal plane for type A, 0/45° for type B and 10/35° for type C wedged grips, respectively. The fixed 45° angle of the supporting notch and the varying inclined angle of the supporting plane (22.5° for type A, 10° for type C, and 0° for type B) had a correspondingly varying effect on the ratio of normal and shear stresses during the loading of the sample.

Use of double-notched samples should reduce in a simple and inexpensive way the volume of metal, located at the breaking section, that is exposed to compression stresses, by replacing it with a hardened steel wedge pressed into the space taken by the supporting notch as shown in Figures 1a and 6.

In all modifications of double-notched samples listed in Tables I and II, the breaking section is exposed mainly to tension-bending stresses and the compression volume is shifted to the wedge type of hardened steel support.

By employing a supporting notch, simple in shape and easy to machine, inexpensive samples that have no breaking notch, such as types A-5-00 and A-3-25, could be broken easily with a more regular fracture under tension-bending loading than could the conventional type of unnotched samples. This type of test should also provide very interesting information on transition temperature ranges of energy, fracture and ductility on unnotched samples and, combined with data obtained on notched samples with notches of variable severities, e.g. 0.25, 1.0 and 25 mm, or other combination of notches, should enable us to set up a notch-sensitivity index for different metals as discussed previously and shown in Table XI.

The impact notch sensitivity index, direct and relative, set up from impact-tension-bending energies obtained on samples Types A-V and A-U for 0.25 mm and 1 mm breaking notches and on unnotched test samples Types A-3-00 and D-3-00, would be an interesting guide, from the metallurgical and mechanical viewpoint, to be used in the application of different metals. This notch sensitivity index at different temperatures could supply the designer with information concerning the safe range of application for different metals in structures where, because of working conditions, brittle failure should be avoided.

Flat double-notched tension-bending impact and slow-bend samples, without geometrical breaking notch, of types shown in Figure 6 and listed in Table II, could be applied to direct tests concerning the effect of different surface conditions and surface treatments on impact and slow bend tests at room, low and elevated temperatures. In this type of proposed double-notched tension-bending sample, the breaking section, i.e. the volume of metal opposite the supporting notch, is exposed to tension-bending stress distributions which are similar to those of many practical examples in actual structural design. The restraining conditions and the tri-axiality of loading in this flat type of sample could be regulated by the width of the sample, up to 3 in., and by the thickness of the tested section and depth of the supporting notch. The rate of straining is affected by the elevation of the impact hammer, the distance between tested section and striking edge, and other conditions. The flat surface opposite the supporting notch provides many different possibilities concerning the preparation of the tested surface, and is large enough to provide sufficient area for testing the surface in such various conditions as: rough, as-rolled, forged, as-cast, carburized, decarburized, shot peened, spiral-rolled, (i.e. differential plastic deformation), cold rolled, heat transition zone, and welded.

The study of the tension-bending properties of metal surfaces, with particular attention to their brittle transition characteristics, is of direct interest in the evaluation of their future behaviour as elements forming a structure or machine.

TABLE XII. — TABLE FOR CLASSIFICATION OF FRACTURES

(a) SYMBOLS FOR CLASSIFICATION OF THE SHAPE OF FRACTURED SPECIMENS

1.	"A"	— regular fracture
2.	"B"	— irregular fracture
	"BB"	— very irregular fracture
3.	"C"	— oblique-shaped fracture (shear fracture less than 45°)
	"CC"	— typical oblique-shaped fracture of the whole area (45° shear fracture)

(b) SYMBOLS FOR CLASSIFICATION OF THE STRUCTURE OF FRACTURED SPECIMEN SURFACES

1.	"M"	— matte fracture
	"M1"	— matte fracture, fine grain. (M2, M3, matte fracture, medium and coarse grains)
2.	"X"	— crystalline fracture
	"X1"	— crystalline fracture, fine bright grain (X2 and X3, medium and coarse bright grains)
3.	"MX"	— matte-crystalline fracture
	"MX1"	— matte-crystalline fracture find grains (MX2 and MX3, medium and coarse grains)
4.	"MD", "XD", "MXD", "WD"	— fracture with grains showing dendritic structure
5.	"W"	— fibrous, woody apprearance
	"WW"	— distinct fibrous fracture
6.	Figures ¼, ½, ¾, etc. affixed to symbols M, X, MX, etc., denote fractional parts of fracture which are matte, crystalline, or matte-crystalline, etc. Symbols (in) or (out) denote that these fractional parts are "inside" or "outside" the cross-section.	
7.	"H"	— flaky fracture, bright crystalline flakes caused by hydrogen embrittlement etc.
8.	"Ni"	— fracture with non-metallic inclusions
	"Np"	— fracture showing porosity
	"Nm"	— fracture showing metallic segregations
9.	Recording of dimensional changes of fractured section used in the observations of the ductility-transition of samples: (a) transversal contraction at the *leading edge* (or leading surface in the unnotched samples). (b) transversal contraction at the *trailing edge*. (c) transversal expansion of the *supporting edge*.	

REMARKS
1. The magnitude of the angle to which the sample is bent can be measured and recorded in degrees, as shown in example below.
2. The symbols should be placed in sequence as listed in the Table (see example below).

EXAMPLE

Fracture classified as BM2Ni-90, means an irregular fracture, matte, medium grain, with non-metallic inclusions, bent 90°.

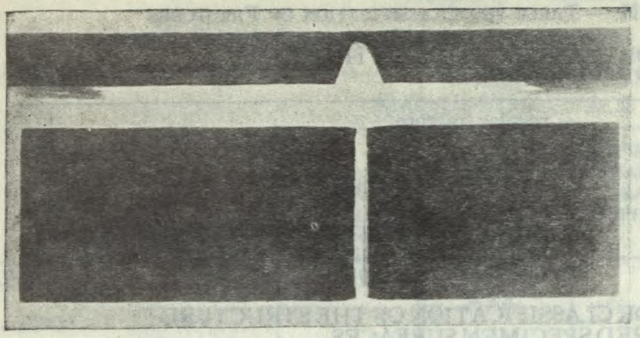


Figure 12.—Tension-bending (V-V) sample for testing of plates.

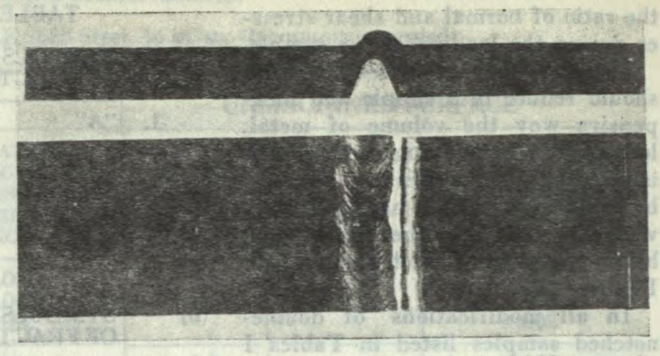


Figure 13.—Tension-bending double-notched (V-V) sample with transverse bead weld, as shown in Figure 8-A.

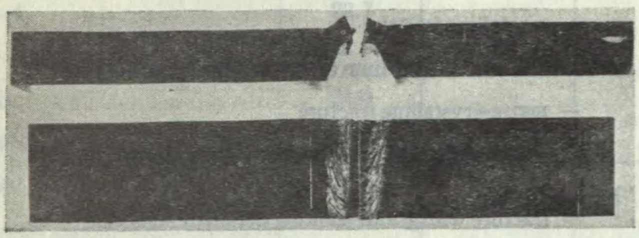


Figure 14.—Tension-bending double-notched (V-V) sample with notched transverse bead weld, as shown in Figure 8-A.

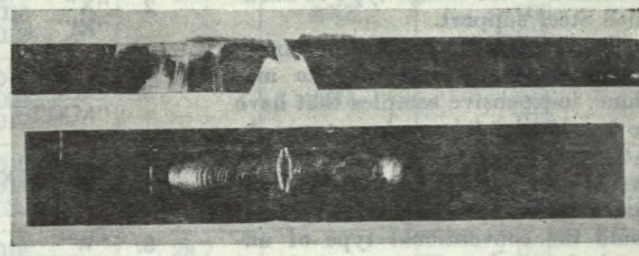


Figure 15.—Tension-bending double-notched (V-V) sample with notched longitudinal bead weld, as shown in Figure 8-C.

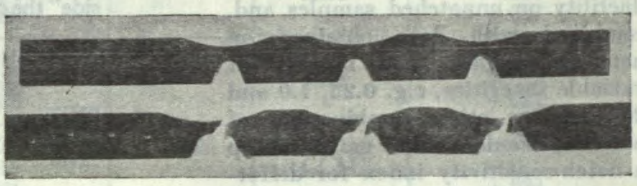


Figure 16.—Tension-bending double-notched (V-V) sample. Type A-3-25.

It should be realized that test data obtained on double-notched (V-V) samples where the surface is left in its original condition, i.e. as used in final design, have a more direct bearing on the performance and safety of an actual element than have the test data obtained from machined samples.

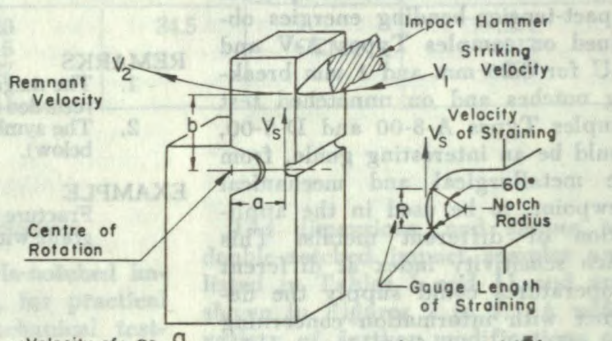
The effects of various surface conditions and surface treatments could also be compared with one another, or compared with a standard surface not affected by treatment under investigation. Both weldability and the effect of welding could be checked by the tension-bending testing of welded and unwelded samples in the selected temperature range and testing conditions. Test data so obtained would provide impact energy values for selected temperatures. Fracture and plasticity transition temperatures for each type of sample could also be obtained from these tests. All this information is very helpful in evaluating the weldability of the material.

During preliminary tests, a flat, double-notched, tension-bending impact sample 1¾ and 1 in. wide, 6⅛ in. long, and ½ in. thick was used. The supporting notch was 2.5 mm in radius and ⅜ in. deep.

Using an impact hammer of 200 ft.-lb. capacity, practically all standard steels can be broken with enough range for recording lower impact values caused by various types of surface imperfections, including welding, heating, residual stresses and others. Figures 12, 13, 14, 15 and 16 show few typical examples of broken double-notched impact samples.

Conclusions

The application of the proposed double-notched (V-V) impact, slow-bend and similar "drop weight" tests can be explored in a number of fields, after necessary modifications of existing testing machines. Selected double-notched (V-V) impact samples, listed in Tables I and II and shown in Figures 1 to 7, could be used for general impact tests, and the data obtained could contribute to a better understanding of the cold brittle behaviour of metals, particularly with respect to the effect of surface conditions.



$$V_s\left(\begin{smallmatrix}\text{Velocity of}\\ \text{Straining}\end{smallmatrix}\right) \cong \frac{a}{b} \cdot V_1 \cdot U; \quad U = F(V_1, V_2, M^*)$$

*(Metal Characteristics, etc)

$$\text{STRAIN RATE} = \frac{V_s}{R} = \frac{a}{b} \cdot V_1 \cdot \frac{1}{R} \cdot U;$$

Calculated Strain Rates (for U=1; a=8mm, b=22 mm)

Type of Impact Testing Machines	Striking Velocity	Notch			
		Sharp V	Izod	Mesnager	Large
		R=0.001"	R=0.01"	R=0.04"	R=0.1"
	feet/sec	inch/sec	inch/sec	inch/sec	inch/sec
TINIUS OLSEN:					
30,60 & 120 ft lbs	11.0	48,000	4800	1200	480
240 ft lbs	16.5	72,000	7200	1800	720
AMSLER:					
120 ft lbs	16.4	71,600	7160	1790	716
240 ft lbs	17.8	77,750	7776	1944	778

Figure 17.—Strain rate relations.

The results of tension-bending tests employing the proposed double-notched V-V samples indicate that these samples may be used to study the following: (a) the effects of different surface treatments and surface conditions, and different types of mechanical and metallurgical notches, on the brittle fracture and brittle transition of metals; and (b) the weldability of metals, or the effect of welding on the mechanical behaviour of metals under simulated service conditions.

By employing the V-V sample shown in Figure 7 to obtain the impact notch-sensitivity index and relative impact notch-sensitivity of metals, the designer would be provided with additional data illustrating the brittle characteristics of metals used in structural machine design.

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CONTRIBUTED DISCUSSION

G. WELTER*: The described testing method using specimens with specially arranged notches and supports is an interesting contribution to the chapter of impact testing in general. The author has to be commended for this work which supplements advantageously the Charpy and Schnadt test methods and which may bring about supplementary results. These results may fit better in the overall picture and conception based on the notched impact bending specimen.

To introduce a tension bending specimen, in many respects similar to Schnadt's so that no compression is meant to develop in the so-called "supporting notch" but only tension on the side of load application where there may be a notch or not, is a worthwhile attempt to break down results.

The object of the following comments is to add to the numerous impact testing techniques used today, a few view points on a new concept about energy absorption of the Charpy test specimen during testing.

Since several decades, a very great number of specimens of the Charpy type have been tested, the absorbed energy of the material being recorded. Despite this tremendous work, we do not yet know today what these results finally mean from the resistance point of view of the material. More and more tests of this kind are proposed and carried out without asking for the causes of these unsatisfactory test results. Looking back on the last forty years and comparing the results obtained by this method with the fairly poor conclusions generally arrived at, it seems evident that something must be wrong in respect to this method. In fact, if we compare the information obtained by the results of the impact tests with those of other testing methods, such as for instance, the static tensile tests, we must admit that the Charpy impact test results are crude and very unsatisfactory. We measure

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*Head, Strength of Materials Department, Ecole Polytechnique, Montreal.

two parameters by one single value. Instead of having, as in static tests, separate records of the load in pounds and the deformation in inches, we measure simply the total energy absorbed by the specimen through a single value expressed in ft.-lb. This means that we are unable to make any distinction between the dynamic load applied in relation to the deformation undergone by the specimen. For instance, a Charpy test of a high resistance steel, having a low ductility, may yield the same total energy absorbed in ft.-lb. as a low resistance steel having a high ductility. To illustrate this, we may compare a tough steel, having a resistance of about 8 units and a ductility of 2 units, giving as final results by the Charpy tests the same indication of energy absorption in ft.-lb. as a mild steel for example, having a low resistance of about 2 units and a high ductility of about 8 units. The final effect is that we measure in both cases the same value (16) in ft.-lb. and all we may conclude from such a test is that both steels are more or less identical regarding their energy absorption under impact loads. These two types of steels have, however, fundamentally different mechanical properties, as measured by the static tensile tests. Furthermore, by the Charpy tests, we do not have any indication of other basic parameters of the tested material, such as its dynamic elastic limit, its yield point as well as its ultimate breaking load, expressed in pounds. The Charpy values can be compared to tensile test results which, when expressed exclusively in ft.-lb. would give an as great confusion of results as does the impact tests of today. We could hardly draw any useful conclusions of such test results expressed exclusively in terms of energy absorption and a classification or evaluation of different types of steels and their mechanical properties as well as their behaviour in structures, would be completely erroneous.

If we want to use the Charpy tests on the same basis as the tensile tests giving as useful detailed results, it will be necessary to improve this method fundamentally. We must know the amount of load in relation to the deformation of the tested material. It will be logical to study the interdependency of these two parameters by recording dynamic stress-strain diagrams on the Charpy tester. Results of this type would give us a fairly good evaluation of the dynamic elastic limit of the material, its yield strength as well as its ultimate load in function of the deformation of the material and we would be much more in a position to judge the dynamic properties of one type of a steel in comparison with those of another steel of similar or of completely different compositions. Besides the total amount of absorbed energy recorded by the original Charpy testing method, we would, by a modified method, have the possibility to note after the tests several other parameters of basic importance simultaneously recorded during the impact tests.

The development of such a new method does not seem to be too far out of reach because several tentative tests have already been made in that direction in this Laboratory which indicate that there exists the possibility of dynamically testing specimens under bending and recording simultaneously load-deformation diagrams of the specimens. The load is measured by the elastic deformation of a thin torsion bar, having an elastic energy absorption of over 220 ft.-lb. and the angle of bending is recorded by the displacement of a small drum around its axis. Copies of original load-deformation diagrams, as recorded in a fraction of a second for two different materials, are represented in the accompanying Figure 18. These diagrams permit already a certain evaluation of the main dynamic properties of different materials tested. These diagrams show a remarkable difference in behaviour of two Stainless steel specimens for example compared with two copper specimens tested under dynamic loads in bending. The diagrams of the two stainless steel specimens are alike and they show a fairly high elastic limit as well as a similar maximum breaking load. The deformation or the angle of bending of the specimens is also alike. On the other hand, the load-deformation diagrams of the copper specimens show a different behaviour from the stainless steels. The maximum load is much lower and the deformation is fairly high compared to its maximum applied dynamic load. Developed several years ago this method shows that basically much more interesting results can be obtained during impact tests of this kind, if the absorbed total energy of the specimen is decomposed by means of a special device into two separate parameters. Thus, the total dynamic load is recorded and the angle of bending is represented in function of that load. Furthermore, instead of recording the load mechanically, as in this method, it might be possible to develop a more elegant method by recording strain gauge indications on an oscillograph. In view of the desperate attempts of the last decades to measure the impact properties of steel specimens by the Charpy impact method, it seems worthwhile to give a new orientation to this basic testing method which up to now gives only a fairly incomplete picture of the behaviour of various materials under dynamic loading.

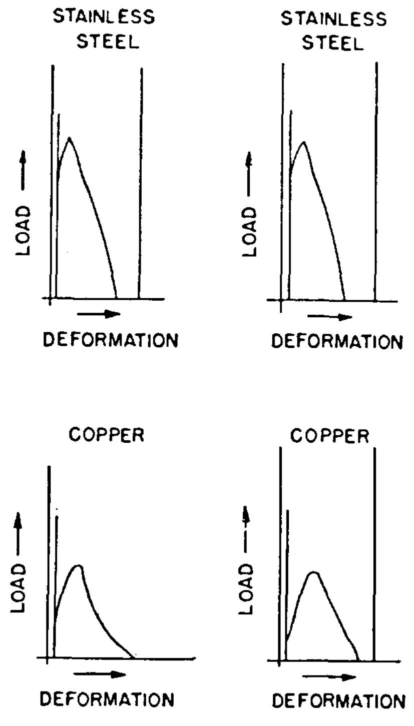

Figure 18.—Dynamic load-deformation diagrams of stainless-steel and copper specimens.

Author's Reply to discussion by Mr. Welter.

We should certainly agree with Professor Welter that merely recording the absorbed breaking energy of the Charpy type — or any other type — of impact sample does not in itself constitute an adequate method for evaluating the mechanical properties of metals, nor for evaluating the behaviour of metals in structures. The example quoted by him, of two metals having similar impact energy absorption but different mechanical properties, is effective. Clearly, further efforts should be made, if possible, on the improvement of the Charpy method as such.

At present, it is generally agreed that the recording of the impact energy should be supplemented by other observations possible from this type of test. The shape and appearance of the fracture, the transversal contraction of the fracture at the leading edge, and the magnitude of the angle to which the sample was bent before its fracture — all referred to in our Table XII—should thus be recorded. Such observations, combined with the transition temperatures for impact energy, fracture and ductility (determined, if possible, under conditions comparable to the working stress conditions existing in the structure under consideration), would also broaden our knowledge.

We should also agree with Professor Welter that the modified Charpy test proposed by him, combined with recording of the dynamic load-deformation relationship, would be an interesting asset in the evaluation of the dynamic properties of metals. However, the tensile test, with its possible variations as to type of loading and conditions of testing, will remain as a basic tool in the evaluation of metal properties.

Further following Professor Welter's suggestions, we found another interesting feature, namely the possibility of verification of strain rates prevailing in our double-notched tension-bending samples under various testing conditions, which are roughly illustrated in Figure 17. Using strain gauges on our type A-3-25 or D-3-00 samples, it would be interesting to establish the relationships between the brittle transition temperature, the strain rates and the probabilities of brittle fracture, existing under our methods of testing in the V-V samples. These strain-time data would also provide strain-stress relationships, at least up to the proportionality region, which would reinforce and broaden our observations in the directions proposed by Professor Welter.

V. Caron*: In this interesting paper the author introduces a series of new test bars for the purpose of studying the notch sensitivity of metals, particularly that of steels. Their main characteristics are to vary the degree of notch severity and to apply a tension-bending load. Such a mode has the advantage of eliminating compressive stresses and thus to create a more favorable condition for crack propagation. However, the situation is much more complex regarding crack initiation because the stress gradients differ in each case and consequently the secondary tensile stresses will also vary, being larger when a steeper gradient exists which is the case of bending when compared to tension-bending.

It can therefore be expected that the values of energy absorbed over an interval of temperatures will differ from those obtained with Charpy specimens and that the transition temperatures should be different when considering an arbitrary energy level. There will be as many transition temperatures as there are different notches and all answers obtained will lead to a relative rating for a given material.

In view of the above we would like to ask the author what would be the main advantages of his proposed series of specimens over the widely used Charpy V-notched specimen inasmuch as applications to engineering structures are concerned?

The interest of various notch designs may be assessed — if equations are sought to establish basic relations between temperature, strain rate and a particular parameter. Limited numerical data is available on such relations and additional information is needed to correlate with theoretical relations derived from dislocation theory. Results obtained by Clark and others indicate that it should be possible to predict the conditions under which brittle fracture will occur in specimens of mild steel having any notch geometry. Such a prediction will be possible if the influence of strain rate and temperature on the yield stress and the true fracture stress under consideration are known. Does the author think that his proposed specimens will help in making such prediction eventually feasible?

*Associate Professor Dept. of Metallurgy, Ecole Polytechnique.

Author's Reply to discussion by Mr. Caron

The advantages to be expected from the application of double-notched (V-V) tension bending samples — based on material accumulated to date — are numerous. A few will be mentioned below, for illustration.

First, the introduction of a supporting notch reduces substantially the volume of material exposed to plastic-compression deformation, and provides a more regular and standard distribution of tension strain on the breaking side of the sample. The breaking energy recorded on the (V-V) type A-3-25 sample or on the D-3-00 sample will better reflect the impact properties than that recorded on an unnotched Charpy or Izod type of sample. (Compare Tables VI, VII and VIII.

Square and flat unnotched tension-bending samples of type A-5-00 or type D-3-00, with different types of surfaces on the breaking side, would make possible the evaluation of the effects of different kinds of surfaces on the tension-bending characteristics. Also, tension-bending samples, without breaking notches but with strain gauges, could be used for recording the initial strain rate, in both principal directions, and in studying the existing inter-relations between temperature, strain rate, constrained factor on that surface, and conditions for brittle fracture.

In the field of testing welded and unwelded steel plates, the proposed (V-V) impact, drop-test and slow-bend test methods, which are illustrated in Figures 1-b, 6 and 8, should provide much more information on the weldability of metals as compared with the presently used conventional samples.

Slow-bend and, similarly, drop-test samples of the type shown in Figure 1-b, and type A-3-25 and type D-3-00 samples, are recommended for study of the brittle characteristics of metals, particularly hydrogen embrittlement.

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