Persen Serat dengan Matriks

1. Spesimen B1L

Luas penampang B1L : 60 mm x 88 mm = 5280 mm²

Baris 1 :

1. 3,14 x (4,5 mm)² = 63,585 mm²
2. 3,14 x (3 mm)² = 28,26 mm²
3. 3,14 x (3,5mm)² = 38,465 mm²
4. 3,14 x (3 mm)² = 28,26 mm²
5. 3,14 x (3 mm)² = 28,26 mm²

______________________________ +

Total Baris 1 = 186,83 mm²

Baris 2 :

1. 3,14 x (2,5 mm)² = 19,625 mm²
2. 3,14 x (4 mm)² = 50,24 mm²
3. 3,14 x (4 mm)² = 50,24 mm²
4. 3,14 x (2 mm)² = 12,56 mm²
5. 3,14 x (2 mm)² = 12,56 mm²

______________________________ +

Total Baris 2 = 145,225 mm²

Baris 3 :

1. 3,14 x (2,2 mm)² = 15,1976 mm²

Baris 4 :

1. 3,14 x (3 mm)^2 = 28,26 mm^2
2. 3,14 x (4,5 mm)^2 = 63,585 mm^2
3. 3,14 x (3 mm)^2 = 28,26 mm^2

_________________________________ +

Total Baris 4 = 120,105 mm^2

Baris 5 :

1. 3,14 x (3 mm)^2 = 28,26 mm^2
2. 3,14 x (5 mm)^2 = 78,5 mm^2
3. 3,14 x (2 mm)^2 = 12,56 mm^2
4. 3,14 x (5 mm)^2 = 78,5 mm^2
5. 3,14 x (2,8 mm)^2 = 8,792 mm^2

_________________________________ +

Total Baris 5 = 206,612 mm^2

Baris 6 :

1. 3,14 x (1,8 mm)^2 = 10,1736 mm^2
2. 3,14 x (2,8 mm)^2 = 8,792 mm^2
3. 3,14 x (2,8 mm)^2 = 8,792 mm^2

_________________________________ +

Total Baris 6 = 27,7576 mm^2

Baris 7 :

1. 3,14 x (3 mm)^2 = 28,26 mm^2

Baris 8 :

1. 3,14 x (5,7 mm)^2 = 102,0186 mm^2

2. 3,14 x (4,8 mm)² = 72,3456 mm²
3. 3,14 x (5 mm)² = 78,5 mm²

_____________________________________ +

Total Baris 8 = 252,8642 mm²

Baris 9 :

1. 3,14 x (3,6 mm)² = 40,6944 mm²

Baris 10 :

1. 3,14 x (2,5 mm)² = 19,625 mm²
2. 3,14 x (4 mm)² = 50,24 mm²
3. 3,14 x (2 mm)² = 12,56 mm²

_____________________________________ +

Total Baris 10 = 82,425 mm²

Baris 11 :

1. 3,14 x (5 mm)² = 78,5 mm²
2. 3,14 x (2,8 mm)² = 8,792 mm²
3. 3,14 x (2 mm)² = 12,56 mm²

_____________________________________ +

Total Baris 11 = 99,852 mm²

Baris 12 :

1. 3,14 x (5,5 mm)² = 94,985 mm²
2. 3,14 x (3,1 mm)² = 30,1754 mm²
3. 3,14 x (3 mm)² = 28,26 mm²

_____________________________________ +

Total Baris 12 = 153,4204 mm²

Total pada penampang patahan B1L :

186,83 mm^2 + 145,225 mm^2 + 15,1976 mm^2 + 120,105 mm^2 + 206,612 mm^2 + 27,7576 mm^2 + 28,26 mm^2 + 252,8642 mm^2 + 40,6944 mm^2 + 82,425 mm^2 + 99,852 mm^2 + 153,4204 mm^2 = 1330,9832 mm^2

Total luas serat pada penampang patahan B1L :

$\frac{1330{,}9832}{4}$ = 332,7458 mm^2

Maka dapat dihitung prosentasi serat pada spesimen B1L dengan :

$$\frac{Luas\ Total\ Serat}{Luas\ Penampang} x\ 100 = \frac{332{,}7458\ mm^2}{5280\ mm^2} x\ 100 = 6{,}3\ \%$$

2. Spesimen C1L

Luas penampang B1L : 60 mm x 88 mm = 5280 mm^2

Perbesaran = 19x

$$\frac{\text{Perbesaran B1L dan D1L}}{\text{Perbesaran C1L}} = \frac{20x}{19x} = 1{,}0526$$

Agar luas permukaan sama, maka :

Luas penampang B1L x 1,0526 = Luas Penampang C1L

Maka:

5280 x 1,0526 = 5557,895 mm^2

Baris 1 :

1. 3,14 x (3,2 mm)² = 32,1536 mm^2
2. 3,14 x (4 mm)² = 50,24 mm^2
3. 3,14 x (5 mm)² = 78,5 mm^2

____________________________ +

Total Baris 1 = 160,8936 mm^2

Baris 2 :

1. 3,14 x (3,5 mm)² = 38,465 mm^2
2. 3,14 x (4,2 mm)² = 55,3896 mm^2

____________________________ +

Total Baris 2 = 93,8546 mm^2

Baris 3 :

1. 3,14 x (4 mm)² = 50,24 mm^2
2. 3,14 x (6 mm)² = 113,04 mm^2

3. $3{,}14 \times (4{,}8\ mm)^2$ = $72{,}3456\ mm^2$
4. $3{,}14 \times (4\ mm)^2$ = $50{,}24\ mm^2$
5. $3{,}14 \times (2{,}8\ mm)^2$ = $24{,}6176\ mm^2$

____ +

Total Baris 3 = $310{,}4832\ mm^2$

Baris 4 :

1. $3{,}14 \times (4\ mm)^2$ = $50{,}24\ mm^2$
2. $3{,}14 \times (6\ mm)^2$ = $113{,}04\ mm^2$
3. $3{,}14 \times (3{,}7\ mm)^2$ = $42{,}9866\ mm^2$
4. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
5. $3{,}14 \times (2\ mm)^2$ = $12{,}56\ mm^2$

____ +

Total Baris 4 = $247{,}0866\ mm^2$

Baris 5 :

1. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
2. $3{,}14 \times (4\ mm)^2$ = $50{,}24\ mm^2$
3. $3{,}14 \times (5{,}5\ mm)^2$ = $94{,}985\ mm^2$

____ +

Total Baris 5 = $173{,}485\ mm^2$

Baris 6 :

1. $3{,}14 \times (5\ mm)^2$ = $78{,}5\ mm^2$
2. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
3. $3{,}14 \times (4{,}1\ mm)^2$ = $52{,}7834\ mm^2$
4. $3{,}14 \times (3{,}1\ mm)^2$ = $30{,}1754\ mm^2$
5. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
6. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$

____ +

Total Baris 6 = $246{,}2388\ mm^2$

Baris 7 :

1. $3{,}14 \times (6\ mm)^2$ = $113{,}04\ mm^2$
2. $3{,}14 \times (5\ mm)^2$ = $78{,}5\ mm^2$
3. $3{,}14 \times (4{,}8\ mm)^2$ = $72{,}3456\ mm^2$
4. $3{,}14 \times (2{,}3\ mm)^2$ = $16{,}6106\ mm^2$
5. $3{,}14 \times (5\ mm)^2$ = $78{,}5\ mm^2$
6. $3{,}14 \times (3{,}7\ mm)^2$ = $42{,}9866\ mm^2$

____ +

Total Baris 7 = $401{,}9829\ mm^2$

Baris 8 :

1. $3{,}14 \times (5{,}5\ mm)^2$ = $94{,}985\ mm^2$
2. $3{,}14 \times (3{,}5\ mm)^2$ = $38{,}465\ mm^2$
3. $3{,}14 \times (3{,}8\ mm)^2$ = $45{,}3416\ mm^2$
4. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
5. $3{,}14 \times (3{,}2\ mm)^2$ = $32{,}1536\ mm^2$
6. $3{,}14 \times (2{,}4\ mm)^2$ = $18{,}0864\ mm^2$

____ +

Total Baris 8 = $257{,}2916\ mm^2$

Baris 9 :

1. $3{,}14 \times (2{,}2\ mm)^2$ = $15{,}1976\ mm^2$
2. $3{,}14 \times (1{,}8\ mm)^2$ = $10{,}1736\ mm^2$
3. $3{,}14 \times (2\ mm)^2$ = $12{,}56\ mm^2$

____ +

Total Baris 9 = $37{,}9312\ mm^2$

Baris 10 :

1. $3{,}14 \times (3{,}3\ mm)^2 = 34{,}1946\ mm^2$
2. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
3. $3{,}14 \times (3{,}1\ mm)^2 = 30{,}1754\ mm^2$
4. $3{,}14 \times (3{,}5\ mm)^2 = 38{,}465\ mm^2$

\+

Total Baris 10 = $153{,}075\ mm^2$

Baris 11 :

1. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
2. $3{,}14 \times (3{,}8\ mm)^2 = 45{,}3416\ mm^2$
3. $3{,}14 \times (5\ mm)^2 = 78{,}5\ mm^2$
4. $3{,}14 \times (2{,}8\ mm)^2 = 24{,}6176\ mm^2$
5. $3{,}14 \times (2\ mm)^2 = 12{,}56\ mm^2$
6. $3{,}14 \times (3{,}4\ mm)^2 = 36{,}2984\ mm^2$
7. $3{,}14 \times (2{,}5\ mm)^2 = 19{,}625\ mm^2$

\+

Total Baris 11 = $267{,}1826\ mm^2$

Baris 12 :

1. $3{,}14 \times (3\ mm)^2 = 28{,}26\ mm^2$
2. $3{,}14 \times (4{,}2\ mm)^2 = 55{,}3896\ mm^2$
3. $3{,}14 \times (5{,}8\ mm)^2 = 105{,}6296\ mm^2$
4. $3{,}14 \times (3\ mm)^2 = 28{,}26\ mm^2$
5. $3{,}14 \times (5\ mm)^2 = 78{,}5\ mm^2$
6. $3{,}14 \times (5\ mm)^2 = 78{,}5\ mm^2$

\+

Total Baris 12 = $374{,}5392\ mm^2$

Total pada penampang patahan C1L :

160,8936 mm² + 93,8546 mm² + 310,4832 mm² + 247,0866 mm² + 173,485 mm² + 246,2388 mm² + 401,9829 mm² + 257,2916 mm² + 37,9312 mm² + 153,075 mm² + 267,1826 mm² + 374,5392 mm² = 2724,0443

2724,0443 x 1,0526 = 2867,32903018 mm²

Total luas serat pada penampang patahan C1L :

$$\frac{2867{,}32903018}{4} = 716{,}8322575 \text{ mm}^2$$

$$\frac{Luas\ Total\ Serat}{Luas\ Penampang} x\ 100 = \frac{716{,}8322575\ mm^2}{5557{,}895\ mm^2} x\ 100 = 12{,}89\ \%$$

Persen Serat dengan Matriks

3. Spesimen D1

Luas penampang D1L : 60 mm x 88 mm = 5280 mm²

Baris 1 :

1. 3,14 x (6,5 mm)² = 132,665 mm²
2. 3,14 x (5,1 mm)² = 81,6714 mm²

_______________________________________ +

Total Baris 1 = 214,3364 mm²

Baris 2 :

1. 3,14 x (1 mm)² = 3,14 mm²
2. 3,14 x (6 mm)² = 113,04 mm²
3. 3,14 x (2,7 mm)² = 22,8906 mm²
4. 3,14 x (3 mm)² = 28,26 mm²
5. 3,14 x (4,8 mm)² = 72,3456 mm²

_______________________________________ +

Total Baris 2 = 239,6762 mm²

Baris 3 :

1. 3,14 x (3,5 mm)² = 38,465 mm²
2. 3,14 x (3 mm)² = 28,26 mm²
3. 3,14 x (4 mm)² = 50,24 mm²

_______________________________________ +

Total Baris 3 = 116,965 mm²

Baris 4 :

1. $3{,}14 \times (4\ mm)^2$ = $50{,}24\ mm^2$
2. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$
3. $3{,}14 \times (5{,}8\ mm)^2$ = $105{,}6296\ mm^2$

_______________________________________ +

Total Baris 4 = $184{,}1296\ mm^2$

Baris 5 :

1. $3{,}14 \times (6\ mm)^2$ = $113{,}04\ mm^2$
2. $3{,}14 \times (4{,}2\ mm)^2$ = $55{,}3896\ mm^2$
3. $3{,}14 \times (3{,}4\ mm)^2$ = $36{,}2984\ mm^2$
4. $3{,}14 \times (1{,}3\ mm)^2$ = $5{,}3066\ mm^2$
5. $3{,}14 \times (4{,}2\ mm)^2$ = $55{,}3896\ mm^2$

_______________________________________ +

Total Baris 5 = $265{,}4242\ mm^2$

Baris 6 :

1. $3{,}14 \times (4\ mm)^2$ = $50{,}24\ mm^2$
2. $3{,}14 \times (3{,}2\ mm)^2$ = $32{,}1536\ mm^2$
3. $3{,}14 \times (3\ mm)^2$ = $28{,}26\ mm^2$

_______________________________________ +

Total Baris 6 = $110{,}6536\ mm^2$

Baris 7 :

1. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
2. $3{,}14 \times (4{,}8\ mm)^2 = 72{,}3456\ mm^2$
3. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
4. $3{,}14 \times (5{,}7\ mm)^2 = 102{,}0186\ mm^2$
5. $3{,}14 \times (3{,}1\ mm)^2 = 30{,}1754\ mm^2$
6. $3{,}14 \times (2{,}4\ mm)^2 = 18{,}0864\ mm^2$

______________________________________ +

Total Baris 7 = $323{,}106\ mm^2$

Baris 8 :

1. $3{,}14 \times (2{,}8\ mm)^2 = 24{,}6176\ mm^2$
2. $3{,}14 \times (5{,}1\ mm)^2 = 81{,}6714\ mm^2$
3. $3{,}14 \times (3\ mm)^2 = 28{,}26\ mm^2$
4. $3{,}14 \times (3\ mm)^2 = 28{,}26\ mm^2$
5. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
6. $3{,}14 \times (7{,}5\ mm)^2 = 176{,}625\ mm^2$
7. $3{,}14 \times (5{,}3\ mm)^2 = 88{,}2026\ mm^2$

______________________________________ +

Total Baris 8 = $477{,}8766\ mm^2$

Baris 9 :

1. $3{,}14 \times (2\ mm)^2 = 12{,}56\ mm^2$
2. $3{,}14 \times (5{,}2\ mm)^2 = 84{,}9056\ mm^2$
3. $3{,}14 \times (3\ mm)^2 = 28{,}26\ mm^2$
4. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
5. $3{,}14 \times (4\ mm)^2 = 50{,}24\ mm^2$
6. $3{,}14 \times (3{,}5\ mm)^2 = 38{,}465\ mm^2$

______________________________________ +

Total Baris 9 = $264{,}6706\ mm^2$

Baris 10 :

1. 3,14 x (5,2 mm)² = 84,9056 mm²
2. 3,14 x (6 mm)² = 113,04 mm²
3. 3,14 x (6 mm)² = 113,04 mm²
4. 3,14 x (4 mm)² = 50,24 mm²

______________________________________ +

Total Baris 10 = 361,2256 mm²

Baris 11 :

1. 3,14 x (6 mm)² = 113,04 mm²
2. 3,14 x (2,5 mm)² = 19,625 mm²
3. 3,14 x (2,5 mm)² = 19,625 mm²

______________________________________ +

Total Baris 11 = 152,29 mm²

Baris 12 :

1. 3,14 x (3 mm)² = 28,26 mm²
2. 3,14 x (2 mm)² = 12,56 mm²
3. 3,14 x (5,1 mm)² = 81,6714 mm²
4. 3,14 x (4 mm)² = 50,24 mm²

______________________________________ +

Total Baris 12 = 172,7314 mm²

Total pada penampang patahan D1L :

214,3364 mm^2 + 239,6762 mm^2 + 116,965 mm^2 + 184,1296 mm^2 + 265,4242 mm^2 + 110,6536 mm^2 + 323,106 mm^2 + 477,8766 mm^2 + 264,6706 mm^2 + 361,2256 mm^2 + 152,29 mm^2 + 172,7314 mm^2 = 2883,0852 mm^2

Total luas serat pada penampang patahan D1L :

$$\frac{2883{,}0852}{4} = 720{,}7713 \text{ mm}^2$$

$$\frac{Luas\ Total\ Serat}{Luas\ Penampang} x\ 100 = \frac{720{,}7713\ mm^2}{5280\ mm^2} x\ 100 = 13{,}65\%$$

Persentase Kenaikan Kekuatan *Impact*

a. Komposit *Epoxy* Berpenguat Serat Ijuk 3 cm Terhadap *Epoxy* Murni.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 3\ cm - Epoxy\ Murni}{Epoxy\ Murni}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{6{,}3546 - 1{,}8584\ kJ/m^2}{1{,}8584\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 241{,}9393\%$$

b. Komposit *Epoxy* Berpenguat Serat Ijuk 6 cm Terhadap *Epoxy* Murni.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 6\ cm - Epoxy\ Murni}{Epoxy\ Murni}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{7{,}4578 - 1{,}8584\ kJ/m^2}{1{,}8584\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 301{,}3022\%$$

c. Komposit *Epoxy* Berpenguat Serat Ijuk 6 cm Terhadap *Epoxy* Murni.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 9\ cm - Epoxy\ Murni}{Epoxy\ Murni}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{8{,}363 - 1{,}8584\ kJ/m^2}{1{,}8584\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 350{,}0107\%$$

d. Komposit *Epoxy* Berpenguat Serat Ijuk 6 cm Terhadap Komposit *Epoxy* Berpenguat Serat Ijuk 3 cm.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 6\ cm - Komposit\ 3\ cm}{Komposit\ 3\ cm}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{7{,}4578 - 6{,}3546\ kJ/m^2}{6{,}3546\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 17{,}3607\%$$

e. Komposit *Epoxy* Berpenguat Serat Ijuk 9 cm Terhadap Komposit *Epoxy* Berpenguat Serat Ijuk 6 cm.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 9\ cm - Komposit\ 6\ cm}{Komposit\ 6\ cm}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{8{,}363 - 7{,}4578\ kJ/m^2}{7{,}4578\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 12{,}1376\%$$

f. Komposit *Epoxy* Berpenguat Serat Ijuk 9 cm Terhadap Komposit *Epoxy* Berpenguat Serat Ijuk 3 cm.

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{Komposit\ 9\ cm - Komposit\ 3\ cm}{Komposit\ 3\ cm}\ x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = \frac{8{,}363 - 6{,}3546\ kJ/m^2}{6{,}3546\ kJ/m^2} x\ 100$$

$$\%\ Kenaikan\ Kekuatan\ Impact = 31{,}6055\%$$

Rata-rata

a. *Epoxy* Murni.

$$Rata - rata\ A = \frac{A1 + A2 + A4 + A5 + A6}{5}$$

$$Rata - rata\ A = \frac{1{,}595 + 1{,}923 + 2{,}23 + 1{,}816 + 1{,}728}{5}$$

$$Rata - rata\ A = 1{,}8584\ kJ/m^2$$

b. Komposit *Epoxy* Berpenguat Serat Ijuk 3 cm.

$$Rata - rata\ B = \frac{B1 + B2 + B4 + B5 + B6}{5}$$

$$Rata - rata\ B = \frac{7{,}336 + 6{,}093 + 7{,}042 + 6{,}134 + 5{,}168}{5}$$

$$Rata - rata\ B = 6{,}3546\ kJ/m^2$$

c. Komposit *Epoxy* Berpenguat Serat Ijuk 6 cm.

$$Rata - rata\ C = \frac{C1 + C2 + C4 + C5 + C6}{5}$$

$$Rata - rata\ C = \frac{9{,}62 + 7{,}377 + 5{,}73 + 8{,}3 + 6{,}262}{5}$$

$$Rata - rata\ C = 7{,}4578\ kJ/m^2$$

d. Komposit *Epoxy* Berpenguat Serat Ijuk 9 cm.

$$Rata - rata\ D = \frac{D1 + D3 + D4 + D5 + D6}{5}$$

$$Rata - rata\ D = \frac{9{,}342 + 8{,}896 + 7{,}027 + 7{,}518 + 9{,}032}{5}$$

$$Rata - rata\ D = 8{,}363\ kJ/m^2$$

Standar Deviasi

A. Data Hasil Pengujian *Impact Epoxy* Murni

Spesifikasi data hasil pengujian dapat dilihat pada tabel berikut :

Tabel 1. Hasil pengujian *impact epoxy* murni.

Date of Testing	:	24-Jun-13		Methode of Tested	:Notch/edgewise		
Material Tested	:	Epoxy Murni		Velocity of Impact	:	3,8 m/s²	
Humidity	:	55,0%		Pendulum Energy	:	2 J	
Temp.	:	22°C		Correction Energy	:	0,007 J	
Methode	:	ISO 179/1eU		Span Length	:	62 mm	
No.	**Kode Spesimen**	**Width** (mm)	**Thickness** (mm)	**Impact Energy** (Joule)	**Corrected Energy** (Joule)	**Impact Charpy Strength** (kJ/m²)	**Type of Failure**
1.	A1	10,48	12,32	0,213	0,206	1,595	C
2.	A2	10,75	11,90	0,253	0,246	1,923	C
3.	A4	10,76	12,71	0,312	0,305	2,230	C
4.	A5	10,22	12,22	0,256	0,249	1,816	C
5.	A6	11,40	11,35	0,211	0,204	1,728	C
Mean						1,859	
Standard Deviation						0,240	
Standard Deviation (%)						13%	

Dapat dilihat pada tabel 1 bahwa kekuatan *impact* tertinggi pada *epoxy* murni ada pada spesimen A4 dengan kekuatan sebesar 2,230 kJ/m² dan terendah ada pada spesimen A1 dengan kekuatan sebesar 1,595 kJ/m². Selain itu, *Type of Failure* pada keseluruhan spesimen diberikan kode “C”, yaitu *Crack* dimana spesimen mengalami patah total dan tidak ada matriks yang tersisa menempel.

Presentasi standar deviasi yang terjadi pada *epoxy murni* masih cukup tinggi yaitu 13%, selain itu nilai standar deviasi yang terjadi sebesar 0,240. Hal ini disebabkan hasil dari pengujian yang terlalu bervariatif sehingga grafik yang terjadi akan menjadi naik dan turun secara signifikan.

B. Data Hasil Pengujian *Impact* Komposit Serat Ijuk 3 cm

Spesifikasi hasil pengujian *impact* komposit serat ijuk 3 cm dapat dilihat sebagai berikut :

Tabel 2. Hasil pengujian komposit serat ijuk 3 cm.

Date of Testing	: 24-Jun-13			Methode of Tested	: Notch/edgewise		
Material Tested	: Komposit Ijuk 3 cm			Velocity of Impact	: 3,8 m/s²		
Humidity	: 55,0%			Pendulum Energy	: 2 J		
Temp.	: 22°C			Correction Energy	: 0,007 J		
Methode	: ISO 179/1eU			Span Length	: 62 mm		
No.	**Kode Spesimen**	**Width** (mm)	**Thickness** (mm)	**Impact Energy** (Joule)	**Corrected Energy** (Joule)	**Impact Charpy Strength** (kJ/m²)	**Type of Failure**
1.	B1	9,62	12,81	0,911	0,904	7,336	C
2.	B2	10,37	11,98	0,764	0,757	6,093	C
3.	B3	10,51	12,70	0,947	0,940	7,042	C
4.	B5	10,64	12,35	0,813	0,806	6,134	C
5.	B6	11,25	12,04	0,707	0,700	5,168	C
Mean						6,355	
Standard Deviation						0,860	
Standard Deviation (%)						14%	

Dari tabel 2 dapat dilihat bahwa kekuatan *impact* komposit serat ijuk 3 cm ada pada spesimen B1 dengan nilai sebesar 7,336 kJ/m², dan terendah ada pada spesimen B5 dengan nilai sebesar 5,168 kJ/m². Selain itu *type of failure* pada komposit serat ijuk 3 cm ini adalah tipe “C”, yaitu *totally crack* atau patah secara menyeluruh tanpa menyisakan serat ataupun matriks yang masih menyambung pada lokasi patahan.

Persentase standar deviasi yang terjadi pada komposit serat ijuk 3 cm terlihat meningkat dibandingkan dengan *epoxy* murni, yaitu sebesar 14% dan nilai standar deviasinya sebesar 0,860. Kenaikan persentase ini disebabkan semakin bervariatifnya nilai yang tercatat dari pengujian *impact*.

C. Data Hasil Pengujian *Impact* Komposit Serat Ijuk 6 cm.

Spesifikasi hasil pengujian *impact* komposit serat ijuk 6 cm dapat dilihat sebagai berikut :

Tabel 3. Hasil pengujian *impact* komposit serat ijuk 6 cm.

Date of Testing	: 24-Jun-13	Methode of Tested	: Notch/edgewise
Material Tested	: Komposit Ijuk 6 cm	Velocity of Impact	: 3,8 m/s²
Humidity	: 55,0%	Pendulum Energy	: 2 J
Temp.	: 22°C	Correction Energy	: 0,007 J
Methode	: ISO 179/1eU	Span Length	: 62 mm

No.	**Kode Spesimen**	**Width** (mm)	**Thickness** (mm)	**Impact Energy** (Joule)	**Corrected Energy** (Joule)	**Impact Charpy Strength** (kJ/m²)	**Type of Failure**
1.	C1	10,28	12,61	1,254	1,247	9,620	C
2.	C2	9,45	12,48	0,877	0,870	7,377	C
3.	C4	10,78	12,11	0,755	0,748	5,730	C
4.	C5	10,60	12,98	1,149	1,142	8,300	C
5.	C6	10,53	12,80	0,851	0,844	6,262	C
Mean						7,458	
Standard Deviation						1,566	
Standard Deviation (%)						21%	

Dari tabel 3 dapat dilihat bahwa kekuatan *impact* komposit serat ijuk 6 cm ada pada spesimen C1 dengan nilai sebesar 9,620 kJ/m², dan terendah ada pada spesimen C4 dengan nilai sebesar 5,730 kJ/m². Selain itu *type of failure* pada komposit serat ijuk 6 cm ini adalah tipe “C”, yaitu *totally crack* atau patah secara menyeluruh tanpa menyisakan serat ataupun matriks yang masih menyambung pada lokasi patahan.

Persentase standar deviasi yang terjadi pada komposit serat ijuk 6 cm terlihat meningkat dibandingkan dengan *epoxy* murni dan komposit serat ijuk 3 cm, yaitu sebesar 21% dan nilai standar deviasinya sebesar 1,566. Hal ini terjadi karena banyaknya hasil pengujian yang nilainya jauh dari rata-rata, sehingga grafiknya tampak naik dan turun secara drastis.

D. Data Hasil Pengujian *Impact* Komposit Serat Ijuk 9 cm.

Spesifikasi hasil pengujian *impact* komposit serat ijuk 9 cm dapat dilihat sebagai berikut :

Tabel 4. Hasil pengujian *impact* komposit serat ijuk 9 cm.

Date of Testing	: 24-Jun-13			Methode of Tested	: Notch/edgewise		
Material Tested	: Komposit Ijuk 9 cm			Velocity of Impact	: 3,8 m/s²		
Humidity	: 55,0%			Pendulum Energy	: 2 J		
Temp.	: 22°C			Correction Energy	: 0,007 J		
Methode	: ISO 179/1eU			Span Length	: 62 mm		
No.	**Kode Spesimen**	**Width** (mm)	**Thickness** (mm)	**Impact Energy** (Joule)	**Corrected Energy** (Joule)	**Impact Charpy Strength** (kJ/m²)	**Type of Failure**
1.	D1	10,86	12,34	1,259	1,252	9,342	C
2.	D3	9,69	11,89	1,032	1,025	8,896	C
3.	D4	10,19	12,29	0,887	0,880	7,027	C
4.	D5	10,59	12,46	0,999	0,992	7,528	C
5.	D6	10,53	12,65	1,209	1,202	9,032	C
Mean						8,363	
Standard Deviation						1,024	
Standard Deviation (%)						12%	

Dari tabel 4 dapat dilihat bahwa kekuatan *impact* komposit serat ijuk 9 cm ada pada spesimen D1 dengan nilai sebesar 9,342 kJ/m², dan terendah ada pada spesimen D4 dengan nilai sebesar 7,027 kJ/m². Selain itu *type of failure* pada komposit serat ijuk 6 cm ini adalah tipe “C”, yaitu *totally crack* atau patah secara menyeluruh tanpa menyisakan serat ataupun matriks yang masih menyambung pada lokasi patahan.

Persentase standar deviasi yang terjadi pada komposit serat ijuk 9 cm justru terlihat menurun dibandingkan dengan *epoxy* murni, komposit serat ijuk 3 cm, maupun komposit serat ijuk 6 yaitu sebesar 12% dan nilai standar deviasinya sebesar 1,024. Hal ini terjadi karena nilai simpangan pada tiap spesimen terhadap hasil rata-rata dari keseluruhan spesimen tidak begitu besar dan berarti bahwa hasil pengujian *impact* pada komposit serat ijuk 9 cm tidak terlalu variatif dibandingkan ketiga variasi sebelumnya.

Dari tabel hasil pengujian tiap variasi didapatkan variasi persentase dan nilai deviasi yang terjadi, yaitu sebesar 13%, dengan standar deviasi sebesar 0,240 untuk *epoxy* murni, kemudian 14% dengan nilai standar deviasinya sebesar 0,860 untuk komposit serat ijuk 3 cm, lalu 21% dengan nilai standar deviasinya sebesar 1,566 untuk komposit serat ijuk 6 cm dan 12% dengan nilai standar deviasinya sebesar 1,024 untuk komposit serat ijuk 9 cm. Sehingga komposit serat ijuk 9 cm adalah variasi dengan persentase deviasi terkecil karena nilai hasil pengujian *impact*-nya tidak terlalu variatif, dan komposit serat ijuk 6 cm adalah variasi dengan persentase terbesar karena nilai hasil pengujian *impact*-nya terlalu bervariasi.

Kenaikan persentase standar deviasi tersebut terjadi karena nilai kekuatan *impact* yang makin bervariatif akibat kegagalan spesimen karena semakin sulitnya pembuatan spesimen komposit serat dibandingkan pembuatan spesimen *epoxy* murni. Sehingga kegagalan dalam proses pembuatan semakin meningkat yang menyebabkan hasilnya bervariasi dimana dalam satu papan komposit distribusi serat dan juga distribusi campuran antara resin dengan hardenernya tidak merata. Namun pada komposit 9 cm terlihat menurunnya persentase deviasi, hal ini terjadi karena pada saat pembuatan komposit dengan serat ijuk 9 ini lebih mudah dalam pengaturan seratnya karena lebih panjang dibandingkan serat 3 cm dan 6 cm.

Persentase Serat Pada Cetakan

1. Komposit Serat Ijuk 3 cm

a. Berat Serat

Berat Cetakan = 71,05 gr

Berat Serat + Cetakan = 95,78 gr

Maka,

Berat Serat = Berat Serat + Cetakan - Berat Cetakan

= 95,78 gr - 71,05 gr

= 24,73 gr

b. Persentasi Serat

Berat Papan Komposit = 184,88

Berat Serat = 24,73 gr

Maka,

Persentasi Serat = $\frac{24{,}73\ gr}{184{,}88\ gr}$

= 13,3%

2. Komposit Serat Ijuk 6 cm

a. Berat Serat

Berat Cetakan = 71,05 gr

Berat Serat + Cetakan = 95,71 gr

Maka,

Berat Serat = Berat Serat + Cetakan - Berat Cetakan

= 95,71 gr - 71,05 gr

= 24,66 gr

b. Persentasi Serat

Berat Papan Komposit = 185,85 gr

Berat Serat = 24,66 gr

Maka,

Persentasi Serat = $\frac{24,66\ gr}{185,85\ gr}$

= 13,2%

3. Komposit Serat Ijuk 9 cm

c. Berat Serat

Berat Cetakan = 118,26 gr

Berat Serat + Cetakan = 143,35 gr

Maka,

Berat Serat = Berat Serat + Cetakan - Berat Cetakan

= 143,35 gr - 118,26 gr

= 25,09 gr

d. Persentasi Serat

Berat Papan Komposit = 185,79 gr

Berat Serat = 25,09 gr

Maka,

Persentasi Serat = $\frac{25{,}09\ gr}{185{,}79\ gr}$

= 13,5%

Persen Serat yang Mengalami Pull-out

Spesimen B1 L:

1. Baris 1; kolom G	=	$(3{,}5\ mm)^2$ x 3,14	= 38,465 mm^2
2. Baris 1; kolom L	=	$(3\ mm)^2$ x 3,14	= 28,26 mm^2
3. Baris 2; kolom G dan H	=	$(4\ mm)^2$ x 3,14	= 50,24 mm^2
4. Baris 2; kolom D	=	$(2{,}5\ mm)^2$ x 3,14	= 19,625 mm^2
5. Baris 2, 3, 4 dan 5; kolom J	=	$(4\ mm)^2$ x 3,14	= 50,24 mm^2
6. Baris 3; kolom N	=	$(2{,}2\ mm)^2$ x 3,14	= 15,197 mm^2
7. Baris 4; kolom H	=	$(4{,}5\ mm)^2$ x 3,14	= 63,585 mm^2
8. Baris 4; kolom M	=	$(3\ mm)^2$ x 3,14	= 28,26 mm^2
9. Baris 5; kolom A	=	$(3\ mm)^2$ x 3,14	= 28,26 mm^2
10. Baris 5; kolom D dan E	=	$(5\ mm)^2$ x 3,14	= 78,5 mm^2
11. Baris 5, 6, 7 dan 8; kolom I	=	$(3\ mm)^2$ x 3,14	= 28,26 mm^2
12. Baris 5; kolom P	=	$(2{,}8\ mm)^2$ x 3,14	= 24,617 mm^2
13. Baris 6; kolom J	=	$(2{,}8\ mm)^2$ x 3,14	= 24,617 mm^2
14. Baris 6; kolom N	=	$(2{,}8\ mm)^2$ x 3,14	= 24,617 mm^2
15. Baris 8; kolom K	=	$(5\ mm)^2$ x 3,14	= 78,5 mm^2
16. Baris 9; kolom O	=	$(3{,}6\ mm)^2$ x 3,14	= 40,69 mm^2
17. Baris 10; kolom A	=	$(2{,}5\ mm)^2$ x 3,14	= 19,625 mm^2
18. Baris 10; kolom E	=	$(4\ mm)^2$ x 3,14	= 50,24 mm^2
19. Baris 11; kolom D	=	$(5\ mm)^2$ x 3,14	= 78,5 mm^2
20. Baris 12; kolom E	=	$(2{,}8\ mm)^2$ x 3,14	= 24,617 mm^2
			+
			794,918 mm^2

794,918/4 = 198,7295

(198,7295/5280) x 100 = 3,764 % serat pullout dari keseluruhan penampang

(198,7295/332,7458) x 100 = 59,72% serat pullout dari keseluruhan serat pada penampang patahan.

Spesimen C1L :

1.	Baris 1; kolom K	= $(4\ mm)^2/4 \times 3{,}14$	= 12,56 mm^2
2.	Baris 2; kolom L	= $(4{,}2\ mm)^2/4 \times 3{,}14$	= 13,8474 mm^2
3.	Baris 4; kolom H	= $(6\ mm)^2/4 \times 3{,}14$	= 28,26 mm^2
4.	Baris 5; kolom J dan K	= $(3\ mm)^2/4 \times 3{,}14$	= 7,065 mm^2
5.	Baris 5; kolom L	= $(4\ mm)^2/4 \times 3{,}14$	= 12,56 mm^2
6.	Baris 6; kolom F, G dan H	= $(3\ mm)^2/4 \times 3{,}14$	= 7,065 mm^2
7.	Baris 7 dan 8; kolom O	= $(5\ mm)^2/4 \times 3{,}14$	= 19,625 mm^2
8.	Baris 10; kolom I	= $(3{,}5\ mm)^2/4 \times 3{,}14$	= 9,616 mm^2
9.	Baris 11; kolom A	= $(4\ mm)^2/4 \times 3{,}14$	= 12,56 mm^2
10.	Baris 11; kolom O	= $(2{,}5\ mm)^2/4 \times 3{,}14$	= 4,906 mm^2
11.	Baris 11 dan 12; kolom O	= $(3{,}4\ mm)^2/4 \times 3{,}14$	= 9,0746 mm^2
12.	Baris 12; kolom N, O, P dan Q	= $(5\ mm)^2/4 \times 3{,}14$	= 19,625 mm^2

+

= 156,764

(156,764/5280) x 100 = 2,969 % serat pullout dari keseluruhan penampang

(156,764/716,8322575) x 100 = 21,87% serat pullout dari keseluruhan serat pada penampang patahan.

Spesimen D1L :

1.	Baris 1; kolom G, H dan I	=	$(5{,}1\ mm)^2/4 \times 3{,}14$	$= 20{,}418\ mm^2$
2.	Baris 6; kolom A dan B	=	$(4\ mm)^2/4 \times 3{,}14$	$= 12{,}56\ mm^2$
3.	Baris 6; kolom P, Q dan R	=	$(3\ mm)^2/4 \times 3{,}14$	$= 7{,}065\ mm^2$
4.	Baris 7; kolom C dan D	=	$(4\ mm)^2/4 \times 3{,}14$	$= 12{,}56\ mm^2$
5.	Baris 8; kolom I	=	$(3\ mm)^2/4 \times 3{,}14$	$= 7{,}065\ mm^2$
6.	Baris 9; kolom I	=	$(3\ mm)^2/4 \times 3{,}14$	$= 7{,}065\ mm^2$
7.	Baris 9 dan 10; kolom J	=	$(6\ mm)^2/4 \times 3{,}14$	$= 28{,}26\ mm^2$
8.	Baris 10; kolom F	=	$(5{,}2\ mm)^2/4 \times 3{,}14$	$= 21{,}226\ mm^2$
9.	Baris 11 dan 12; kolom F dan G	=	$(5{,}1\ mm)^2/4 \times 3{,}14$	$= 20{,}418\ mm^2$

\+

$136{,}637\ mm^2$

(136,637/5280) x 100 = 2,588 % serat pullout dari keseluruhan penampang

(136,637/720,7713) x 100 = 18,957% serat pullout dari keseluruhan serat pada penampang patahan.

Designation: D 6110 – 04

Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics[1]

This standard is issued under the fixed designation D 6110; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method is used to determine the resistance of plastics to breakage by flexural shock as indicated by the energy extracted from standardized (see Note 1) pendulum-type hammers, mounted in standardized machines, in breaking standard specimens with one pendulum swing. This test method requires specimens to be made with a milled notch (see Note 2). The notch produces a stress concentration which promotes a brittle, rather than a ductile, fracture. The results of this test method are reported in terms of energy absorbed per unit of specimen width (see Note 3).

NOTE 1—The machines with pendulum-type hammers have been standardized in that they must comply with certain requirements including a fixed height of hammer fall, which results in a substantially fixed velocity of the hammer at the moment of impact. Hammers of different initial energies (produced by varying their effective weights), however, are recommended for use with specimens of different impact resistance. Moreover, manufacturers of the equipment are permitted to use different lengths and constructions of pendulums with possible differences in pendulum rigidities resulting (see Section 5). Be aware that other differences in machine design do exist.

NOTE 2—The specimens are standardized in that they have a fixed length and fixed depth, however, the width of the specimens is permitted to vary between limits. One design of milled notch is allowed. The notch in the specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. Because of differences in the elastic and viscoelastic properties of plastics, however, response to a given notch varies among materials.

NOTE 3—Caution must be exercised in interpreting the results of this test method. The following testing parameters have been shown to affect test results significantly: method of specimen fabrication, including but not limited to processing technology, molding conditions, mold design, and thermal treatment; method of notching; speed of notching tool; design of notching apparatus; quality of the notch; time between notching and test; test specimen thickness; test specimen width under notch; and environmental conditioning.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 4—This standard resembles ISO 179 in title only. The content is significantly different.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 618 Practice for Conditioning Plastics for Testing

D 647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials[3]

D 883 Terminology Relating to Plastics

D 4000 Classification System for Specifying Plastic Materials

D 4066 Classification System for Nylon Injection and Extrusion Materials

D 5942 Test Method for Determination of Charpy Impact Strength

D 5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E 691 Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods

3. Terminology

3.1 *Definitions*—For definitions related to plastics, see Terminology D 883.

4. Summary of Test Method

4.1 A notched specimen is supported as a horizontal simple beam and is broken by a single swing of the pendulum with the impact line midway between the supports and directly opposite the notch.

5. Significance and Use

5.1 Before proceeding with this test method, refer to the material specification for the material being tested. Any test specimen preparation, conditioning, dimensions and testing parameters required by the materials specification shall take

[1] This test method are under the jurisdiction of ASTM Committee D20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] *Discontinued 1994; Replaced by D 1896, D 5419, D 5641, D 4703, D 5227.*

*A Summary of Changes section appears at the end of this standard.

precedence over those required by this test method. Table 1 of Classification D 4000 lists the ASTM materials standards that currently exist. If there is no material specification, then the requirements of this test method apply.

5.2 The excess energy pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated conditions of specimen mounting, notching (stress concentration), and pendulum velocity at impact.

5.3 For this test method, the energy lost by the pendulum during the breakage of the specimen is the sum of the energies required to initiate fracture of the specimen; to propagate the fracture across the specimen; to throw the free ends of the broken specimen (toss energy); to bend the specimen; to produce vibration in the pendulum arm; to produce vibration or horizontal movement of the machine frame or base; to overcome friction in the pendulum bearing and in the excess energy indicating mechanism, and to overcome windage (pendulum air drag); to indent or deform, plastically, the specimen at the line of impact; and to overcome the friction caused by the rubbing of the striking nose over the face of the bent specimen.

NOTE 5—The toss energy, or the energy used to throw the free ends of the broken specimen, is suspected to represent a very large fraction of the total energy absorbed when testing relatively dense and brittle materials. No procedure has been established for estimating the toss energy for the Charpy method.

5.4 For tough, ductile, fiber-filled, or cloth-laminated materials, the fracture propagation energy is usually large compared to the fracture initiation energy. When testing these materials, energy losses due to fracture propagation, vibration, friction between the striking nose and the specimen has the potential to become quite significant, even when the specimen is accurately machined and positioned, and the machine is in good condition with adequate capacity (see Note 6). Significant energy losses due to bending and indentation when testing soft materials have also been observed.

NOTE 6—Although the frame and the base of the machine should be sufficiently rigid and massive to handle the energies of tough specimens without motion or excessive vibration, the pendulum arm cannot be made very massive because the greater part of its mass must be concentrated near its center of percussion at its striking nose. Locating the striking nose precisely at the center of percussion reduces the vibration of the pendulum arm when used with brittle specimens. Some losses due to pendulum arm vibration (the amount varying with the design of the pendulum) will occur with tough specimens even when the striking nose is properly positioned.

5.5 In a well-designed machine of sufficient rigidity and mass the losses due to vibration and friction in the pendulum bearing and in the excess energy indicating mechanism should be very small. Vibrational losses are observed when wide specimens of tough materials are tested in machines of insufficient mass, or in machines that are not securely fastened to a heavy base.

5.6 Since this test method permits a variation in the width of the specimens and since the width dictates, for many materials, whether a brittle, low-energy break (as evidenced by little or no drawing down or necking and by a relatively low energy absorption) or a ductile, high-energy break (as evidenced by considerable drawing or necking down in the region behind the notch and by a relatively high energy absorption) will occur, it is necessary that the width be stated in the specification covering that material and that the width be stated along with the impact value.

5.7 This test method requires that the specimen break completely. Results obtained when testing materials with a pendulum that does not have sufficient energy to complete the breaking of the extreme fibers and toss the broken pieces shall be considered a departure from standard and should not be reported as a standard result. Impact values cannot be directly compared for any two materials that experience different types of failure.

5.8 The value of this impact test method lies mainly in the areas of quality control and materials specification. If two groups of specimens of supposedly the same material show significantly different energy absorptions, critical widths, or critical temperatures, it is permitted to assume that they were made of different materials or were exposed to different processing or conditioning environments. The fact that a material shows twice the energy absorption of another under these conditions of test does not indicate that this same relationship will exist under another set of test conditions.

6. Apparatus

6.1 *Pendulum Impact Machine*—The machine shall consist of a massive base on which are mounted a pair of supports for holding the specimen and to which is connected, through a rigid frame and bearings, one of a number of pendulum-type hammers having an initial energy suitable for use with the particular specimen to be tested (or one basic pendulum designed to accept add-on weights), plus a pendulum holding and releasing mechanism and a mechanism for indicating the excess energy remaining in the pendulum after breaking specimen. The specimen anvil, pendulum, and frame shall be sufficiently rigid to maintain correct alignment of the striking edge and specimen, both at the moment of impact and during the propagation of the fracture, and to minimize energy losses due to vibration. The base shall be sufficiently massive so that the impact will not cause it to move. The machine shall be designed, constructed, and maintained so that energy losses due to pendulum air drag (windage), friction in the pendulum bearings, and friction and inertia in the excess energy indicating mechanism are held to a minimum.

6.1.1 *Pendulum*—The simple pendulum shall consist of a single or multi-membered arm with a bearing on one end and a head, containing the striking nose, on the other. Although a large proportion of the mass of the pendulum should be concentrated in the head, the arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibrational energy losses, which are always included in the measured impact value. A machine with a simple pendulum design is illustrated in Fig. 1. Instruments with a compound-pendulum design also have been found to be acceptable for use. A compound-pendulum design is illustrated in Fig. 2.

6.1.1.1 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.7 ± 0.14 J [2.0 ± 0.10 ft·lbf]. This pendulum shall be used for specimens that extract less than 85 % of this energy when breaking a specimen. Heavier pendulums or additional weights designed to

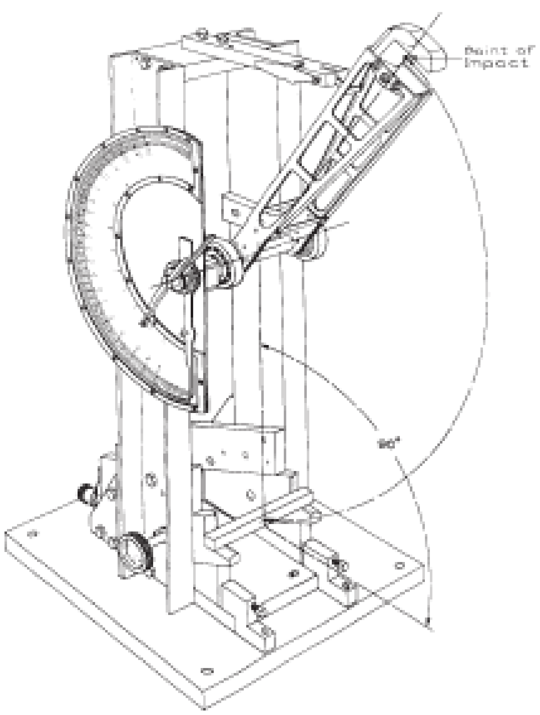


FIG. 1 Simple Beam (Charpy-Type) Impact Machine

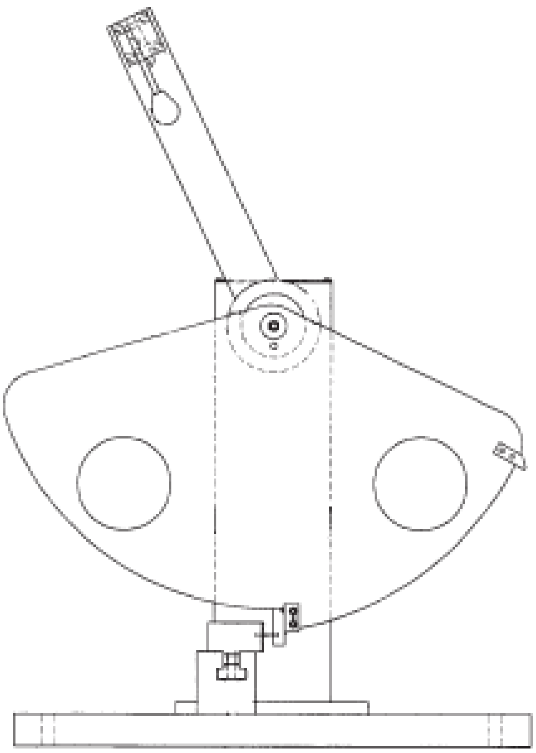


FIG. 2 Example of Compound–Pendulum–Type Machine

attach to the basic pendulum shall be provided for specimens that require more energy to break. A series of pendulums such that each has twice the energy of the next lighter one has been found convenient.

6.1.1.2 The effective length of the pendulum shall be between 0.325 and 0.406 m [12.8 an 16.0 in.] so that the required elevation of the striking nose is obtained by raising the pendulum to an angle between 60 and 30° above the horizontal.

6.1.2 *Striking Edge*—The striking edge (nose) of the pendulum shall be made of hardened steel, tapered to have an included angle of 45 ± 2° and shall be rounded to a radius of 3.17 ± 0.12 mm [0.125 ± 0.005 in.]. The pendulum shall be aligned in such a way that when it is in its free hanging position, the center of percussion of the pendulum shall lie within ±2.54 mm [0.10 in.] of the middle of the line of contact made by the striking nose upon the face of a standard specimen of square cross section. The distance from the axis of support to the center of percussion is determined experimentally from the period of motion of small amplitude oscillations of the pendulum by means of the following equation:

$$L = (g/4\pi^2)\, p^2 \quad (1)$$

where:

L = distance from the axis of support to the center of percussion, m,
g = local gravitational acceleration (known to an accuracy of one part in one thousand), m/s^2
π = 3.1416 ($4\pi^2$= 39.48), and
p = period, in s, of a single complete swing (to and fro) determined from at least 20 consecutive and uninterrupted swings. The angle of swing shall be less than 5° each side of center.

6.1.3 *Pendulum Holding and Releasing Mechanism*—The mechanism shall be designed, constructed, and operated so that it will release the pendulum without imparting acceleration or vibration to the pendulum. The position of the pendulum holding and releasing mechanism shall be such that the vertical height of fall of the striking nose shall be 610 ± 2 mm [24.0 ± 0.005 in.]. This will produce a velocity of the striking nose at the moment of impact of approximately 3.46 m [11.4 ft]/s as determined by the following equation:

$$v = \sqrt{2gh} \quad (2)$$

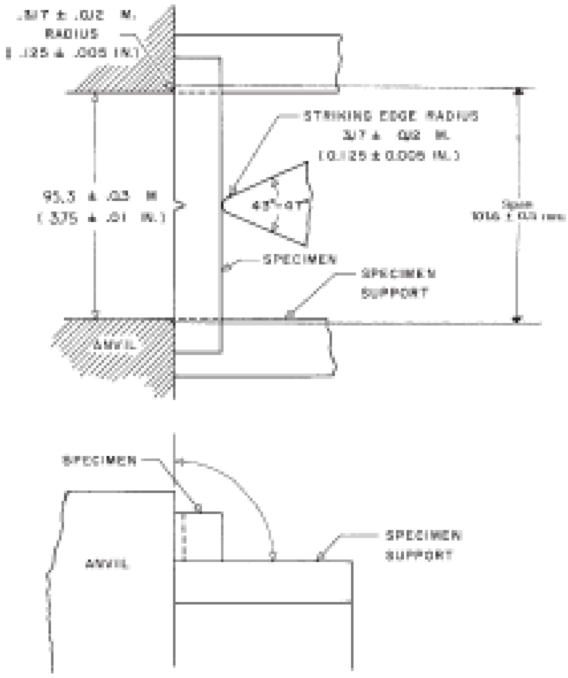


FIG. 3 Relationship of Anvil, Specimen, and Striking Edge to Each Other for Charpy Test Method

where:
v = velocity of the striking nose at the moment of impact,
g = local gravitational acceleration, and
h = vertical height of fall of the striking nose.

This assumes no windage or friction.

6.1.4 *Specimen Supports*—The test specimen shall be supported against two rigid anvils in such a position that its center of gravity and the center of the notch shall lie on tangent to the arc of travel of the center of percussion of the pendulum drawn at the position of impact. The edges of the anvils shall be rounded to a radius of 3.17 ± 0.12 mm [0.125 ± 0.005 in.] and the anvils' lines of contact (span) with the specimen shall be 101.6 ± 0.5 mm [4.0 ± 0.02 in.] apart (see Fig. 3). A jig for positioning the specimen on the supports should be supplied by the machine manufacturer.

NOTE 7—Some machines currently in use employ a 108.0-mm span. Data obtained under these conditions are valid.[4]

6.1.5 *Excess Energy Indicator*—Means shall be provided for determining energy remaining in the pendulum after breaking a specimen. One acceptable method is the use of a pointer and dial mechanism which indicate the height of rise of the pendulum beyond the point of impact in terms of energy removed from that specific pendulum. More modern instruments use an electronic digital display or computer to measure the energy loss and indicate the breaking energy of the specimen. The indicated remaining energy must be corrected for pendulum bearing friction, pointer friction, pointer inertia, and pendulum windage. The equipment manufacturer should provide graphs or tables to aid in the calculation of the correction friction and windage. Instructions for making these corrections are found in Annex A1 and Annex A2. Many digital indicating systems automatically correct for windage and friction. The equipment manufacturer should be consulted for information on how this is performed.

6.1.6 The calibration procedure in Appendix X2 should be used to establish the accuracy of the equipment. A check of the calibration of an impact machine is difficult to make under dynamic conditions. The basic parameters normally are checked under static conditions. If the machine passes the static tests, then it is assumed to be accurate. Appendix X2, however, also describes a dynamic test for checking certain features of the machine and specimen. For some machine designs, it might be necessary to change the recommended method of obtaining the required calibration measurements. Additional instructions for adjusting a particular machine should be supplied by the manufacturer. Other methods of performing the required checks are acceptable provided that they are proven to result in an equivalent accuracy.

6.2 *Specimen Notching Machine*—Notching shall be done on a milling machine, engine lathe, or other suitable machine tool. A carbide-tipped or industrial diamond-tipped notching cutter is recommended. Both cutter speed and feed rate shall be controllable. Provision for cooling the specimen is recommended. Water and compressed air are suitable coolants for many plastics.

6.2.1 The profile of the cutting tooth or teeth shall be such as to produce a notch in the test specimen of the contour and depth specified in Fig. 4 and in the manner specified in Section 8.

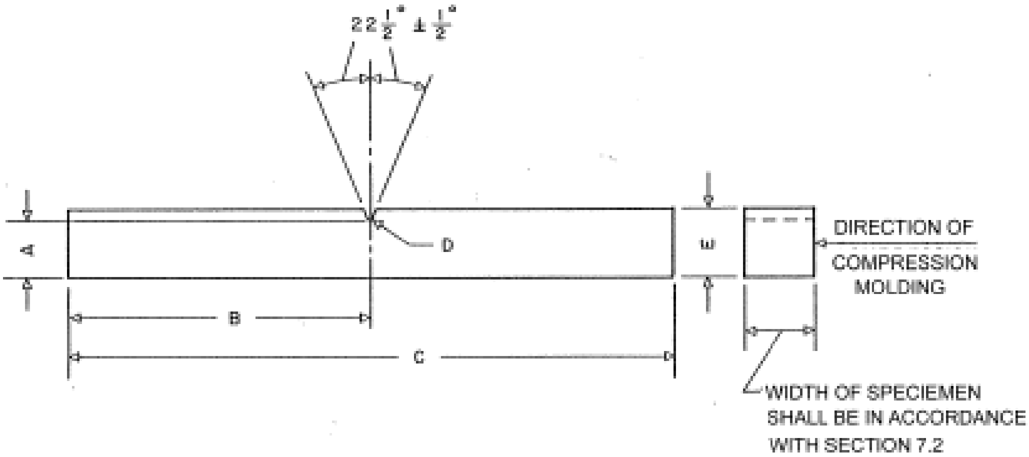
6.2.2 A single-tooth cutter shall be used for notching the specimen, unless it is demonstrated that notches of an equivalent quality are produced with a multi-tooth cutter. Single-tooth cutters are preferred because of the ease of grinding the cutter to the specimen contour and because of the smoother cut on the specimen. The cutting edge shall be ground and honed carefully to ensure sharpness and freedom from nicks and burrs. Tools with no rake and a work relief angle of 15 to 20° have been found satisfactory.

6.3 *Micrometers*—Apparatus for measurement of the width of the specimen shall comply with the requirements of Test Methods D 5947. Apparatus for the measurement of the depth of plastic material remaining in the specimen under the notch shall comply with requirements of Test Methods D 5947, provided however that the one anvil or presser foot shall be a tapered blade conforming to the dimensions given in Fig. 5. The opposing anvil or presser foot shall be flat and conforming to Test Methods D 5947.

7. Test Specimen

7.1 The test specimen shall conform to the dimensions and geometry of Fig. 4, except as modified in accordance with 7.2-7.5. To ensure the correct contour and conditions of the specified notch, all specimens shall be notched in accordance with Section 8.

[4] Supporting data is available from ASTM Headquarters. Request Research Report RR: D20-1083.



A	10.16 ± 0.05	0.400 ± 0.002
B	63.5 max	2.50 max
	61.0 min	2.40 min
C	127.0 max	5.00 min
	124.5 min	4.90 min
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

FIG. 4 Dimensions of Simple Beam, Charpy Type, Impact Test Specimen

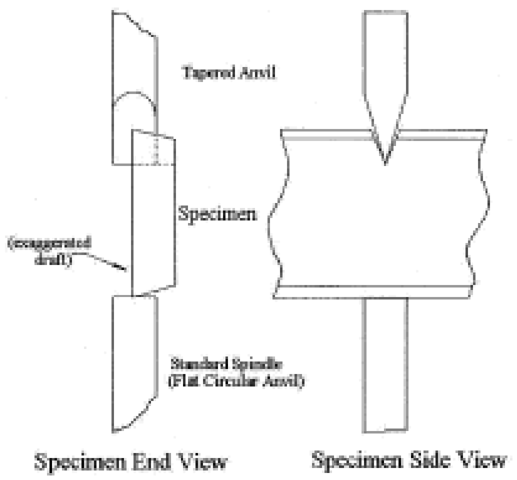


FIG. 5 Notch Depth Measurement on Test Specimens

7.2 Molded specimens shall have a width between 3.00 and 12.7 mm [0.118 and 0.500 in.]. Use the specimen width as specified in the material specification or as agreed upon between the supplier and the customer.

7.2.1 The type of mold and molding machine used and the flow behavior in the mold cavity will influence the strength obtained. It is possible that results from a specimen taken from one end of a molded bar will give different results than a specimen taken from the other end. Cooperating laboratories should therefore agree on standard molds conforming to Practice D 647, and upon a standard molding procedure for the material under investigation.

7.2.2 A critical investigation of the mechanics of impact testing has shown that tests made upon specimens under 6.35 mm [0.250 in.] in width absorb more energy due to crushing, bending, and twisting than do wider specimens. Specimens 6.35 mm [0.250 in.] or over in width are therefore recommended. The responsibility for determining the minimum specimen width shall be the investigator's, with due reference to the specification for that material.

7.2.3 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the direction of molding.

7.3 For sheet materials, the specimens shall be cut from the sheet in both the lengthwise and crosswise directions unless otherwise specified. The width of the specimen shall be the thickness of the sheet if the sheet thickness is between 3.00 and 12.7 mm [0.118 and 0.500 in.]. Sheet material thicker than 12.7 mm [0.500 in.] shall be machined down to 12.7 mm [0.500 in.]. It is acceptable to test specimens with a 12.7–mm [0.500–in.] square cross section either edgewise or flatwise as cut from the sheet. When specimens are tested flatwise, the notch shall be made on the machined surface if the specimen is machined on one face only. When the specimen is cut from a thick sheet, notation shall be made of the portion of the thickness of the sheet from which the specimen was cut, for example, center, top, or bottom surface.

7.3.1 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the grain of an anisotropic bar cut from a sheet. Specimens cut from sheets that are suspected of being anisotropic shall be prepared and tested both lengthwise and crosswise to the direction of the anisotropy.

7.4 The practice of cementing, bolting, clamping, or otherwise combining specimens of substandard width to form a composite test specimen is not recommended and should be avoided since test results will be seriously affected by interface effects or effects of solvents and cements on energy absorption of composite test specimens, or both. If Charpy test data on such thin materials are required, however, and if possible sources of error are recognized and acceptable, the following technique of preparing composites ought to be utilized. The test specimens shall be a composite of individual thin specimens totaling 6.35 to 12.7 mm [0.125 to 0.500 in.] in width. Individual members of the composite shall be aligned accurately with each other and clamped, bolted, or cemented together. Care must be taken to select a solvent or adhesive that will not affect the impact resistance of the material under test. If solvents or solvent–containing adhesives are employed, a conditioning procedure shall be established to ensure complete removal of the solvent prior to test. The composite specimens shall be machined to proper dimensions and then notched. In all such cases, the use of composite specimens shall be noted in the report of test results.

7.5 Each specimen shall be free of twist and shall be bounded by mutually perpendicular pairs of plane, paralleled surfaces and free from scratches, pits, and sink marks. The specimens shall be checked for conformity with these requirements by visual observation against straight edges, squares or flat plates, and by measuring with micrometer calipers. Any specimen showing observable or measurable departure from one or more of these requirements shall be rejected or machined to the proper size and shape before testing. A specimen that has a slight twist to its notched face of 0.05 mm [0.002 in.] at the point of contact with the pendulum striking edge will be likely to have a characteristic fracture surface with considerable greater fracture area than for a normal break. In this case, the energy to break and toss the broken section will be considerably larger (20 to 30 %) than for a normal break.

8. Notching Test Specimens

NOTE 8—When testing a material for the first time, it is necessary to study the effect of all variations in the notching conditions, including cutter dimensions, notch depth, cutter speed, and feed rate. To establish that the notching parameters are suitable, it is advisable to notch several specimens of the material and inspect both the tool entrance and tool exit side of each notched specimen, in accordance with Appendix X1. Adjust the notching machine as required. The specimens used to determine notching conditions shall not be used to make determinations of impact resistance.

8.1 *Notch Dimensions*—The included angle of the notch shall be 45 ± 1° with a radius of curvature at the apex of 0.25 ± 0.05 mm [0.010 ± 0.002 in.]. The plane bisecting the notch angle shall be perpendicular to the face of the test specimen within 2°.

8.1.1 The notch is a critical factor of this test. It is extremely important, therefore, that dimensions of the notch in the specimen are verified. There is evidence that the contour of notches cut in materials of widely differing physical properties by the same cutter will differ. It is sometimes necessary to alter the cutter dimensions in order to produce the required notch contour for certain materials.

8.1.2 Both the notch and the cutter used to make the notch shall be inspected, at a minimum, after every 500 notches. The specimen used to verify the notch shall be the same material that is being prepared for testing. Follow the procedure in Appendix X1 when inspecting and verifying the notch in the specimen. If the angle or radius of the notch does not meet the requirements of 8.1, the cutter should be replaced.

NOTE 9—The contour of the notch made using multi-tooth cutters is checked by measuring the contour of the notch on a strip of soft metal that is inserted between two specimens during the notching process.

NOTE 10—When the same material is being tested on a repetitive basis, and it is demonstrated that the notch in the specimen takes the contour of the tip of the cutter and that the notch meets the contour requirements when checked in accordance with Appendix X1, then it is acceptable to check the contour of the tip of the cutter instead of the notch in the specimen.

8.2 *Notch Depth*—The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm [0.400 ± 0.002 in.]. This dimension shall be measured with apparatus in accordance with 6.3. The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface centered on the micrometer's flat circular anvil.

8.3 *Cutter Speed and Feed Rate*—The cutter speed and feed speed should be selected based on the material being tested. The quality of the notch will be adversely affected by thermal deformations and stresses induced during the cutting operation if proper conditions are not selected.[5] The notching parameters used shall not alter the physical state of the material, such as by raising the temperature of a thermoplastic above its glass transition temperature.

8.3.1 In general, high cutter speeds, slow feed rates, and lack of coolant induce more thermal damage than a slow cutter speed, fast feed speed, and the use of a coolant. Too high a feed speed/cutter speed ratio, however, has been shown to cause impacting and cracking of the specimen. The range of cutter speed/feed ratios possible to produce acceptable notches has been shown to be extended by the use of a suitable coolant.

8.3.1.1 For some thermoplastics, suitable notches have been produced using cutter speeds from 54 to 150 m/min and a feed rate of 89 to 160 mm/min without a water coolant. Satisfactory notches also have been produced using the same cutter speeds at feed speeds of from 36 to 160 mm/min with water coolant.

8.3.1.2 Embedded thermocouples have been used to determine the temperature rise in the material near the apex of the notch during machining. Thermal stresses induced during the notching operation have been observed in transparent materials by viewing the specimen at low magnification between crossed

[5] Supporting data is available from ASTM Headquarters. Request Research Report RR: D20–1066.

polars in monochromatic light. The specimens used to determine temperature rise shall not be used to make determinations of impact resistance.

8.3.2 The feed rate and the cutter speed shall remain constant throughout the notching operation.

8.4 It is acceptable to notch specimens individually or in a group. In either case, however, an unnotched backup or dummy bar shall be placed behind the last specimen in the sample holder to prevent distortion and chipping by the cutter as it exits from the last test specimen.

8.5 All specimens having one dimension less than 12.7 mm [0.500 in.] shall have the notch cut on the shorter side. Compression molded specimens shall be notched on the side parallel to the direction of application of molding pressure. The impact resistance of a plastic material will be different if the notch is perpendicular to rather than parallel to the direction of molding, as with or across the grain of an anisotropic bar cut from a plate.

9. Conditioning

9.1 Check the materials specification for the material that is being tested. If there are no conditioning requirements stated by the materials specification, the test specimens shall be conditioned at 23 ± 2°C [73 ± 3.6°F] and 50 ± 5 % relative humidity for not less than 40 h after notching and prior to testing in accordance with Procedure A of Practice D 618, unless documented (between supplier and customer) that shorter conditioning time is sufficient for a given material to reach equilibrium of impact resistance.

9.2 For hygroscopic materials, such as nylons, the material specifications (for example, Classification System D 4066) call for testing dry-as-molded specimens. Such requirements take precedence over the above routine preconditioning to 50 % relative humidity. These specimens shall be sealed in water vapor-impermeable containers as soon as molded. When notching these specimens, minimize the exposure time during notching and return the specimens to a dry container after notching to allow for full cooling of the specimens prior to testing.

9.3 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C [73 ± 3.6°F] and 50 ± 5 % relative humidity, unless otherwise specified. In cases of disagreement, the tolerances shall be ±1°C and ±2 % relative humidity.

10. Procedure

10.1 *Specimen Preparation:*

10.1.1 Prepare the test specimens in accordance with the procedures in Section 7. At least five and preferably ten or more individual determinations of impact resistance shall be made to determine the average impact resistance for a particular sample. The specimens shall be of nominal width only.

10.1.2 Notch the specimens in accordance with the procedure in Section 8.

10.1.3 Condition the specimens in accordance with the materials specification for the material that is being tested. If there are no conditioning requirements detailed in the materials specification, follow the conditioning requirements in Section 9.

10.2 *Machine Preparation:*

10.2.1 Estimate the breaking energy for the sample and select a pendulum of suitable energy. Select the lightest standard pendulum that is expected to break all specimens in the group with an energy loss of not more than 85 % of its capacity (see 6.1). If the breaking energy cannot be estimated, the correct pendulum can be determined by performing trial runs. Caution should be used to avoid damaging the pendulum by selecting a pendulum that is too light for a particular sample.

NOTE 11—Ideally, an impact test would be conducted at a constant test velocity. In a pendulum-type test, however, the velocity decreases as the fracture progresses. For specimens that have an impact energy approaching the capacity of the pendulum, there is insufficient energy to complete the break and toss. By avoiding the higher 15 % scale energy readings, the velocity of the pendulum will not be reduced below 1.33 m/s. On the other hand, the use of a pendulum that is too heavy would reduce the sensitivity of the reading.

10.2.2 After installing the selected pendulum on the machine, check the machine for conformity with the requirements of Section 6 before starting the tests.

10.2.3 When using a machine equipped with a pointer and dial mechanism or an electronic indicator that does not automatically correct for windage and friction, determine the windage and friction correction factors for the machine before testing specimens. Windage and friction correction factors shall be determined on a daily basis and shall be calculated each time weights are added to the pendulum or the pendulum is changed. Refer to Annex A1 for information on constructing windage and friction correction charts or refer to Annex A2 for a procedure to calculate the windage and friction correction. If excessive friction is indicated (see X2.12 and X2.13) the machine shall be adjusted before testing specimens. Follow the machine manufacturer's instructions to correct for excessive windage and friction.

NOTE 12—The actual correction factors for windage and friction will be smaller than these factors in an actual test because the energy absorbed by the specimen prevents the pendulum from making a full swing. The indicated breaking energy of the specimen, therefore, must be included in the calculation of the machine correction.

10.2.4 Some machines equipped with an electronic digital display or computer automatically compensate for windage and friction.

10.3 *Specimen Testing:*

10.3.1 Check all of the specimens in the sample group for conformity with the requirements of Sections 7 and 8 and 10.1.

10.3.2 Measure and record the width of each specimen after notching to the nearest 0.025 mm [0.001 in]. Measure the width in one location adjacent to the notch centered about the anticipated fracture plane.

10.3.3 Measure and record the depth of material remaining in the specimen under the notch of each specimen to the nearest 0.025 mm [0.001 in]. The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface so that it is centered on the micrometer's flat circular anvil. See Fig. 5.

10.3.4 Position a test specimen horizontally on the supports and against the anvils so that it will be impacted on the face opposite the notch (see Fig. 3). The notch should be centered between the anvils. A centering jig is useful for this purpose.

10.3.5 Raise and secure the pendulum in the release mechanism. Zero the excess energy indicating mechanism.

10.3.6 Release the pendulum, allowing the striking edge of the pendulum to impact the specimen. Note the indicated breaking energy.

10.3.7 Calculate the net breaking energy (see 11.1). If the net breaking energy is greater than 85 % of the pendulum's nominal energy, the wrong pendulum was used. Discard the result. Select and install a pendulum with a greater available energy or add additional weight to the pendulum, determine the windage and friction correction factor, and repeat the test on a new specimen.

10.3.8 If the proper pendulum was used, test the remaining specimens as described in 10.3.1-10.3.6. Results from specimens that do not break should be discarded. A specimen that does not break completely into two or more pieces is not considered to be broken.

10.3.9 After all of the specimens for the sample have been tested, calculate the impact resistance, in joules per metre, for each individual specimen (see 11.2).

10.3.10 Calculate the average impact resistance for the group of specimens (see 11.3). Values obtained from specimens that did not break completely shall not be included in the average.

10.3.11 Calculate the standard deviation for the group of specimens (see 11.4).

11. Calculation

11.1 *Net Breaking Energy*—Subtract the windage and friction loss energy from the indicated breaking energy.

11.2 *Impact Resistance*—Divide the net breaking energy by the measured width of each individual specimen.

11.3 Calculate the average impact resistance for a group of specimens by adding the individual impact resistance values for the group and dividing the sum by the total number of specimens in the group.

11.4 Calculate the standard deviation as follows and report it to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)} \quad (3)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type source, manufacturer's code number, and previous history.

12.1.2 A statement of how the specimens were prepared, the testing conditions used, the number of hours the specimens were conditioned after notching, and for sheet materials, the direction of testing with respect to anisotropy, if any.

12.1.3 The capacity of the pendulum, J.

12.1.4 The span.

12.1.5 The width and depth under the notch of each specimen tested.

12.1.6 The total number of specimens tested per sample of material (that is five, ten, or more).

12.1.7 The average impact resistance, J/m. Impact resistance is not to be reported for other than complete breaks. Reporting results in kJ/m^2 is optional (see Appendix X4).

12.1.8 The standard deviation of the values of the impact resistance of the specimens in 10.3.11.

13. Precision and Bias

13.1 Table 1 is based on a round robin[6] conducted in 1987 in accordance with Practice E 691, involving five materials tested by nine laboratories. For each material, all samples were prepared at one source, but the individual specimens were notched and conditioned at the laboratories which tested them. Each laboratory tested an average of nine specimens for each material. **Warning**—The explanations of *r* and *R* (13.2-13.2.3) are intended only to present a meaningful way of considering the approximate precision of this test method. The data presented in Table 1 should not be applied to acceptance or rejection of materials, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously representative of other lots, formulations, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their materials and laboratory, or between specific laboratories. The principles of 13.2-13.2.3 would then be valid for such data.

13.2 *Concept of r and R in Table 1* —If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing nine specimens for each test result, then:

13.2.1 *Repeatability*—*r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the

[6] Supporting data is available from ASTM Headquarters. Request Research Report RR: D20–1041 and 1134.

TABLE 1 Precision for Charpy Test

Values in ft·lbf/in. of Width						
Material	Average	S_r[A]	S_R[B]	r[C]	R[D]	Number of Laboratories
Phenolic	0.55	0.029	0.050	0.08	0.14	7
Reinforced nylon	1.98	0.065	0.143	0.18	0.40	7
Polycarbonate	2.85	0.083	0.422	0.23	1.19	8
Polypropylene	4.06	0.151	0.422	0.42	1.19	9
ABS	10.3	0.115	0.629	0.32	1.76	9

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test result from all of the participating laboratories:

$$S_r = [[(S_1)^2 + (S_2)^2 \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.
[C] r = within-laboratory critical interval between two test results = 2.8 × S_r.
[D] R = between laboratories critical interval between two test results = 2.8 × S_R.

same day in the same laboratory. Two tests results shall be judged not equivalent if they differ by more than the *r* value for that material.

13.2.2 *Reproducibility*—*R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories, not necessarily on the same day. Two test results shall be judged not equivalent if they differ by more than the *R* value for that material.

13.2.3 Any judgement in accordance with 13.2.1 or 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

13.3 There are no recognized standards by which to estimate bias of this test method.

14. Keywords

14.1 Charpy impact; impact resistance; notch sensitivity; notched specimen

ANNEXES

(Mandatory Information)

A1. INSTRUCTIONS FOR THE CONSTRUCTION OF A WINDAGE AND FRICTION CORRECTION CHART

A1.1 The construction and use of the chart herein described is based upon the assumption that the friction and windage losses are proportional to the angle through which these loss torques are applied to the pendulum. Fig. A1.1 shows the assumed energy loss versus the angle of the pendulum position during the pendulum swing. The correction chart to be described is principally the left half of Fig. A1.1. The windage and friction correction charts should be available from commercial testing machine manufacturers. The energy losses designated as A or B are described in 10.3.

A1.2 Start the construction of the correction chart (Fig. A1.2) by laying off to some convenient linear scale on the abscissa of a graph the angle of pendulum position for the portion of the swing beyond the free hanging position. For convenience, place the free hanging reference point on the right end of the abscissa with the angular displacement increasing linearly to the left. The abscissa is referred to as Scale C. Although angular displacement is the quantity to be represented linearly on the abscissa, this displacement is more conveniently expressed in terms of indicated energy read from the machine dial. This yields a nonlinear Scale C with indicated pendulum energy increasing to the right.

A1.3 On the right hand ordinate lay off a linear Scale B starting with zero at the bottom and stopping at the maximum expected pendulum friction and windage value at the top.

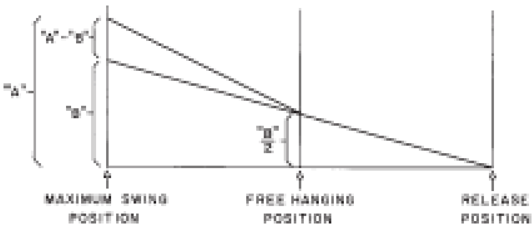


FIG. A1.1 Method of Construction of a Windage and Friction Correction Chart

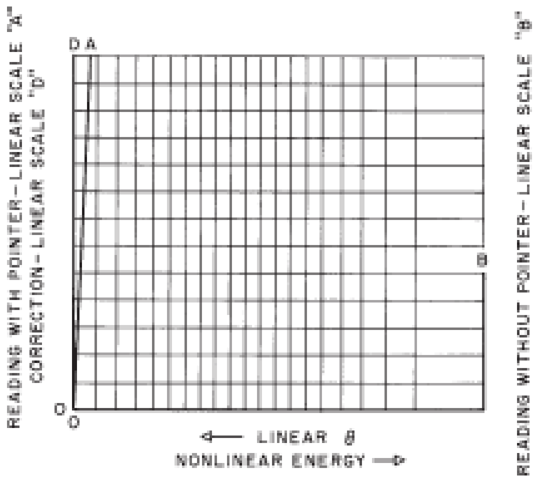


FIG. A1.2 Sample Windage and Friction Correction Chart

A1.4 On the left ordinate construct a linear Scale D ranging from zero at the bottom to 1.2 times the maximum ordinate value appearing on Scale B, but make the scale twice the scale used in the construction of Scale B.

A1.5 Adjoining Scale D draw a curve OA which is the focus of points whose coordinates have equal values of energy correction on Scale D and indicated energy on Scale C. This curve is referred to as Scale A and utilizes the same divisions and numbering system as the adjoining Scale D.

A1.6 *Instructions for Using Chart:*

A1.6.1 Locate and mark on Scale A the reading A obtained from the free swing of the pendulum with the pointer prepositioned in the free hanging or maximum indicated energy position on the dial.

A1.6.2 Locate and mark on Scale B the reading B obtained after several free swings with the pointer pushed up close to zero indicated energy position of the dial by the pendulum in accordance with instructions in 10.3.

A1.6.3 Connect the two points thus obtained by a straight line.

A1.6.4 From the indicated impact energy on Scale C project up to the constructed line and across to the left to obtain the correction for windage and friction from Scale D.

A1.6.5 Subtract this correction from the indicated impact reading to obtain the energy delivered to the specimen.

A2. PROCEDURE FOR THE CALCULATION OF WINDAGE AND FRICTION CORRECTION

A2.1 The procedure for the calculation of the windage and friction correction in this annex is based on the equations developed by derivation in Appendix X3. This procedure is acceptable as a substitute for the graphical procedure described in Annex A1 and is applicable to small electronic calculator and computer analysis.

A2.2 Calculate L, the distance from the axis of support to the center of percussion as indicated in 6.3. It is assumed here that the center of percussion is approximately the same as the center of strike.

A2.3 Measure the maximum height, h_M, of the center of percussion (center of strike) of the pendulum at the start of the test as indicated in X2.16.

A2.4 Measure and record the energy correction, E_A, for windage of the pendulum plus friction in the dial, as determined with the first swing of the pendulum with no specimen in the testing device. This correction must be read on the energy scale, E_M, appropriate for the pendulum used.

A2.5 Without resetting the position of the indicator obtained in A2.4, measure the energy correction, E_B, for pendulum windage after two additional releases of the pendulum with no specimen in the testing device.

A2.6 Calculate β_{max} as follows:

$$\beta_{max} = \cos^{-1} \{1 - [(h_M/L)(1 - E_A/E_M)]\} \tag{A2.1}$$

where:

E_A = energy correction for windage of pendulum plus friction in dial, J [ft·lbf],

E_M = full-scale reading for pendulum used, J [ft·lbf],

L = distance from fulcrum to center of strike of pendulum, m [ft],

h_M = maximum height of center of strike of pendulum at start of test, m [ft], and

β_{max} = maximum angle pendulum will travel with one swing of the pendulum.

A2.7 Measure specimen breaking energy, E_S, J [ft·lbf].

A2.8 Calculate β for specimen measurement E_s as:

$$\beta = \cos^{-1} \{1 - [(h_M/L)(1 - E_S/E_M)]\} \tag{A2.2}$$

where:

β = angle pendulum travels for a given specimen, and

E_S = dial reading breaking energy for a specimen, J [ft·lbf].

A2.9 Calculate total correction energy, E_{TC} as:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/2) \tag{A2.3}$$

where:

E_{TC} = total correction energy for the breaking energy, E_S, of a specimen, J [ft·lbf], and

E_B = energy correction for windage of the pendulum, J [ft·lbf].

A2.10 Calculate the impact resistance using the following formula:

$$I_s = (E_s - E_{TC})/t \tag{A2.4}$$

where:

I_s = impact resistance of specimen, J/m [ft·lbf/in.] of width, and

t = width of specimen or width of notch, m [in.]

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURE FOR THE INSPECTION AND VERIFICATION OF NOTCH

X1.1 The purpose of this procedure is to describe the microscopic method to be used for determining the radius and angle of the notch. These measurements could also be made using a comparator if available.

NOTE X1.1—The notch shall have a radius of 0.25 ± 0.05 mm [0.010 ± 0.002 in.] and an angle of 45 ± 1°.

X1.2 *Apparatus*:

X1.2.1 *Optical Device*, with minimum magnification of 60×, Filar glass scale and camera attachment.

X1.2.2 *Transparent Template*, that will be developed in this procedure.

X1.2.3 *Ruler*.

X1.2.4 *Compass*.

X1.2.5 *Plastic Drafting Set Squares (Triangles)*, 45–45–90°.

X1.3 A transparent template must be developed for each magnification and for each microscope used. It is preferable that each laboratory standardize on one microscope and one magnification. It is not necessary for each laboratory to use the same magnification because each microscope and camera combination have somewhat different blowup ratios.

X1.3.1 Set the magnification of the optical device at a suitable magnification with a minimum magnification of 60×.

X1.3.2 Place the Filar glass slide on the microscope platform. Focus the microscope so the most distinct of the Filar scale is visible.

X1.3.3 Take a photograph of the Filar scale (see Fig. X1.1).

X1.3.4 Create a template similar to that shown in Fig. X1.2.

X1.3.4.1 Find the approximate center of the piece of paper.

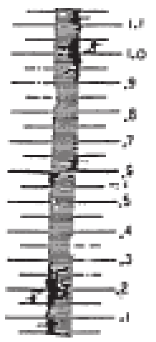
X1.3.4.2 Draw a set of perpendicular coordinates through the center point.

X1.3.4.3 Draw a family of concentric circles that are spaced in accordance with the dimensions of the Filar scale. This task is accomplished by first setting a mechanical compass at a distance of 0.1 mm [0.004 in.] as referenced by the magnified photograph of the Filar eyepiece. Subsequent circles shall be spaced 0.02 mm apart [0.001 in.], as rings, with the outer ring being 0.4 mm [0.016 in.] from the center.

X1.3.5 Photocopy the paper with the concentric circles to make a transparent template of the concentric circles.

X1.3.6 Construct Fig. X1.3 by taking a second piece of paper, finding its approximate center, and marking this point. Draw one line through this center point. Label this line zero degree (0°). Draw a second line perpendicular to the first line through this center point. Label this line 90°. From the center draw a line that is 44° relative to the 0°. Label the line 44°. Draw another line at 46°. Label the line 46°.

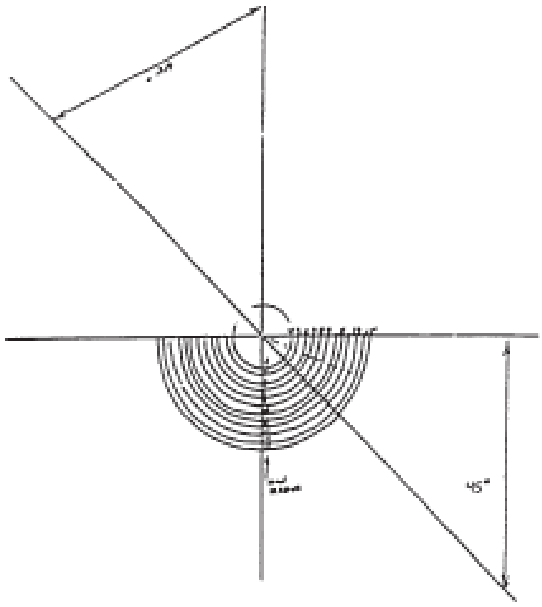
X1.4 Place a microscope glass slide on the microscope platform. Place the notched specimen on top of the slide. Focus



NOTE 1—100× reference.

NOTE 2—0.1 mm major scale; 0.01 mm minor scale.

FIG. X1.1 Filar Scale



NOTE 1—Magnification = 100×.

FIG. X1.2 Example of Transparent Template for Determining Radius of Notch

the microscope. Move the specimen around using the platform adjusting knobs until the specimen's notch is centered and near the bottom of the viewing area. Take a picture of the notch.

X1.4.1 *Determination of Notching Radius* (Fig. X1.4):

X1.4.1.1 Place the picture on a sheet of paper. Position the picture so that bottom of the notch in the picture faces downwards and is about 64 mm [2.5 in.] from the bottom of the paper. Tape the picture down to the paper.

X1.4.1.2 Draw two lines along the sides of the notch projecting down to a point where they intersect below the notch Point I (see Fig. X1.4B).

X1.4.1.3 Open the compass to about 51 mm [2 in.]. Using Point I as a reference, draw two arcs intersecting both sides of the notch (see Fig. X1.4C). These intersections are called 1a and 1b.

X1.4.1.4 Close the compass to about 38 mm [1.5 in.]. Using Point 1a as the reference point, draw an arc (2a) above the notch, draw a second arc (2b) that intersects with arc 2a at Point J. Draw a line between I and J. This establishes the centerline of the notch (see Fig. X1.4D)

X1.4.1.5 Place the transparent template on top of the picture and align the center of the concentric circles with the drawn centerline of the notch (see Fig. X1.4E).

X1.4.1.6 Slide the template down the centerline of the notch until one concentric circle touches both sides of the notch. Record the radius of the notch and compare it against the limits of 0.2 to 0.3 mm [0.008 to 0.012 in.].

X1.4.1.7 Examine the notch to ensure that there are no flat spots along the measured radius.

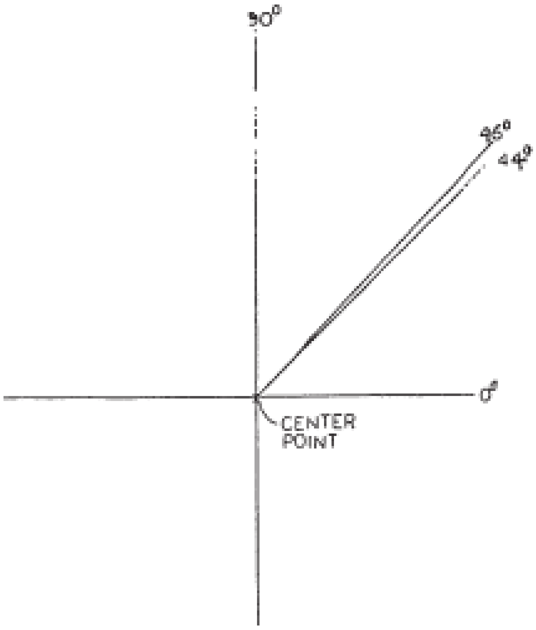


FIG. X1.3 Example of Transparent Template for Determining Angle of Notch

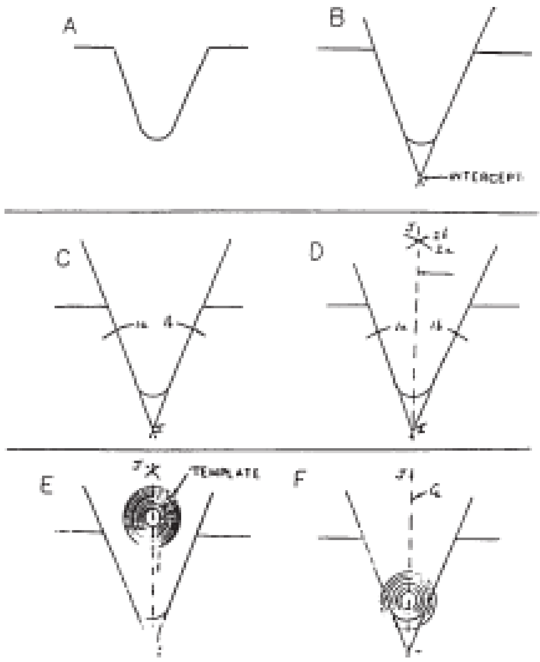


FIG. X1.4 Determining Radius

X1.4.2 *Determination of Notch Angle*—Place transparent template for determining notch angle (Fig. X1.3) on top of the photograph attached to the sheet of paper. Rotate the picture so that the notch tip is pointed towards you. Position the center point of the template on top of the Point I established in 0° axis of the template with the right side straight portion of the notch. Check the left side straight portion of the notch to ensure that this portion falls between the 44° and 46° lines. If not, replace the blade.

X1.5 A picture of a notch shall be taken at least every 500 notches or if a control sample gives a value outside its 3-sigma limits for that test.

X1.6 If the notch in the control specimen is not within the requirements, a picture of the notching blade should be taken and analyzed by the same procedure used for the specimen notch. If the notching blade does not meet ASTM requirements or shows damage, it should be replaced with a new blade which has been checked for proper dimensions.

X1.7 If a cutter has the correct dimensions, but does not cut the correct notch in the specimen, it will be necessary to evaluate other conditions (cutter and feed speeds) to obtain the correct notch dimension for that material.

X2. CALIBRATION OF PENDULUM-TYPE HAMMER IMPACT MACHINES FOR USE WITH PLASTIC SPECIMENS

X2.1 This calibration procedure applies specifically to the Charpy impact machine.

X2.2 Locate the impact machine on a sturdy base. It shall not walk on the base and the base shall not vibrate appreciably. Loss of energy from vibrations will give high readings. It is recommended that the impact tester be bolted to a base having a mass of at least 23 kg if it is used at capacities higher than 2.7 J [2 ft·lbf].

X2.3 Check the level of the machine in both directions on the plane of the base with spirit levels mounted in the base, by a machinist's level if a satisfactory reference surface is available, or with a plumb bob. The machine should be made level to within $\tan^{-1}$ 0.001 in the plane of swing and to within $\tan^{-1}$ 0.002 in the place perpendicular to the swing.

X2.4 Contact the machine manufacturer for a procedure to ensure the striker radius is in tolerance (3.17 ± 0.12 mm) (see 6.3).

X2.5 Check the transverse location of the center of the pendulum striking edge that shall be within 0.40 mm [0.016 in.] of the center of the anvil. Readjust the shaft bearings or relocate the anvil or straighten the pendulum shaft as necessary to attain the proper relationship between the two centers.

X2.6 Check the pendulum arm for straightness within 1.2

mm [0.05 in.] with a straightedge or by sighting down the shaft. This arm is sometimes bent by allowing the pendulum to slam against the catch when high–capacity weights are on the pendulum.

X2.7 Center a notched 12.7–mm square metal bar having opposite sides parallel within 0.025 mm and 125 mm long on the Charpy anvils. Place a thin oil film on the striking edge of the pendulum with an oiled cloth and let the striking edge rest gently against the bar. A thin line of oil should be transferred across the entire width of the bar, thereby verifying that the striking edge is in contact across the entire specimen width.

X2.8 When the pendulum is hanging free in its lowest position, the energy reading must be within 0.2 % of full scale.

X2.9 Swing the pendulum to a horizontal position, and support it by the striking edge in this position with a vertical bar. Allow the other end of this bar to rest at the center of a load pan on a balanced scale. Subtract the weight of the bar from the total weight to find the effective weight of the pendulum. The effective pendulum weight should be within 0.4 % of the required weight for that pendulum capacity. If weight must be added or removed, take care to balance the added or removed weight without affecting the center of percussion relative to the striking edge. It is not advisable to add weight to the opposite side of the bearing axis from the striking edge to decrease the effective weight of the pendulum since the distributed mass has the potential to result in large energy losses from vibration of the pendulum.

X2.10 Calculate the effective length of the pendulum arm or the distance to the center of percussion from the axis of rotation by the procedure in Note 5. The effective length must be within the tolerance stated in 6.3.

X2.11 Determine the vertical distance of fall of the pendulum striking edge from its latched height to its lowest point. This distance should be 610 ± 2 mm. This measurement is made with a half-width specimen positioned on the anvils. Place a thin oil film on the specimen and bring the striking edge against it. The upper end of the oil line on the striking edge is the center of strike. Measure the change in vertical height of the center of strike from the latched to the free hang position (the lowest point). This vertical fall distance is adjusted by varying the position of the pendulum latch.

X2.12 If a pointer and dial mechanism is used to indicate the energy, the pointer friction should be adjusted so that the pointer will just maintain its position anywhere on the scale. The striking pin of the pointer should be securely fastened to the pointer. Friction washers with glazed surfaces should be replaced with new washers. Friction washers should be on either side of the pointer collar. The last friction washer installed should be backed by a heavy metal washer. Pressure on this metal washer is produced by a thin bent spring washer and locknuts. If the spring washer is placed next to the fiber friction washer, the pointer will tend to vibrate during impact.

X2.13 The free-swing reading of the pendulum (without specimen) from the latched height should be less than 2.5 % of pendulum capacity on the first swing. If the reading is higher than this, the friction in the indicating mechanism is excessive or the bearings are dirty. To clean the bearings, dip them in grease solvent and spin dry in an air jet. Clean the bearings until they spin freely or replace them. Oil very lightly with instrument oil before replacing. A reproducible method of starting the pendulum from the proper height must be devised.

X2.14 The shaft about which the pendulum rotates shall have no detectable radial play, less than 0.05 mm [0.002 in.]. An end play of 0.25 mm [0.010 in.] is permissible when a 9.8–N [2.2–lbf] axial force is applied in alternate directions.

X2.15 The machine should not be used to indicate more than 85 % of the energy capacity of the pendulum. Extra weight added to the pendulum will increase available energy of the machine. This weight must be added so as to maintain the center of percussion within the tolerance stated in 6.3. Correct effective weight for any range is calculated as follows:

$$W = E_p / h \quad \text{(X2.1)}$$

where:

W = the effective pendulum weight, N [lbf] (see X2.13),
E_p = potential or available energy of the machine, J [ft × lbf], and
h = the vertical distance of fall of the pendulum striking edge, m [ft] (see X2.11).

Each 4.5 N [1 lbf] of added effective weight increases the capacity of the machine by 2.7 J [2 ft × lbf].

NOTE X2.1—If the pendulum is designed for use with add-on weight, it is recommended that they be obtained through the equipment manufacturer.

X3. DERIVATION OF PENDULUM IMPACT CORRECTION EQUATIONS

X3.1 From right triangle distances in Fig. X3.1:

$$L - h = L \cos \beta \quad \text{(X3.1)}$$

X3.2 The potential energy gain of pendulum, E_p, is:

$$E_p = hW_p g \quad \text{(X3.2)}$$

X3.3 Combining Eq X3.1 and Eq X3.2 gives the following:

$$L - E_p/W_p g = L \cos \beta \quad \text{(X3.3)}$$

X3.4 The maximum energy of the pendulum is the potential energy at the start of the test, E_M, or

$$E_M = h_M W_p g \quad \text{(X3.4)}$$

X3.5 The potential energy gained by the pendulum, E_p, is related to the absorption of energy of a specimen, E_s, by the following equation:

$$E_M - E_s = E_p \quad \text{(X3.5)}$$

X3.6 Combining Eq X3.3-X3.5 gives the following:

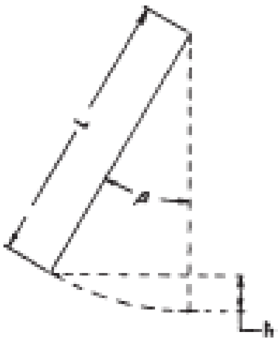


FIG. X3.1 Swing of Pendulum from Its Rest Position

$$(E_M - E_S)/E_M = L/h_M(1 - \cos\beta) \quad \text{(X3.6)}$$

X3.7 Solving Eq X3.6 for β gives the following:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_S/E_M)]\} \quad \text{(X3.7)}$$

X3.8 From Fig. X3.2, the total energy correction, E_{TC}, is given as:

$$E_{TC} = m\beta + b \quad \text{(X3.8)}$$

X3.9 At the zero point of the pendulum the potential energy is:

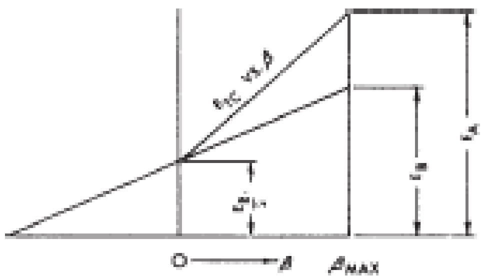


FIG. X3.2 Total Energy Correction for Pendulum Windage and Dial Friction as a Function of Pendulum Position

$$E_B/2 = m(0) + b$$
or $\quad$ (X3.9)

$$b = E_B/2 \quad \text{(X3.9)}$$

X3.10 The energy correction, E_A, on the first swing of the pendulum occurs at the maximum pendulum angle, β_{max}. Substituting in Eq X3.8 gives the following:

$$E_A = m\beta_{max} + (E_B/2) \quad \text{(X3.10)}$$

X3.11 Combining Eq X3.8 and Eq X3.11 gives the following:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/2) \quad \text{(X3.11)}$$

X3.12 *Nomenclature:*

b = intercept of total correction energy straight line,
E_A = energy correction, including both pendulum windage plus dial friction, J,
E_B = energy correction for pendulum windage only, J,
E_M = maximum energy of the pendulum (at the start of test), J,
E_p = potential energy gain of pendulum from the pendulum rest position, J,
E_S = uncorrected breaking energy of specimen, J,
E_{TC} = total energy correction for a given breaking energy, E_S, J,
g = acceleration of gravity, m/s^2,
h = distance center of gravity of pendulum rises vertically from the rest position of the pendulum, m,
h_m = maximum height of the center of gravity of the pendulum, m,
m = slope of total correction energy straight line,
L = distance from fulcrum to center of gravity of pendulum, m,
W_p = weight of pendulum, as determined in X2.13, kg, and
β = angle of pendulum position from the pendulum rest position.

X4. UNIT CONVERSIONS

X4.1 Joules per metre cannot be converted directly into kilojoules per square metre.

NOTE X4.1—The optional units of kJ/m^2 [ft·lbf/in.^{2}] also may be required; therefore, the cross-sectional area under the notch must be reported.

X4.2 The following examples are approximations:

1ft·lbf/39.37 in. = 1.356 J/m

1ft·lbf/in. = (39.37)(1.356) J/m
1ft·lbf/in. = 53.4 J/m
1ft·lbf/in. = 0.0534 kJ/m

1ft·lbf/1550 in.^{2} = 1.356 J/m^2
1ft·lbf/in.^{2} = (1550)(1.356) J/m^2
1ft·lbf/in.^{2} = 2101 J/m^2
1ft·lbf/in.^{2} = 2.1 kJ/m^2

SUMMARY OF CHANGES

This section identifies the location of selected changes to this test method. For the convenience of the user, Committee D20 has highlighted those changes that impact the use of this test method. This section also includes descriptions of the changes or reasons for the changes, or both.

D6110-04:

(*1*) Add reference to D5947 in paragraph 2.1.
(*2*) Changed requirements for micrometer in paragraph 6.3.
(*3*) Removed requirement to mill draft angle from specimens.
(*4*) Changed notch depth dimensions to 10.16 ± 0.05 mm in order to agree with Figure 4; and clarified procedure to measure notch depth in paragraph 8.2.
(*5*) Added paragraphs 10.3.2 and 10.3.3 on clarifying notch depth measuring technique. Renumbered subsequent sections.
(*6*) Added Figure 6.
(*7*) Permissive language removed.
(*8*) Imperial units added for reference.

INTERNATIONAL STANDARD

ISO 179-1

Second edition
2010-06-15

Plastics — Determination of Charpy impact properties —

Part 1:
Non-instrumented impact test

Plastiques — Détermination des caractéristiques au choc Charpy —

Partie 1: Essai de choc non instrumenté

Reference number
ISO 179-1:2010(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 179-1 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

This second edition cancels and replaces the first edition (ISO 179-1:2000), which has been technically revised. The main changes are as follows:

— a new subclause (6.5) has been added, defining the span between the specimen supports and indicating a convenient position at which it can be measured;

— a new annex, Annex C, has been added, giving a method of measuring the radius of the notch in a notched specimen.

This second edition also incorporates the Amendment ISO 179-1:2000/Amd.1:2005.

ISO 179 consists of the following parts, under the general title *Plastics — Determination of Charpy impact properties*:

— *Part 1: Non-instrumented impact test*

— *Part 2: Instrumented impact test*

Plastics — Determination of Charpy impact properties —

Part 1: Non-instrumented impact test

1 Scope

1.1 This part of ISO 179 specifies a method for determining the Charpy impact strength of plastics under defined conditions. A number of different types of specimen and test configurations are defined. Different test parameters are specified according to the type of material, the type of test specimen and the type of notch.

1.2 The method can be used to investigate the behaviour of specified types of specimen under the impact conditions defined and for estimating the brittleness or toughness of specimens within the limitations inherent in the test conditions. It can also be used for the determination of comparative data from similar types of material.

1.3 The method has a greater range of applicability than that given in ISO 180[1] and is more suitable for the testing of materials showing interlaminar shear fracture or of materials exhibiting surface effects due to environmental factors.

1.4 The method is suitable for use with the following range of materials:

— rigid thermoplastic moulding and extrusion materials (including filled and reinforced compounds in addition to unfilled types) and rigid thermoplastics sheets;

— rigid thermosetting moulding materials (including filled and reinforced compounds) and rigid thermosetting sheets (including laminates);

— fibre-reinforced thermosetting and thermoplastic composites incorporating unidirectional or multi-directional reinforcements (such as mats, woven fabrics, woven rovings, chopped strands, combination and hybrid reinforcements, rovings and milled fibres) or incorporating sheets made from pre-impregnated materials (prepregs), including filled and reinforced compounds;

— thermotropic liquid-crystal polymers.

1.5 Notched samples are not normally suitable for use with rigid cellular materials, long-fibre-reinforced composites or thermotropic liquid-crystal polymers. In these cases, unnotched samples may be used.

1.6 The method is suited to the use of specimens moulded to the chosen dimensions, machined from the central portion of a standard multipurpose test specimen (see ISO 3167) or machined from finished or semifinished products such as mouldings, laminates and extruded or cast sheet.

1.7 The method specifies preferred dimensions for the test specimen. Tests which are carried out on specimens of different dimensions or with different notches, or specimens which are prepared under different conditions, might produce results which are not comparable. Other factors, such as the energy capacity of the apparatus, the impact velocity and the conditioning of the specimens can also influence the results. Consequently, when comparative data are required, these factors must be carefully controlled and recorded.

1.8 The method should not be used as a source of data for design calculations. Information on the typical behaviour of a material can be obtained, however, by testing at different temperatures, by varying the notch radius and/or the specimen thickness and by testing specimens prepared under different conditions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 293, *Plastics — Compression moulding of test specimens of thermoplastic materials*

ISO 294-1, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 1: General principles, and moulding of multipurpose and bar test specimens*

ISO 294-3, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 3: Small plates*

ISO 295, *Plastics — Compression moulding of test specimens of thermosetting materials*

ISO 1268-11, *Fibre-reinforced plastics — Methods of producing test plates — Part 11: Injection moulding of BMC and other long-fibre moulding compounds — Small plates*

ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval*

ISO 2818, *Plastics — Preparation of test specimens by machining*

ISO 3167, *Plastics — Multipurpose test specimens*

ISO 10724-1, *Plastics — Injection moulding of test specimens of thermosetting powder moulding compounds (PMCs) — Part 1: General principles and moulding of multipurpose test specimens*

ISO 13802, *Plastics — Verification of pendulum impact-testing machines — Charpy, Izod and tensile impact-testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
Charpy unnotched impact strength
a_{cU}
impact energy absorbed in breaking an unnotched specimen, referred to the original cross-sectional area of the specimen

NOTE It is expressed in kilojoules per square metre (kJ/m^2).

3.2
Charpy notched impact strength
a_{cN}
impact energy absorbed in breaking a notched specimen, referred to the original cross-sectional area of the specimen at the notch, where N = A, B or C, depending on the notch type (see 6.3.1.1.2)

NOTE It is expressed in kilojoules per square metre (kJ/m^2).

3.3
edgewise impact
e
direction of blow parallel to the dimension b, with impact on the narrow longitudinal surface $h \times l$ of the specimen (see Figure 1, left, and Figures 2 and 4)

3.4
flatwise impact
f
direction of blow parallel to the dimension h, with impact on the broad longitudinal surface $b \times l$ of the specimen (see Figure 1, right, and Figures 3 and 4)

3.5
normal impact
n
⟨laminar-reinforced plastics⟩ impact with the direction of blow normal to the plane of reinforcement (see Figure 4)

3.6
parallel impact
p
⟨laminar-reinforced plastics⟩ impact with the direction of blow parallel to the plane of reinforcement (see Figure 4)

4 Principle

The test specimen, supported near its ends as a horizontal beam, is impacted by a single blow of a striker, with the line of impact midway between the supports, and bent at a high, nominally constant, velocity.

In the case of edgewise impact with notched specimens, the line of impact is directly opposite the single notch (see Figure 1, left, and Figure 2).

5 Apparatus

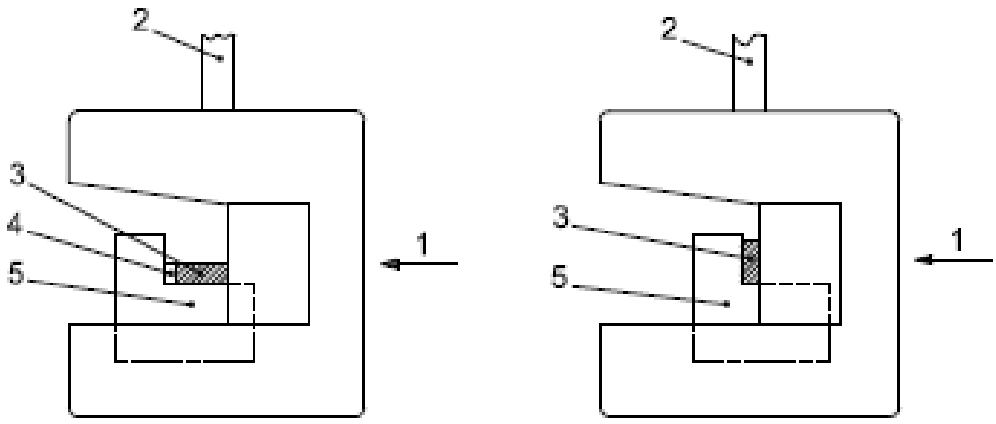
5.1 Test machine

The principles, characteristics and verification of suitable test machines are detailed in ISO 13802.

ISO 13802 describes partial verification and full verification. In the case of full verification, some items are difficult to verify when the apparatus is assembled. Such verifications are assumed to be incumbent on the manufacturer.

5.2 Micrometers and gauges

Micrometers and gauges capable of measuring the essential dimensions of test specimens to an accuracy of 0,02 mm are required. For measuring the dimension b_N of notched specimens, the micrometer shall have a spindle with a measuring tip having a suitable profile to fit the shape of the notch.



a) Edgewise impact

b) Flatwise impact

Key

1 direction of blow
2 rod of pendulum
3 test specimen
4 notch
5 support

Figure 1 — Striking edge and support blocks for type 1 test specimen at moment of impact

6 Test specimens

6.1 Preparation

6.1.1 Moulding and extrusion compounds

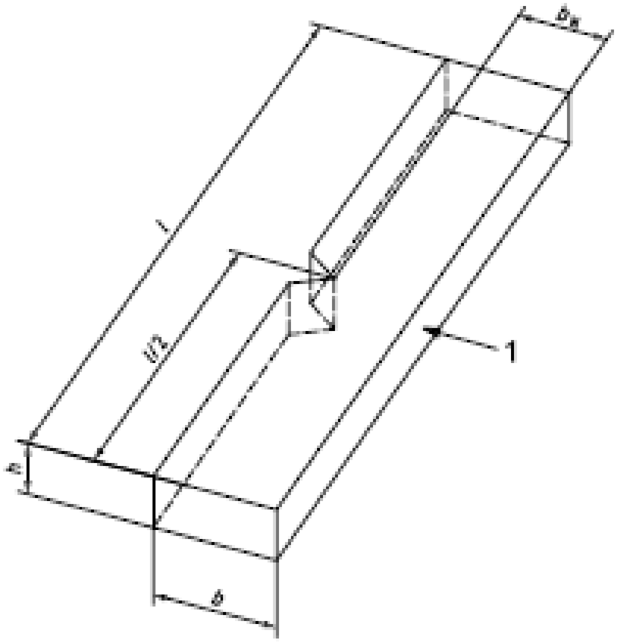
Specimens shall be prepared in accordance with the relevant material specification. The specimens shall be either directly compression moulded in accordance with ISO 293 or ISO 295 or injection moulded from the material in accordance with ISO 294-1, ISO 294-3 or ISO 10724-1, as appropriate, or machined in accordance with ISO 2818 from sheet that has been compression or injection moulded from the compound. Type 1 specimens may be cut from multipurpose test specimens complying with ISO 3167, type A.

6.1.2 Sheets

Specimens shall be machined from sheets in accordance with ISO 2818.

6.1.3 Long-fibre-reinforced materials

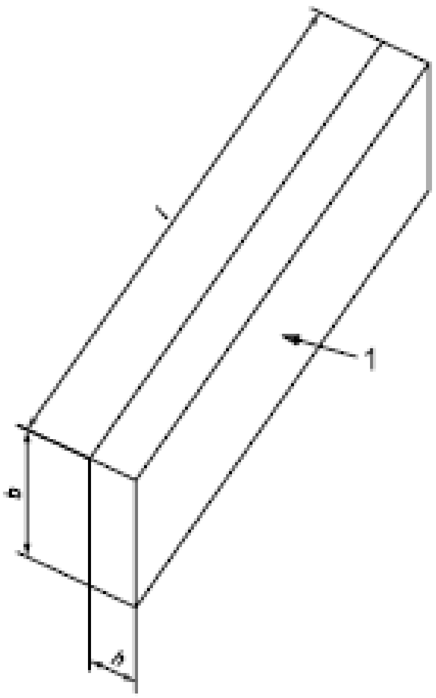
A panel shall be prepared in accordance with ISO 1268-11 or another specified or agreed upon preparation procedure. Specimens shall be machined in accordance with ISO 2818.



Key

1 direction of blow

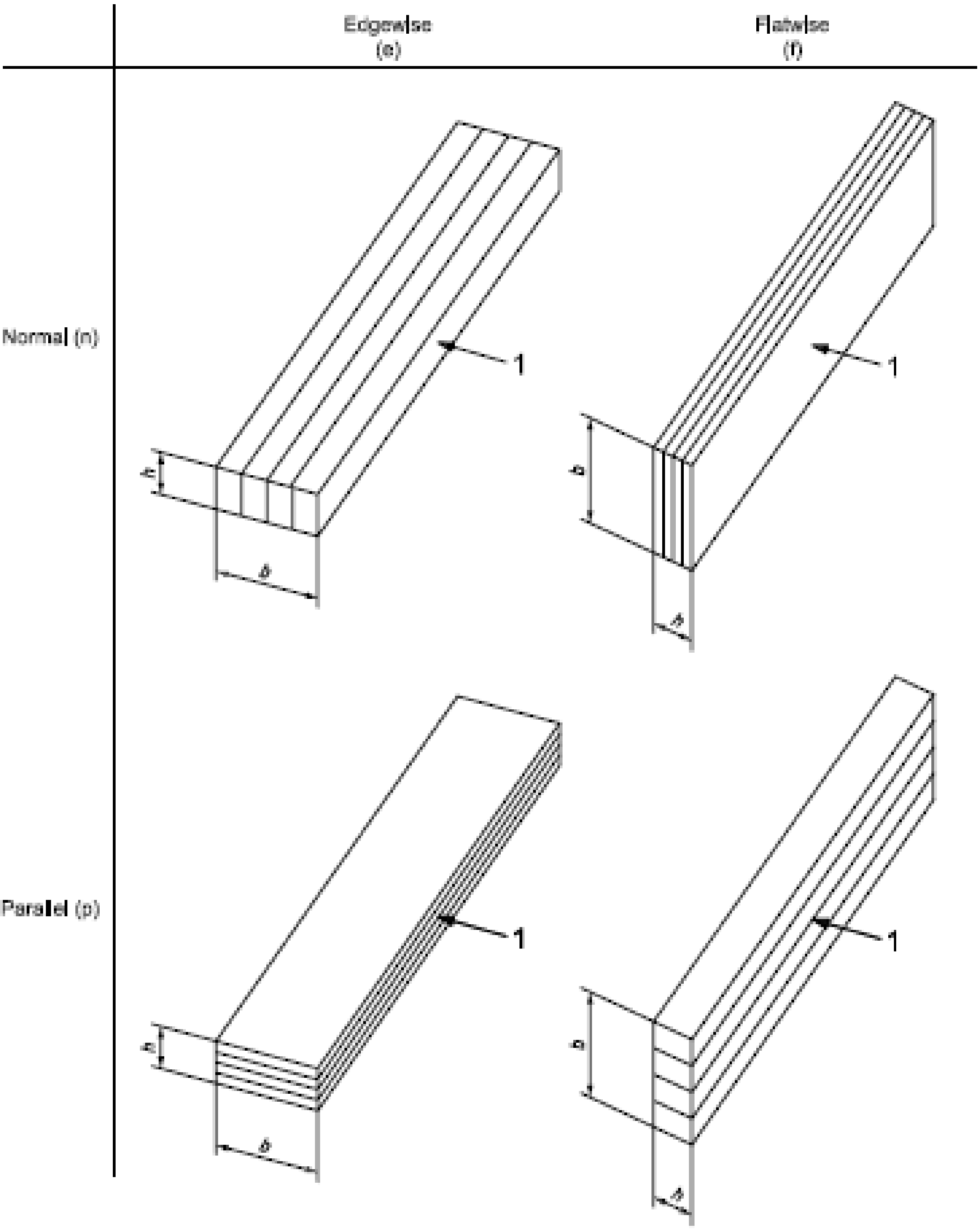
Figure 2 — Charpy edgewise impact (e) with single-notched specimen



Key

1 direction of blow

Figure 3 — Charpy flatwise impact (f)



Key

1 direction of blow

Edgewise (e) and flatwise (f) indicate the direction of the blow with respect to the specimen thickness, h, and specimen width, b. Normal (n) and parallel (p) indicate the direction of the blow with respect to the laminate plane.

The Charpy "fn" and "ep" tests are used for laminates, while both the Charpy "en" and "ep" tests are used for other materials. The Charpy "fn" and "fp" tests are used for testing materials exhibiting surface effects.

Figure 4 — Scheme of designations describing the direction of blow

6.1.4 Checking

The specimens shall be free of twist and shall have mutually perpendicular parallel surfaces. The surfaces and edges shall be free from scratches, pits, sink marks and flash.

The specimens shall be checked for conformity with these requirements by visual observation against straightedges, set squares and flat plates, and by measuring with micrometer callipers.

Specimens showing measurable or observable departure from one or more of these requirements shall be rejected or machined to proper size and shape before testing.

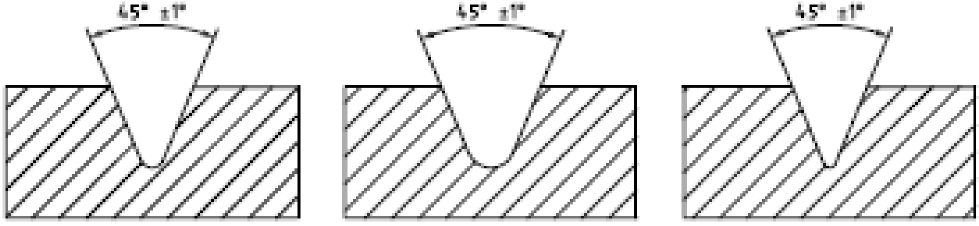
6.1.5 Notching

6.1.5.1 Machined notches shall be prepared in accordance with ISO 2818. The profile of the cutting tooth shall be such as to produce in the specimen a notch of the contour and depth shown in Figure 5, at right angles to its principal axes (see Note).

NOTE The radius of the notch tip can be measured by the method given in Annex C.

6.1.5.2 Specimens with moulded-in notches may be used if specified for the material being tested (see Note).

NOTE Specimens with moulded-in notches do not give results comparable to those obtained from specimens with machined notches.



a) **Type A**

Radius of notch tip
$r_N = (0,25 \pm 0,05)$ mm

b) **Type B**

Radius of notch tip
$r_N = (1,00 \pm 0,05)$ mm

c) **Type C**

Radius of notch tip
$r_N = (0,10 \pm 0,02)$ mm

Figure 5 — Notch types

6.2 Anisotropy

Certain types of sheet or panel material or specimen taken from injection-moulded plates can show different impact properties, depending on the direction in the plane of the sheet or panel. In such cases, it is customary to cut groups of test specimens with their major axes respectively parallel and perpendicular to the direction of some feature of the sheet or panel which is either visible or inferred from knowledge of the method of manufacture.

6.3 Shape and dimensions

6.3.1 Materials not exhibiting interlaminar shear fracture

6.3.1.1 Moulding and extrusion compounds

6.3.1.1.1 Type 1 test specimens, unnotched or with one of three different types of notch, shall be used as specified in Tables 1 and 2 and shown in Figures 2 and 5. The notch shall be located at the centre of the specimen. Type 1 specimens (see Table 1) may be taken from the central part of the type A multipurpose test specimen specified in ISO 3167.

Table 1 — Specimen types, specimen dimensions and spans between specimen supports
(see Figures 2 and 6)

Dimensions in millimetres

Specimen type	Length[a] l	Width[a] b	Thickness[a] h	Span L
1	80 ± 2	$10{,}0 \pm 0{,}2$	$4{,}0 \pm 0{,}2$	$62^{+0{,}5}_{-0{,}0}$
2[b]	$25h$	10 or 15[c]	3[d]	$20h$
3[b]	$11h$ or $13h$			$6h$ or $8h$

[a] The specimen dimensions (thickness, h, width, b, and length, l) are defined by $h < b < l$.

[b] Specimen types 2 and 3 shall be used only for materials described in 6.3.2.

[c] 10 mm for materials reinforced with a fine structure, 15 mm for those with a large stitch structure (see 6.3.2.2).

[d] Preferred thickness. If the specimen is cut from a sheet or a piece, h shall be equal to the thickness of the sheet or piece, up to 10,2 mm (see 6.3.1.2).

Table 2 — Method designations, specimen types, notch types and notch dimensions — Materials not exhibiting interlaminar shear fracture

Dimensions in millimetres

Method designation[a]	Specimen type	Blow direction	Notch type	Notch tip radius, r_N (see Figure 5)	Remaining width, b_N, at notch tip (see Figure 2)
ISO 179-1/1eA[b]	1	Edgewise	A	$0{,}25 \pm 0{,}05$	$8{,}0 \pm 0{,}2$
ISO 179-1/1eB			B	$1{,}00 \pm 0{,}05$	$8{,}0 \pm 0{,}2$
ISO 179-1/1eC			C	$0{,}10 \pm 0{,}02$	$8{,}0 \pm 0{,}2$
ISO 179-1/1eU[b]			Unnotched		
ISO 179-1/1fU[c]		Flatwise	Unnotched		

[a] If specimens are taken from sheet or products, the thickness of the sheet or product shall be added to the designation. Unreinforced specimens shall not be tested with their machined surface under tension.

[b] Preferred method.

[c] Especially for the study of surface effects (see 6.3.1.1.3).

6.3.1.1.2 The preferred type of notch is type A (see Table 2 and Figure 5). For most materials, unnotched specimens or specimens with a single type A notch tested by edgewise impact (see 3.3) are suitable. If specimens with a type A notch do not break during the test, specimens with a type C notch shall be used. If information on the notch sensitivity of the material is desired, specimens with notch types A, B and C shall be tested.

6.3.1.1.3 Unnotched or double-notched specimens tested by flatwise impact (see 3.4) can be used to study surface effects (see 1.3 and Annex A).

6.3.1.2 Sheet materials

The recommended value of the thickness, h, is 4 mm. If the specimen is cut from a sheet or a piece taken from a structure, the thickness of the specimen, up to 10,2 mm, shall be the same as the thickness of the sheet or the structure.

Specimens taken from pieces thicker than 10,2 mm shall be machined to $(10 \pm 0,2)$ mm from one surface, provided that the sheet is homogeneous in its thickness and contains only one type of reinforcement uniformly distributed. If unnotched or double-notched specimens are tested by flatwise impact, the original surface shall be tested under tension.

6.3.2 Materials exhibiting interlaminar shear fracture (e.g. long-fibre-reinforced materials)

6.3.2.1 Unnotched specimens of type 2 or 3 are used. Apart from the thickness, the specimen dimensions are not specified. The most important parameter is the ratio of the span between the specimen supports to the specimen dimension in the direction of the blow (see Table 1).

Usually specimens are tested in the normal direction (see Figure 4).

6.3.2.2 "Flatwise normal" testing (see Figure 4): the width of specimen shall be 10 mm for materials reinforced with a fine structure (thin fabrics and parallel yarns) and 15 mm for materials reinforced with a large stitch structure (roving fabrics) or an irregularly manufactured structure.

6.3.2.3 "Edgewise parallel" testing (see Figure 4): when testing specimens in the parallel direction, the specimen dimension perpendicular to the blow direction shall be the thickness of the sheet from which the specimen was cut.

6.3.2.4 The length, l, of the specimen shall be chosen to give a span-to-thickness ratio, L/h, of 20 for type 2 specimens and 6 for type 3 specimens although, if the apparatus does not allow a ratio $L/h = 6$, a ratio $L/h = 8$ may be used, especially for thin sheets, as indicated in Table 1.

6.3.2.5 With type 2 specimens, tensile-type failure occurs; with type 3 specimens, interlaminar shear failure of the sheet usually occurs. The different types of failure which can occur are summarized in Table 3.

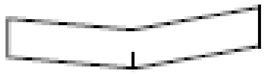
NOTE In some cases (thin-fabric reinforcement), shear failure does not occur. In the case of type 3 specimens, the fracture starts as a single or multiple shear failure and continues as tensile failure.

6.4 Number of test specimens

6.4.1 Unless otherwise specified in the standard for the material being tested, a set consisting of 10 specimens shall be tested. When the coefficient of variation (see ISO 2602) has a value of less than 5 %, a minimum number of five test specimens is sufficient.

6.4.2 If laminates are tested in the normal and parallel directions, 10 specimens shall be used for each direction.

Table 3 — Method designation and specimen types — Materials exhibiting interlaminar shear fracture

Method designation	Specimen type	L/h	Type of failure		Schematic
ISO 179-1/2 n or p[a]	2	20	Tension	t	
			Compression	c	
			Buckling	b	
ISO 179-1/3 n or p[a]	3	6 or 8	Shear	s	
			Multiple shear	ms	
			Shear followed by tensile fracture	st	

[a] "n" is the normal direction and "p" is the parallel direction with respect to the sheet plane (see Figure 4).

6.5 Definition of span between specimen supports, L

The span between the specimen supports, L, is defined as the distance between the lines of contact of the specimen with the supports. Figure 6 shows the span, L, and a suitable way in which it can be calculated by measuring the radius of the supports and the distance between them.

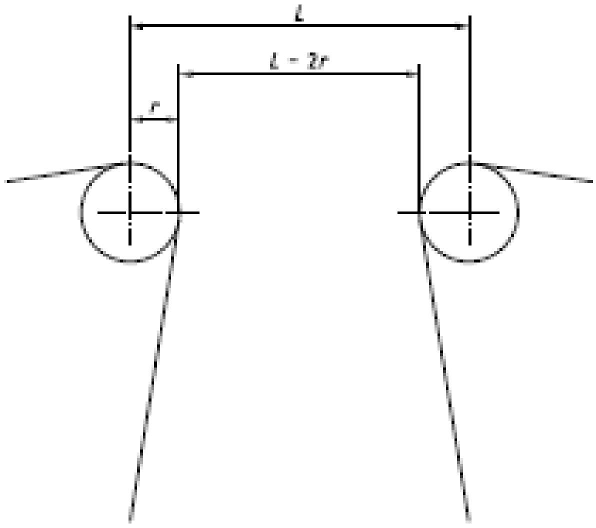


Figure 6 — Span, L, and suitable measurement position

6.6 Conditioning

Unless otherwise specified in the standard for the material under test, the specimens shall be conditioned for at least 16 h at (23 ± 2) °C and (50 ± 5) % relative humidity in accordance with ISO 291, unless other conditions are agreed upon by the interested parties. In the case of notched specimens, the conditioning time is after notching.

7 Procedure

7.1 Conduct the test in the same atmosphere as that used for conditioning, unless otherwise agreed upon by the interested parties, e.g. for testing at high or low temperatures.

7.2 Measure the thickness, h, and width, b, of each test specimen, in the centre, to the nearest 0,02 mm. In the case of notched specimens, carefully measure the remaining width, b_N, to the nearest 0,02 mm.

In the case of injection-moulded specimens, it is not necessary to measure the dimensions of each specimen. It is sufficient to measure one specimen from a set to make sure that the dimensions correspond to those in Table 1. With multiple-cavity moulds, ensure that the dimensions of the specimens are the same for each cavity.

Check the span between the specimen supports and adjust it, if necessary, in accordance with Table 1 and 6.5.

7.3 Check that the impact machine is able to perform the test with the specified velocity of impact and that it is in the correct range of absorbed energy, W, which shall be between 10 % and 80 % of the available energy at impact, E. If more than one of the pendulums conform to these requirements, the pendulum having the highest energy shall be used.

7.4 Determine the frictional losses and correct the absorbed energy in accordance with ISO 13802.

7.5 Lift the pendulum to the prescribed height and support it. Place the specimen on the supports in the machine in such a manner that the striking edge will hit the centre of the specimen. Carefully align notched specimens so that the centre of the notch is located directly in the plane of impact (see Figure 1, left).

7.6 Release the pendulum. Record the impact energy absorbed by the specimen and apply any necessary corrections for frictional losses, etc. (see 7.4).

7.7 For moulding and extrusion compounds, four types of failure, designated by the following code-letters, can occur:

C complete break: a break in which the specimen separates into two or more pieces

H hinge break: an incomplete break such that both parts of the specimen are held together only by a thin peripheral layer in the form of a hinge having low residual stiffness

P partial break: an incomplete break that does not meet the definition for hinge break

N non-break: there is no break, and the specimen is only distorted, possibly combined with stress whitening

8 Calculation and expression of results

8.1 Unnotched specimens

Calculate the Charpy impact strength of unnotched specimens, a_{cU}, expressed in kilojoules per square metre, using the following equation:

$$a_{cU} = \frac{E_c}{h \cdot b} \times 10^3 \qquad (1)$$

where

E_c is the corrected energy, in joules, absorbed by breaking the test specimen;

h is the thickness, in millimetres, of the test specimen;

b is the width, in millimetres, of the test specimen.

8.2 Notched specimens

Calculate the Charpy impact strength of notched specimens, a_{cN}, expressed in kilojoules per square metre, with notches A, B or C, using the following equation:

$$a_{cN} = \frac{E_c}{h \cdot b_N} \times 10^3 \qquad (2)$$

where

E_c is the corrected energy, in joules, absorbed by breaking the test specimen;

h is the thickness, in millimetres, of the test specimen;

b_N is the remaining width, in millimetres, of the test specimen.

8.3 Statistical parameters

Calculate as the test result the arithmetic mean of the individual test results and, if required, the standard deviation of the mean value, using the procedure given in ISO 2602. For each type of failure within one sample, the relevant numbers of specimens shall be given and mean values shall be calculated.

8.4 Significant figures

Report all calculated mean values to two significant figures.

9 Precision

See Annex B.

10 Test report

The test report shall include the following information:

a) a reference to this part of ISO 179;

b) the method used, designated in accordance with Table 2, e.g.:

Charpy impact test ISO 179-1/ 1 e A

Specimen type (see Table 1)
Direction of blow (see Figure 4)
Type of notch (see Figure 5)

or in accordance with Table 3, e.g.:

Charpy impact test ISO 179-1/ 2 n

Specimen type (see Table 1)
Direction of blow (see Figure 4)

c) all information necessary for identification of the material tested, including type, source, manufacturer's code, grade and history, where these are known;

d) a description of the nature and form of the material, i.e. whether a product, semifinished product, test plate or specimen, and including principal dimensions, shape, method of manufacture, etc., where these are known;

e) the velocity of impact;

f) the nominal pendulum energy;

g) the method of test specimen preparation;

h) if the material is in the form of a product or a semifinished product, the orientation of the test specimen in relation to the product or semifinished product from which it was cut;

i) the number of specimens tested;

j) the standard atmosphere used for conditioning and testing, plus any special conditioning treatment if required by the standard for the material or product;

k) the type(s) of failure observed;

l) the individual test results, presented as follows (see also Table 4):

1) group the results according to the three basic types of failure:

C complete break, including hinge break H

P partial break

N non-break,

2) select the most frequent type and record the mean value, x, of the impact strength as the test result for this type of failure, followed by the letter C or P for the type of failure,

3) if the most frequent failure type is N, record the letter N only,

4) add (between brackets) the letter C, P or N for the second most frequent failure type, but only if its frequency is higher than 1/3 (if not relevant, insert an asterisk);

m) the standard deviations of the mean values, if required;

n) the date(s) of testing.

Table 4 — Presentation of results

Type of failure			Designation
C	**P**	**N**	
x	*	*	xC*
x	(P)	*	xC(P)
x	*	(N)	xC(N)
*	x	*	xP*
(C)	x	*	xP(C)
*	x	(N)	xP(N)
*	*	N	N*
(C)	*	N	N(C)
*	(P)	N	N(P)

x	Mean value of impact strength for most frequent failure type, excluding type N.
C, P or N	Most frequent failure type.
(C), (P) or (N)	Second most frequent failure type, to be recorded only if its frequency is higher than 1/3.
*	Not relevant.

Annex A
(informative)

Additional methods for investigating the influence of surface effects

The following additional methods with double V-notches can be used for materials described in 6.3.1.

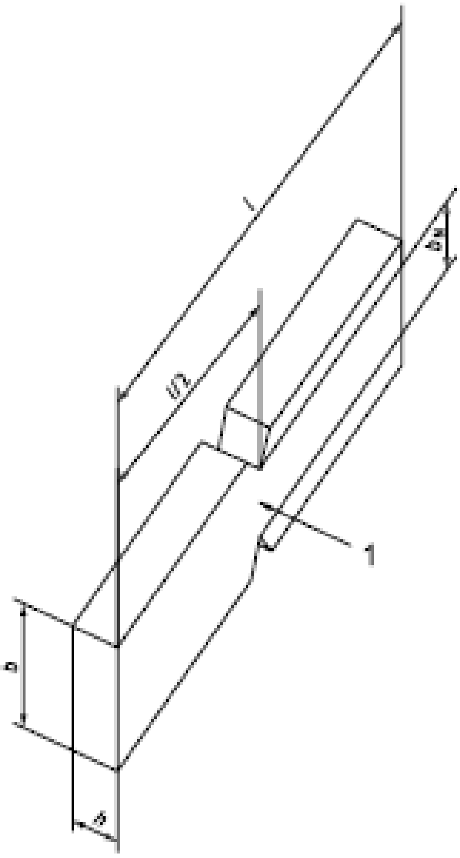
If the influence of surface effects on moderate- or high-impact materials is to be measured, flatwise impact may be used with double V-notches. Two notches are made perpendicular to the line of impact. The length of each notch is h, as shown in Figure A.1.

Table A.1 — Parameters for tests on double-notched specimens

Dimensions in millimetres

Method designation[a]	Specimen type	Blow direction	Notch type	Notch tip radius, r_N	Remaining width, b_N, at notch tip
			Double notch		
ISO 179-1/1fA	1	Flatwise	A	0,25 ± 0,05	6,0 ± 0,2
ISO 179-1/1fB	1	Flatwise	B	1,00 ± 0,05	6,0 ± 0,2
ISO 179-1/1fC	1	Flatwise	C	0,10 ± 0,02	6,0 ± 0,2

[a] If specimens are taken from sheets or products, the thickness of the sheet or product shall be added to the designation.



Key

1 direction of blow

Figure A.1 — Double-notched specimen

Annex B
(informative)

Precision data

B.1 General

B.1.1 Tables B.1 and B.2 are based on round robins[1)] performed in accordance with ASTM E691. For each material, all the test bars were prepared by one source, except for notching. Notches were verified by the laboratory responsible for specimen distribution. Tables B.1 and B.2 are presented by analysis, day 1 and day 2. Each analysis is based on participating laboratories testing 10 specimens of each material. One specimen (determination) is a test result for calculating the statistics as per ASTM E691 statistical software.

B.1.2 Table B.1 is based on a round robin involving nine laboratories and three materials and Table B.2 is based on a round robin involving seven laboratories and two materials. The laboratories and materials were grouped by the required velocity (2,9 m/s or 3,8 m/s) due to the difficulty in finding laboratories that had the necessary pendulums to carry out testing at both velocities.

NOTE The following explanations of r and R (see Clause B.2) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables B.1 and B.2 are not intended to be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and might not be representative of other lots, conditions, materials or laboratories. Users of this test method are recommended to apply the principles of ASTM E691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of Clause B.2 would then be valid for such data.

B.2 Concept of r and R

If s_r and s_R have been calculated from a large enough body of data, and for test results that were from one test determination, then:

For the **repeatability**, r (comparing two test results for the same material, obtained by the same operator using the same equipment on the same day), the two test results should be judged not equivalent if they differ by more than the r-value for that material.

For the **reproducibility**, R (comparing two results for the same material, obtained by different operators using different equipment on different days), the two test results should be judged not equivalent if they differ by more than the R-value for that material.

Any judgment in accordance with the above would have an approximately 95 % (0,95) probability of being correct.

1) Supporting data are available from the Secretariat of TC 61/SC 2 at AENOR.

Table B.1 — Precision data for Charpy impact at 2,9 m/s

All values in kJ/m²

	Material	Average	s_r [a]	s_R [b]	r [c]	R [d]
Day 1	ABS	13,48	0,47	1,86	1,32	5,21
	GF-PBT	8,52	0,61	1,27	1,71	3,55
	Polypropylene	10,48	0,63	1,58	1,77	4,43
Day 2	ABS	13,44	0,45	1,90	1,25	5,31
	GF-PBT	8,54	0,60	1,29	1,68	3,62
	Polypropylene	10,80	0,65	1,45	1,82	4,06

[a] s_r is the within-laboratory standard deviation.

[b] s_R is the between-laboratory standard deviation.

[c] $r = 2,83 s_r$.

[d] $R = 2,83 s_R$.

Table B.2 — Precision data for Charpy impact at 3,8 m/s

All values in kJ/m²

	Material	Average	s_r [a]	s_R [b]	r [c]	R [d]
Day 1	Polycarbonate	91,69	5,30	8,37	14,85	23,43
	Polyurethane	94,33	5,37	6,21	15,03	17,38
Day 2	Polycarbonate	91,72	3,85	6,49	10,78	18,16
	Polyurethane	92,39	6,32	7,86	17,69	22,00

[a] s_r is the within-laboratory standard deviation.

[b] s_R is the between-laboratory standard deviation.

[c] $r = 2,83 s_r$.

[d] $R = 2,83 s_R$.

Annex C
(informative)

Determining the notch tip radius using a CCD microscope

C.1 The Charpy test result is sometimes very sensitive to the radius of the notch tip. In such cases, it is necessary for the radius to be measured accurately. This annex illustrates the effect of notch tip radius on the Charpy impact strength and describes the CCD microscope method as a suitable way of measuring the notch radius.

C.2 Figure C.1 shows the effect of the notch radius on the Charpy impact strength of four types of plastics material.

C.3 Table C.1 compares three methods of determining the notch radius.

C.4 Figure C.2 shows a CCD microscope and a view of a typical notch. The notch radius can be determined from measurements at three points, using the following equations:

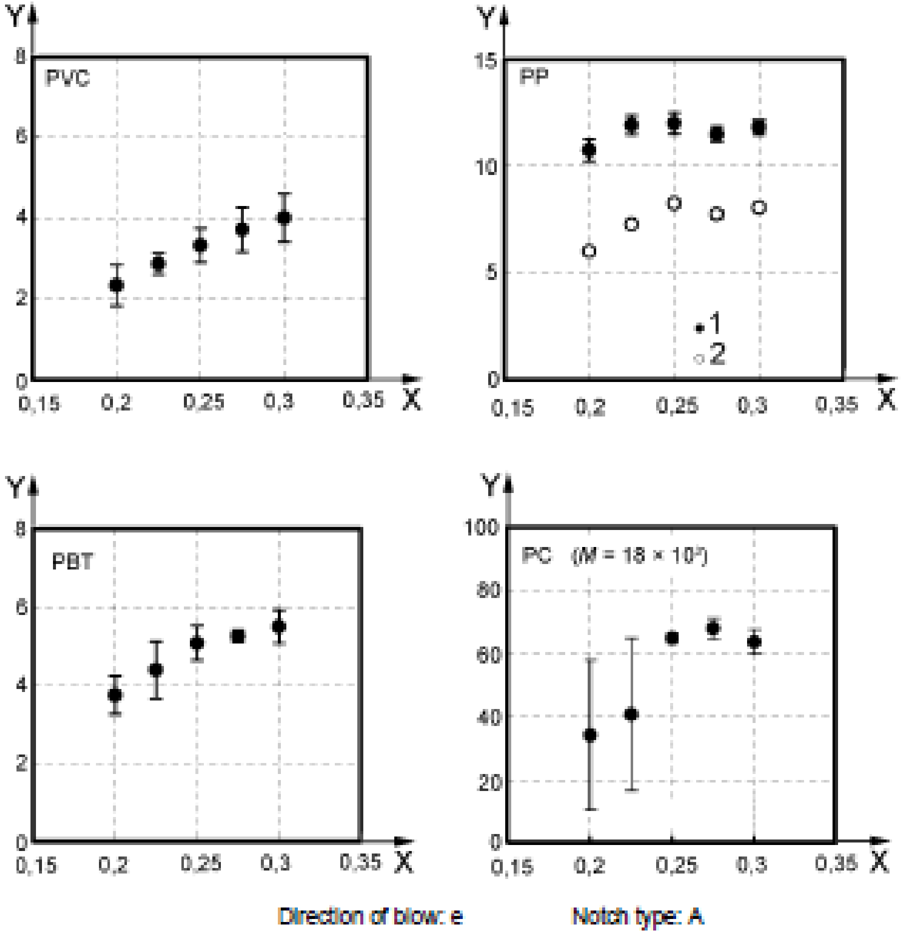
$$x^2 + y^2 + ax + by + c = 0$$

$$(x + a/2)^2 + (y + b/2)^2 = a^2/4 + b^2/4 - c$$

$$r_N = (a^2/4 + b^2/4 - c)^{1/2}$$

where

x and y	are the x- and y-coordinates of a point;
a, b and c	are constants;
r_N	is the notch radius.



Key

X notch tip radius (mm)

Y impact strength (kJ/m²)

1 PP block copolymer

2 PP homopolymer

Figure C.1 — Effect of notch tip radius on Charpy impact strength

Table C.1 — Methods for determining the notch tip radius

Method	Principle	Determination	Procedure	Detection capability mm	Remarks
Digital-microscope method	Optical CCD microscope Simple, good precision	Digital	Notch profile obtained using CCD microscope (magnification ×100 to ×500). Radius calculated by digital processing (see Clause C.4).	1/1 000	Operation is quick and simple. Superior depth of field is beneficial for 3D image measurement.
Comparator method (ASTM D6110)	Optical comparison with template Indirect method, not simple	Comparison	Magnified image compared with a transparent template (prepared in advance) to determine whether notch tip radius falls within a specified range.	1/100	Method does not determine actual value of radius.
Stylus instrument method	Physical outline trace of notch with needle Simple but affected by vibration	Digital	Stylus used to explore surface of specimen and acquire notch profile. Radius calculated by digital processing.	1/1 000	Stylus is susceptible to vibration. Burrs in notch can cause errors.

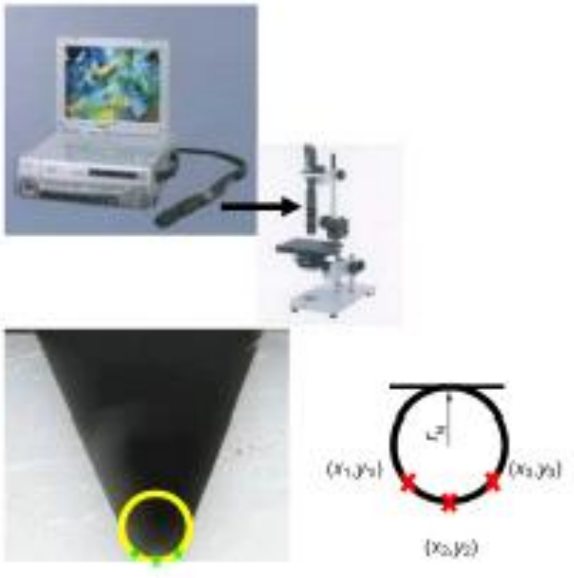


Figure C.2 — Typical CCD microscope and view of a typical notch

Bibliography

[1] ISO 180, *Plastics — Determination of Izod impact strength*

[2] ASTM E691, *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method*

[3] ASTM D6110, *Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics*

Epoxy resins

MEE Y. SHELLEY

TRADE NAMES Araldite, DER, Epi-Cure, Epi-Res, Epikote, Epon, Epotuf, etc.

CLASS Thermoset polymers, after curing (the uncured base resins are thermoplastic)

MAJOR RESIN TYPES DGEBA (diglycidyl ether of bisphenol A), novolacs, peracid resins, hydantoin resins, etc.

OTHER INGREDIENTS IN EPOXY FORMULATION Diluents, resinuous modifiers (to affect flexibility, toughness, peel strength, adhesion, etc.), fillers, colorants and dyes, other additives (e.g., rheological additives, flame retardants).

MAJOR APPLICATIONS Protective coatings (for appliance, automotive primers, pipes, etc.). Encapsulation of electrical and electronic devices. Adhesives. Bonding materials for dental uses. Replacement of welding and riveting in aircraft and automobiles. In composites for materials in space industry, printed circuitry, pressure vessels and pipes. Construction uses such as flooring, paving, and airport runway repair.

PROPERTIES OF SPECIAL INTEREST Wide range of properties depending on the formulation and processing. Chemical and weathering resistance, toughness, durability. Excellent adhesion to a variety of surfaces. Good electrical and thermal insulation. Better mechanical properties than most other castable plastics. Discolor when exposed to UV. Some are skin sensitizers.

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Specific gravity	—	Unfilled	1.2–1.3	(1)
		Bisphenol molding compounds (glass fiber-reinforced/mineral-filled)	1.6–2.1	(2)
		Bisphenol molding compounds (low density glass sphere-filled)	0.75–1.0	(2)
		Sheet molding compounds	0.1	(2)
		Novolac molding compounds	1.6–2.05	(2)
		Casting resins, silica-filled	1.6–2.0	(2)
		Casting resins, aluminum-filled	1.4–1.8	(2)
		Casting resins, flexibilized	0.96–1.35	(2)
		Casting resins, cycloaliphatic	1.16–1.21	(2)
Water absorption	%	1/8 in. thick specimen, 24 h		
		Bisphenol molding compounds	0.04–1.0	(2)
		Sheet molding compounds	1.4–1.6	(2)
		Novolac molding compounds	0.04–0.29	(2)
		Casting resins, silica-filled	0.04–0.1	(2)
		Casting resins, aluminum-filled	0.1–4.0	(2)
		Casting resins, flexibilized	0.27–0.5	(2)
		Filament wound (80 wt% glass fiber-reinforced)	0.50	(3, 4)

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Impact strength, Izod	$J m^{-1}$	Unfilled	10–50	(1)
		Silica-filled	16–24	(2)
		Aluminum-filled	21–85	(2)
		Flexibilized	120–270	(2)
		Bisphenol molding compounds (glass fiber-reinforced)	16–530	(2)
		Bisphenol molding compounds (mineral-filled)	16–27	(2)
		Bisphenol molding compounds (low density glass sphere-filled)	8–13	(2)
		Sheet molding compounds (glass fiber-reinforced)	1,600–2,100	(2)
		Sheet molding compounds (carbon fiber-reinforced)	800–1,100	(2)
		Novolac molding compounds	16–27	(2)
		Filament wound (80 wt% glass fiber-reinforced)	2,400	(3, 4)
Hardness	Shore	Casting resins, flexibilized	D65–89	(2)
	Barcol	Novolac molding compounds	70–78	(2)
	Rockwell	Filament wound (80 wt% glass fiber-reinforced)	M98	(3, 4)
Fracture toughness	$J cm^{-3} m^{1/2}$	Unspecified	0.6	(1)
Tensile modulus	MPa	Unfilled	3,000–5,000	(1)
		Casting, unfilled	2,400	(2)
		Bisphenol molding compounds (glass fiber-reinforced)	21,000	(2)
		Bisphenol molding compounds (mineral-filled)	2,400	(2)
		Sheet molding compounds (glass fiber-reinforced)	14,000–28,000	(2)
		Sheet molding compounds carbon fiber-reinforced)	70,000	(2)
		Novolac molding compounds	14,500–16,600	(2)
		Filament wound (80 wt% glass fiber-reinforced)	27,600	(3, 4)
Compressive modulus	MPa	Casting, flexibilized	7–2,400	(2)
		Casting, cycloaliphatic	3,400	
		Bisphenol molding compounds (mineral-filled)	4,500	
		Novolac molding compounds (mineral- and glass-filled, high temperature)	4,550	

Epoxy resins

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Stress at break	MPa	Unfilled	30–90	(1)
Tensile strength at break	MPa	Casting resins, unfilled	28–90	(2)
		Casting resins, silica-filled	48–90	(2)
		Casting resins, aluminum-filled	48–83	(2)
		Casting resins, flexibilized	14–70	(2)
		Casting resins, cycloaliphatic	55–83	(2)
		Bisphenol molding compounds (glass fiber-reinforced/mineral-filled)	28–140	(2)
		Bisphenol molding compounds (low density glass sphere-filled)	17–28	(2)
		Sheet molding compounds (glass fiber-reinforced)	140–240	(2)
		Sheet molding compounds (carbon fiber-reinforced)	280–340	(2)
		Novolac molding compounds	34–110	(2)
		Filament wound (80 wt% glass fiber-reinforced)	552	(3, 4)
Elongation at break	%	Unfilled	1–2	(1)
		Bisphenol molding compounds (filled with glass fiber)	4	(2)
		Sheet molding compounds	0.5–2	(2)
		Casting resins, unfilled	3–6	(2)
		Casing resins, aluminum-filled	0.5–3	(2)
		Casing resins, silica-filled	1–3	(2)
		Casing resins, flexibilized	20–85	(2)
		Casing resins, cycloaliphatic	2–10	(2)
		Filament wound (80 wt% glass fiber-reinforced)	1.6	(3, 4)
Flexural strength	MPa	Bisphenol molding compounds	34–200	(2)
		Sheet molding compounds	340–660	
		Novolac molding compounds	70–150	
		Casting resins and compounds	55–170	
Flexural modulus	MPa	Bisphenol molding compounds	3,400–31,000	(2)
		Sheet molding compounds	14,000–34,000	(2)
		Novolac molding compounds	9,700–17,000	(2)
		Filament wound (80 wt% glass fiber-reinforced)	34,500	(3, 4)
Compressive strength	MPa	Casting, unfilled	100–170	(2)
		Casting, silica or alumina-filled	100–240	(2)
		Casting, flexibilized	7–97	(2)
		Casting, cycloaliphatic	100–140	(2)
		Bisphenol molding compounds (glass fiber-reinforced/mineral-filled)	120–280	(2)

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Compressive strength	MPa	Bisphenol molding compounds (low density glass sphere-filled)	70–100	(2)
		Sheet molding compounds (glass fiber-reinforced)	140–210	(2)
		Sheet molding compounds (carbon fiber-reinforced)	210–280	(2)
		Novolac molding compounds	170–330	(2)
		Filament wound (80 wt% glass fiber-reinforced)	310	(3, 4)

Surface tension

Polymer	Temp. (K)	Value (mN m^{-1})	Reference
DGEBA with 6 wt% N-N-diethylaminopropylamine, cured	293	46.8	(5)
DGEBA with stoichiometric amount of triethylenetetramine, cured	293	39.1	(5)
DGEBA, 2,3-(diglycidoxy-1,4-phenylene)propane, chain extended with bisphenol A	296	51.2	(5, 6)

Interfacial tension[5]

Polymer	Temp. (K)	Value (mN m^{-1})
Poly(butadiene) vs. epoxy resin*	296	1.77
	328	1.40
Poly(butadiene-stat-acrylonitrile) 18 wt% AN vs. epoxy resin*	293	1.23
	328	0.57
Poly(butadiene-stat-acrylonitrile) 26 wt% AN vs. epoxy resin*	328	0.58

*Epoxy resin: DGEBA, chain extended with bisphenol A.

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Volume resistivity	ohm cm	Filled with glass	10^{16}	(7)
		Filled with mineral	10^{16}	
Dielectric strength	V mil^{-1}	Filled with glass	360	(7)
		Filled with mineral	400	
Dielectric constant		At 1 MHz		(7)
		Filled with glass	4.6	
		Filled with mineral	5.0	

Epoxy resins

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Thermal conductivity	$W\ m^{-1}\ K^{-1}$	Casting grade, 293 K	0.19	(8, 9)
		Casting grade, 300–500 K	0.19–0.34	(9, 10)
		Foam, $d = 0.032–0.048\ g\ cm^{-3}$	0.016–0.022	(9, 11)
		Foam, $d = 0.080–0.128\ g\ cm^{-3}$	0.035–0.040	(9, 11)
		Filled with 50% aluminum	1.7–3.4	(9, 12)
		Filled with 25% Al_2O_3	0.35–0.52	(9, 12)
		Filled with 50% Al_2O_3	0.52–0.69	(9, 12)
		Filled with 75% Al_2O_3	1.4–1.7	(9, 12)
		Filled with 30% mica	0.24	(9, 8)
		Filled with 50% mica	0.39	(9, 8)
		Filled with silica	0.42–0.84	(9, 8, 12)
		Filament wound (80 wt% glass fiber-reinforced)	1.77	(3, 4)
Deflection temperature	K	Under flexural load, 1.82 MPa		(2)
		Bisphenol molding compounds, glass fiber-reinforced/mineral-filled	380–530	
		Bisphenol molding compounds, low density glass sphere-filled	370–390	
		Sheet molding compounds	560	
		Novolac molding compounds	420–530	
		Casting resins and compounds (unfilled)	320–560	
		Casting resins and compounds (silica-filled)	340–560	
		Casting resins and compounds (aluminum-filled)	360–590	
		Casting resins and compounds (flexibilized)	296–390	
		Casting resins and compounds (cycloaliphatic)	370–510	

Radiation resistance, half-value dose in air*

Conditions	Dose rate ($Gy\ h^{-1}$)	Value (MGy)	Reference
Filled with glass fiber	10^3	25–100+	(13, 14)
Filled with graphite	10^3	50	(13, 14)
Filled with mineral flour	10^3	10–30	(13, 14)
Filled with mineral flour (85% quartz sand)	500	7	(13, 15)
Filled with cotton	10^3	1	(13, 14)

*Defined as the absorbed dose that reduces a property (flexural strength) to 50% of the initial value.

PROPERTY	UNITS	CONDITIONS	VALUE	REFERENCE
Solubility parameters	$(MPa)^{1/2}$			
Hildebrand parameter δ		–	22.3	(16, 17)
Hansen parameters		Epikote 1001 (Shell)		(17, 18)
δ_d			20.36	
δ_p			12.03	
δ_h			11.48	
δ_t			26.29	
Processing temperature	K	Bisphenol molding compounds		(2)
		Compression	390–440	
		Transfer	390–470	
		Sheet molding compounds		
		Compression	390–440	
		Transfer	405–440	
		Novolac molding compounds		
		Compression	410–460	
		Injection	420–450	
		Transfer	390–480	
Molding pressure	MPa	Bisphenol molding compounds	0.7–34	(2)
		Sheet molding compounds	3.4–14	
		Novolac molding compounds	1.7–21	
Compression ratio	–	Bisphenol molding compounds	2.0–7.0	(2)
		Sheet molding compounds	2.0	
		Novolac molding compounds	1.5–2.5	
Mold shrinkage (linear)	–	Bisphenol molding compounds	0.001–0.01	(2)
		Sheet molding compounds	0.001	
		Novolac molding compounds	0.004–0.008	
		Casting resins	0.0005–0.01	

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