SEP282 – PROCESSOS PARA INDÚSTRIA AERONÁUTICA

AULA 7

CORTE E DOBRA DE CHAPAS

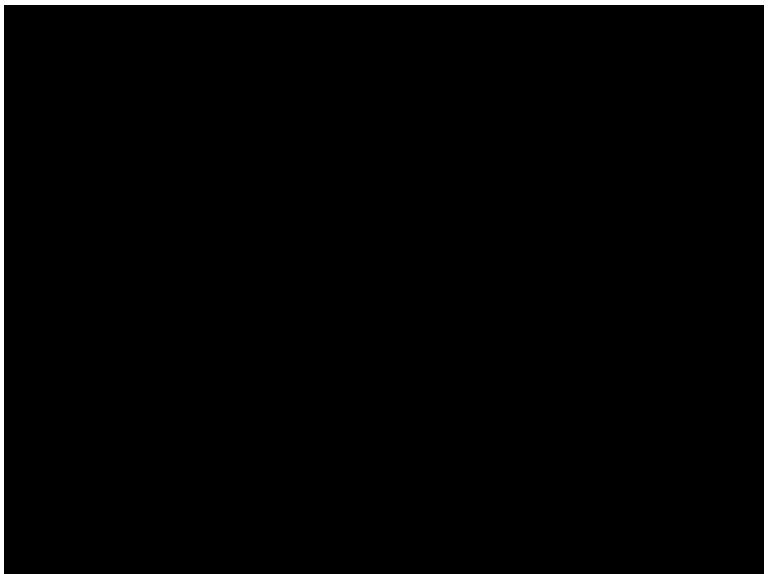
Prof. Reginaldo T. Coelho – Outubro 2020

CORTE E DOBRA DE DE CHAPAS

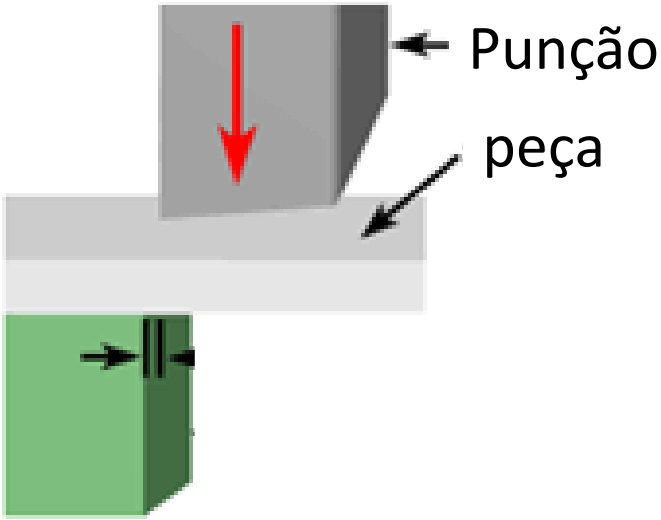
Corte e dobra de chapas

Furação por cisalhamento

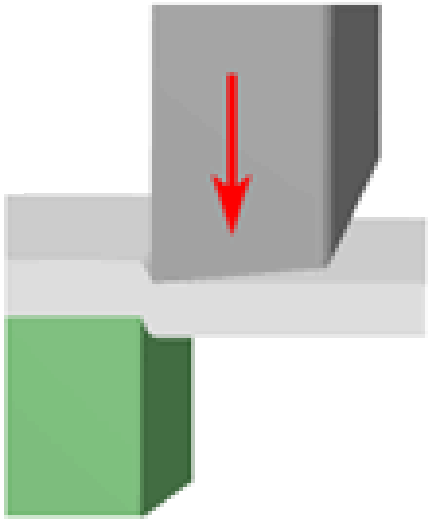
Dobra de chapas com matriz em “V”



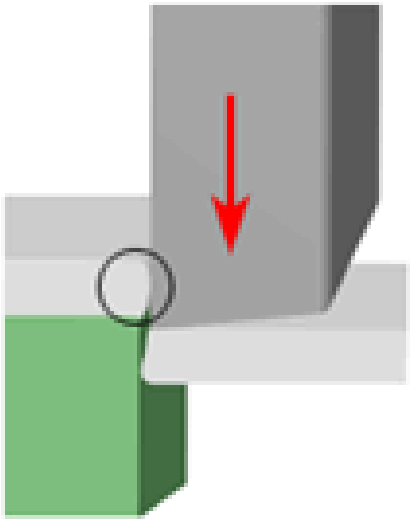
Fases do processo



Deformação elástica

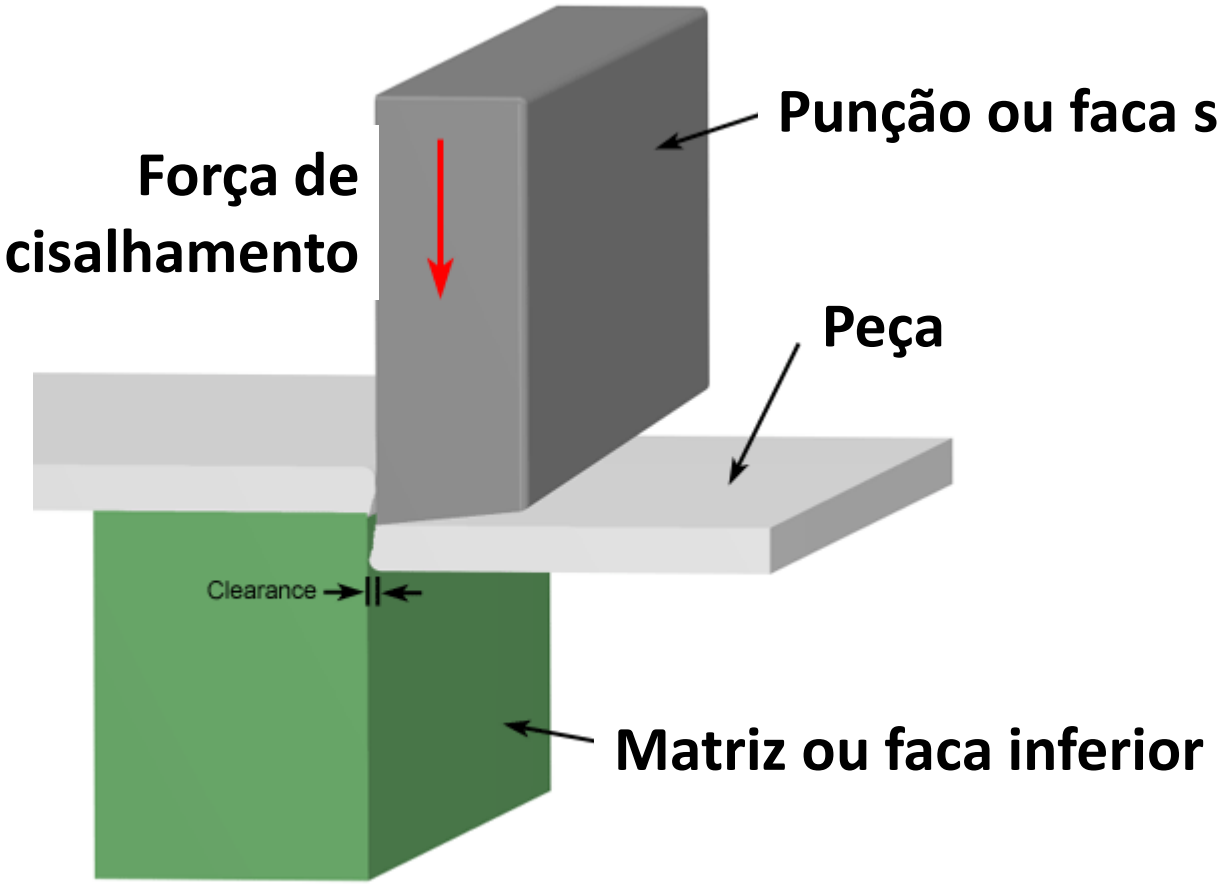


Deformação Plástica



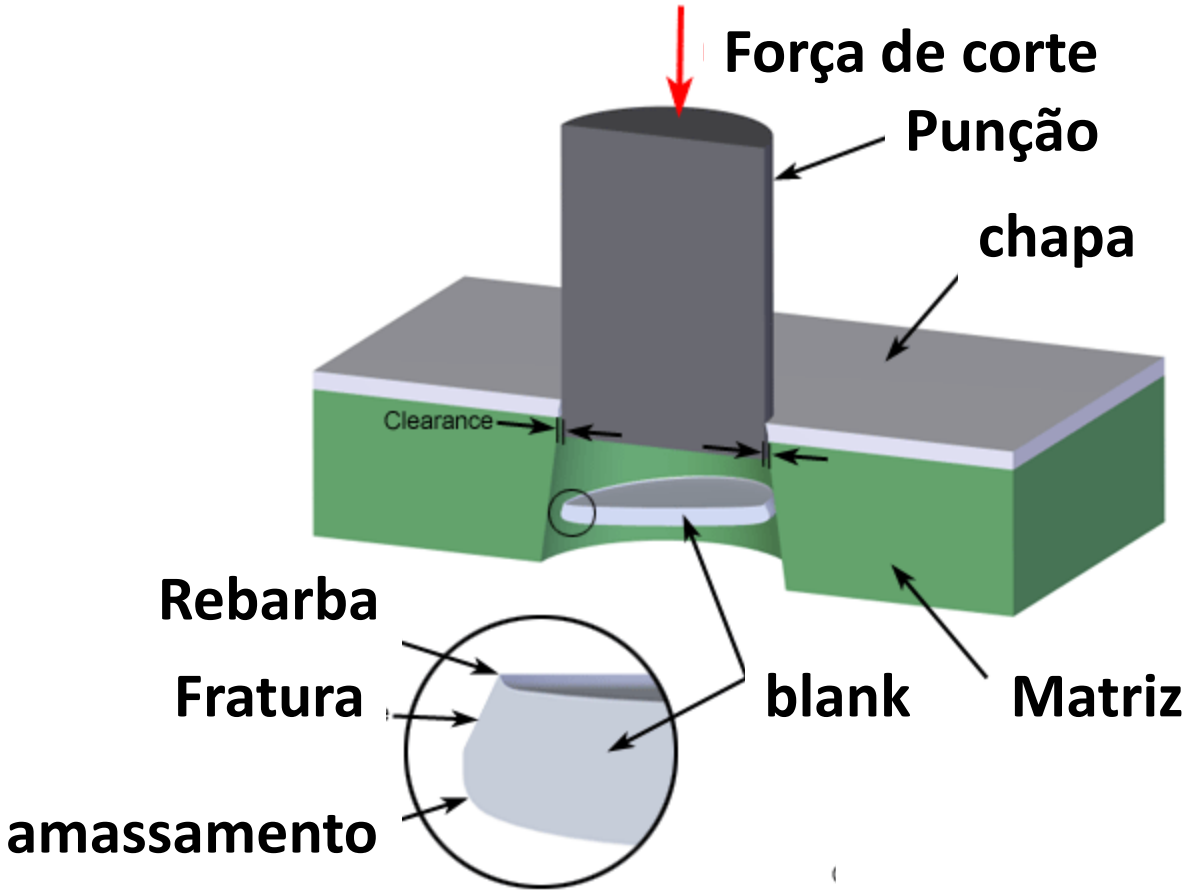
Trinca e ruptura

Nomenclatura do processo



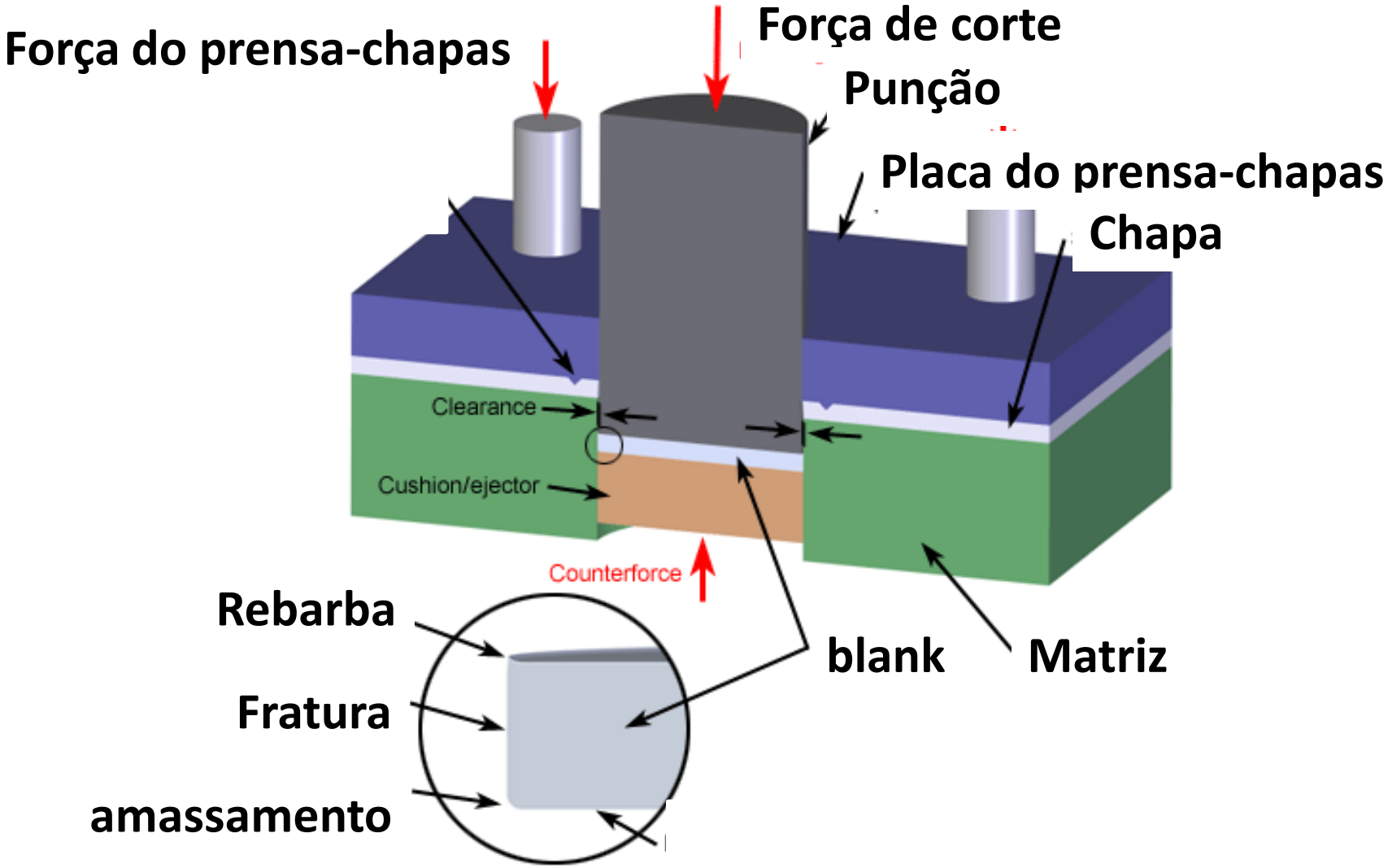
CORTE E DOBRA DE DE CHAPAS

Nomenclatura do processo



CORTE E DOBRA DE DE CHAPAS

Corte com prensa-chapas

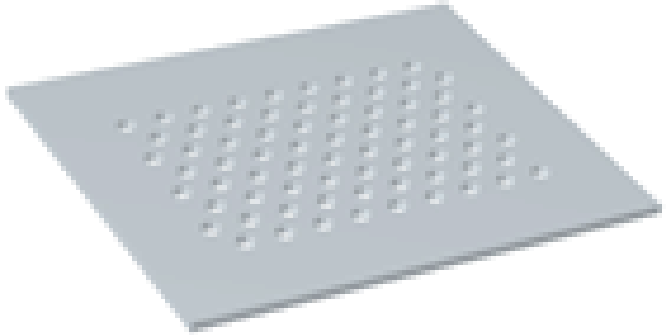


Exemplos de peças cortadas por cisalhamento

Furo simples

Cortes laterais diversos

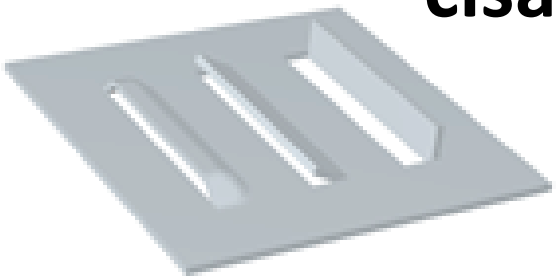
Rasgos cantos vivos



Perfurações

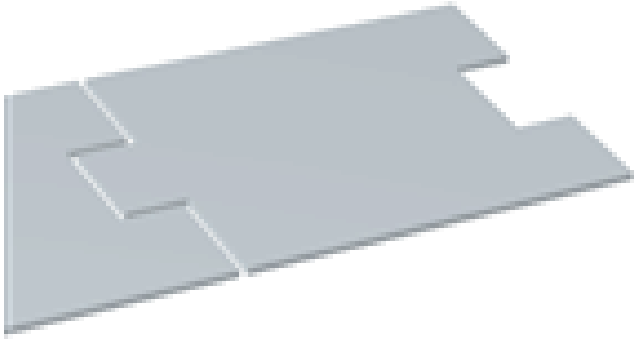
CORTE E DOBRA DE DE CHAPAS

Exemplos de peças cortadas por cisalhamento e dobradas

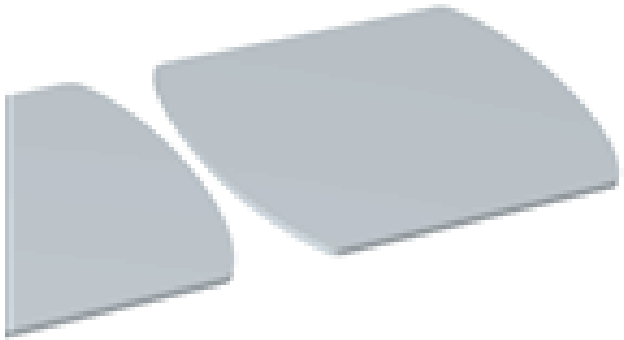


Rasgos e dobras

Rasgo e Repuxo



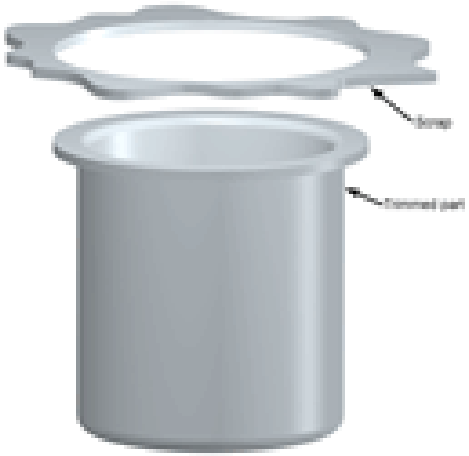
Cortes em encaixes



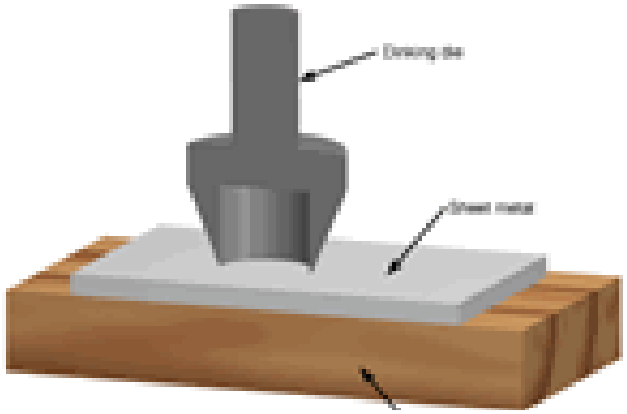
Cortes em raios

Exemplos de peças cortadas por cisalhamento e dobradas

Repuxo e corte

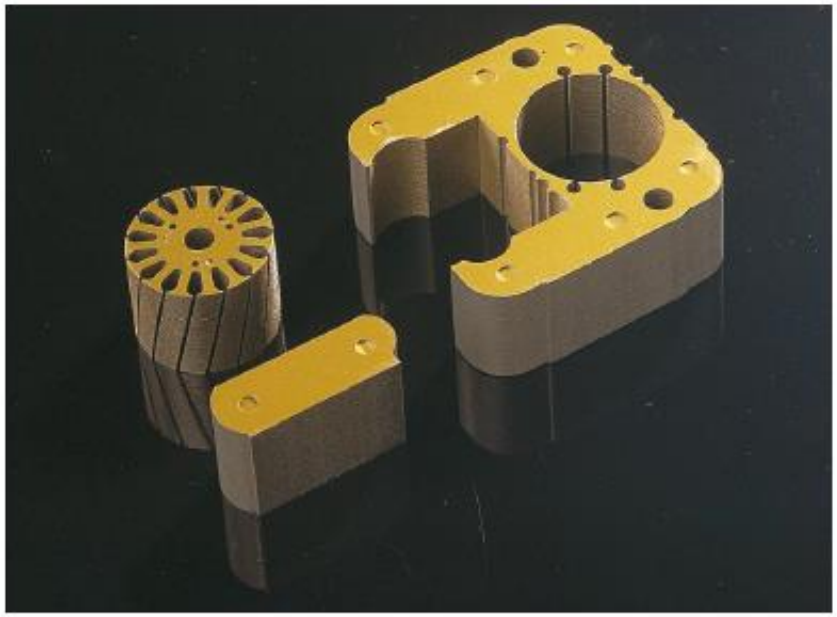


Puncionamento



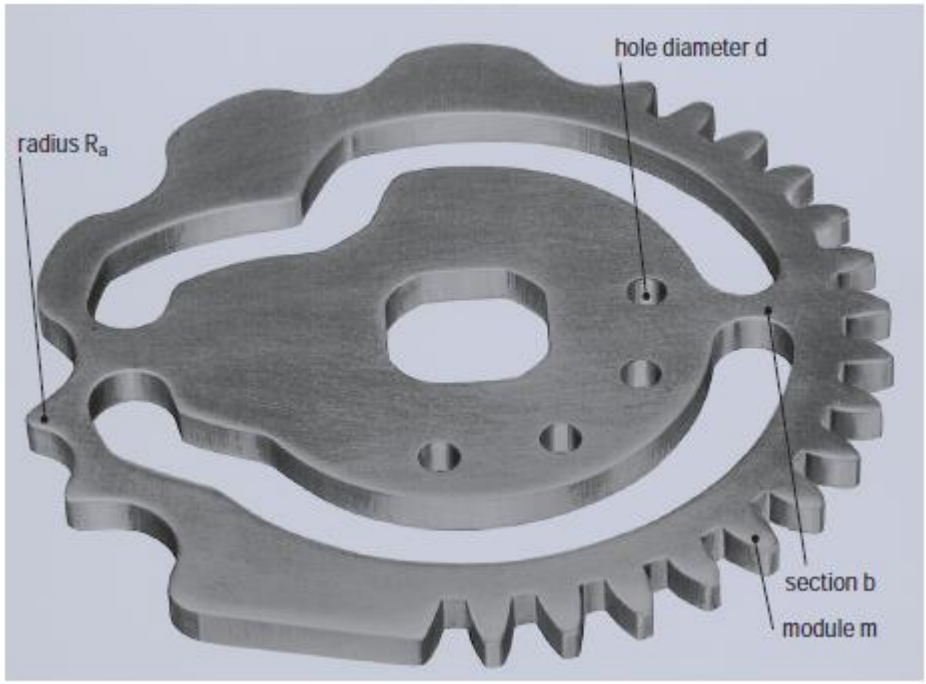
Corte parcial

Exemplos de peças cortadas por cisalhamento

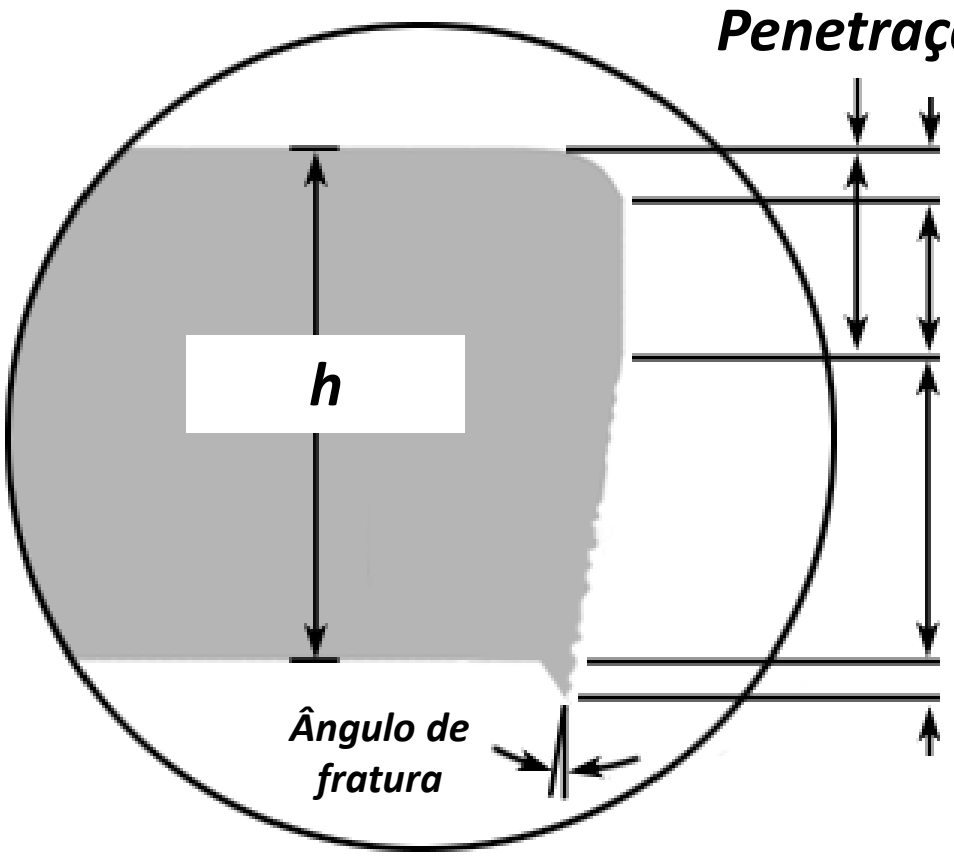


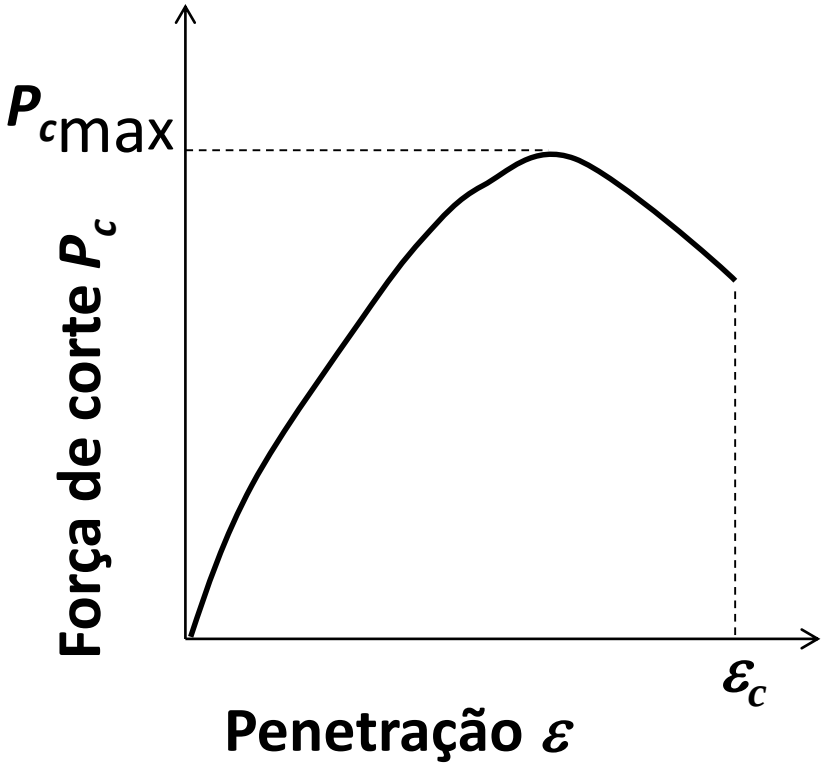
Núcleo e estatores de motores

Cortes de engrenagens

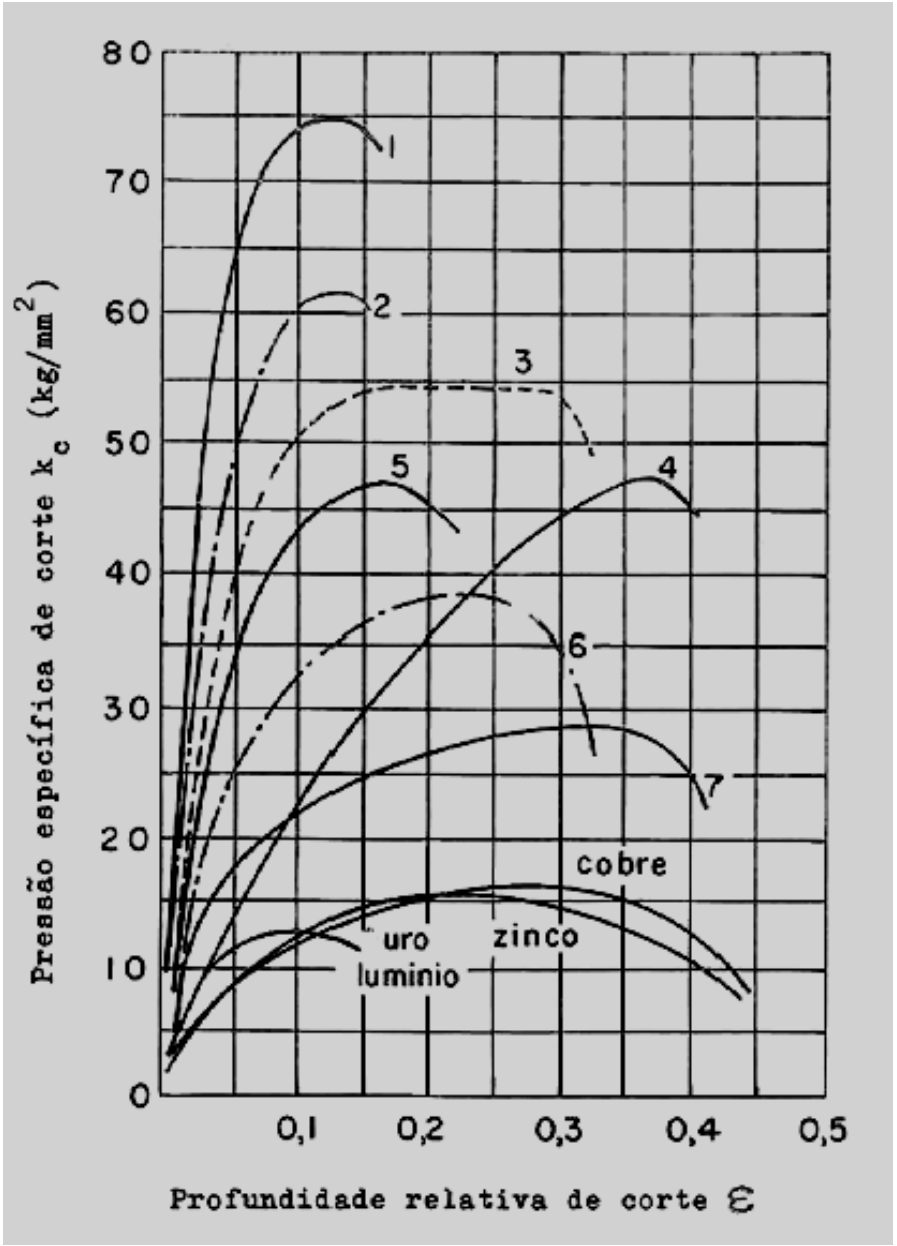


Carga para corte de chapas





CORTE E DOBRA DE DE CHAPAS



Carga para corte de chapas

$$P_c = k_c . b . h$$

$\boldsymbol{P_c}$ = Carga máxima [N]

$\boldsymbol{k_c}$ = Pressão específica de corte por cisalhamento [N/mm^2]

$\boldsymbol{b}$ = perímetro de corte [mm]

$\boldsymbol{h}$ = espessura de corte [mm]

CORTE E DOBRA DE DE CHAPAS

MATERIAL	Composição química em porcento							σ_s kg/mm²	σ_r kg/mm²
	C	Si	Mn	P	S	Cr	Ni		
1	0,16	0,23	0,34	0.018	0,006	1,42	4,31	58,5	110,0
2	0,75	0,31	0,63	0,028	0,220	0,15	-	58,5	100,8
3	0,40	0,33	0,55	0,024	0,027	1,10	0,13	44,8	83,8
4	0,14	0,70	0,50	0,020	0,020	13,00	8,50	-	60,0
5	0,47	0,23	0,58	0,027	0,030	0,050	-	35,4	67,3
6	0,20	0,24	0,52	0,026	0,030	0,040	-	42,6	53,7
7	0,15	0,20	0,40	0,040	0,040	0,200	0,30	18,0	38,0

MATERIAL	k_{cmx} (kg/mm²)	δ (%)	ε_c	φ (kgmm/mm³)
1	75	9	0,16	9,7
2	61	10,8	0,16	7,4
3	54	16,6	0,33	15,0
4	47	45,0	0,40	12,4
5	46	19,7	0,23	8,5
6	38	21,7	0,35	10,4
7	28	32,0	0,41	9,7
Cobre	16	-	0,42	5,7
Zinco	15	-	0,41	5,2
Duro-alumínio	13	-	0,13	1,3

Pressão específica de corte

Apostila:

$$k_c \cong 0,75\sigma_r$$

CORTE E DOBRA DE DE CHAPAS

Pressão específica de corte **Apostila:**

$$k_c \cong 0,75\sigma_r$$

(VALORES MEDIOS) PRESSÕES ESPECÍFICAS DE CORTE DE ALGUNS MATERIAIS

Material	Kc(kg/mm^2)	Material	Kc(kg/mm^2)
- Chumbo	2 - 3	Cartolina	7 - 9
- Estanho	3 - 4	Papel isolante	10 - 13
- Couro	0,7 - 1,5	Fibra isolante	9 - 12
- Mica 0,5 espessura	8	Madeira	1 - 3
- Mica 2,0 espessura	5	Magnésio Liga	11 - 16
- Celuloide	4 - 6	Klingerit	4 - 6
- Borracha mole	0,7	Aço 0,1 % C	24 - 30
- Borracha dura	2 - 6	0,2 % C	32 - 40
- Papel 0,25 espessura	6	0,3 % C	36 - 48
- Papel 5 x 0,25 espessura.	4,5	0,4 % C	45 - 56
- Papel 10 x 0,25 espessura	2,3	0,6 % C	55 - 70
- Papel 20 x 0,25 espessura	1,4	0,8 % C	70 - 90
- Papelão	2 - 3,5	Aço silício	45 - 55

CORTE E DOBRA DE DE CHAPAS

Table 4.2.3: Summary of the more commonly used sheet metal materials

Unalloyed steels

	Material No.	R_m [N/mm²]	$R_{p0,2}$ or R_{eL} [N/mm²]	A_{80} [%]	Fields of application, examples
St 12	10330	270...410	max. 280	28	automotive engineering
USt 13	10333	270...370	max. 250	32	automotive engineering
St 14	10338	270...350	max. 225	38	automotive engineering

Phosphor-alloyed steels

	Material No.	R_m [N/mm²]	$R_{p0,2}$ or R_{eL} [N/mm²]	A_{80} [%]	Fields of application, examples
ZStE 220 P	10397	340...420	220...280	30	automotive engineering
ZStE 260 P	10417	380...460	260...320	28	car body work: doors, hoods, roofs
ZStE 300 P	10448	420...500	300...360	26	automotive engineering

Bake-hardening steels

	Material No.	R_m [N/mm²]	$R_{p0,2}$ or R_{eL} [N/mm²]	A_{80} [%]	Fields of application, examples
ZStE 180 BH	10395	300...380	180...240	32	automotive engineering
ZStE 220 BH	10396	320...400	220...280	30	automotive engineering
ZStE 260 BH	10400	360...440	260...320	28	automotive engineering
ZStE 300 BH	10444	400...480	300...360	26	automotive engineering

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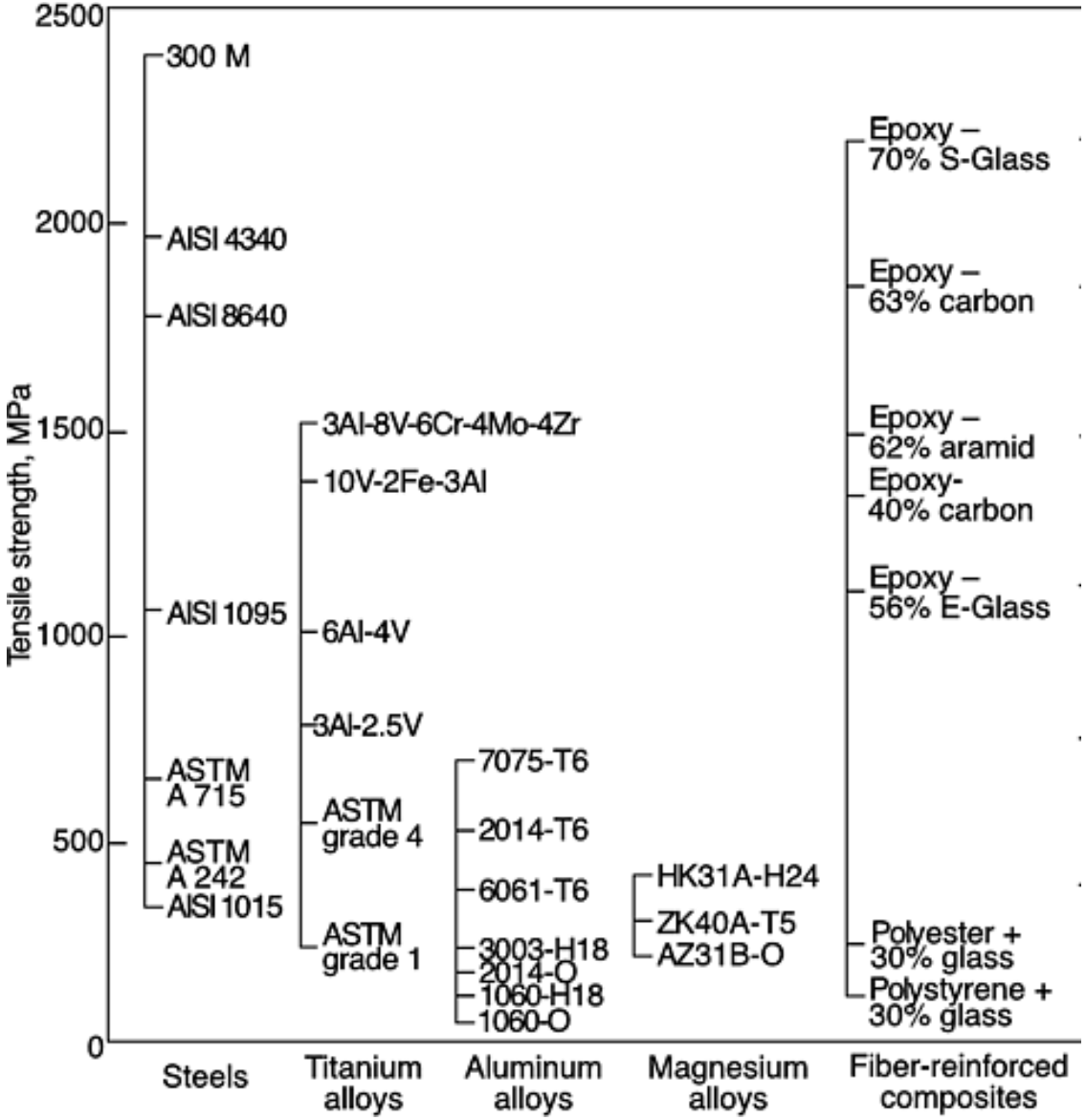
Pressão específica de corte

$$k_c \cong 0,8R_m$$

CORTE E DOBRA DE DE CHAPAS



Pressão específica de corte

$$k_c \cong 0,75\sigma_r$$

ASM – Metals Handbook, v8

CORTE E DOBRA DE DE CHAPAS

VALORES DE τ_c EM Kg/mm² PARA CADA MATERIAL

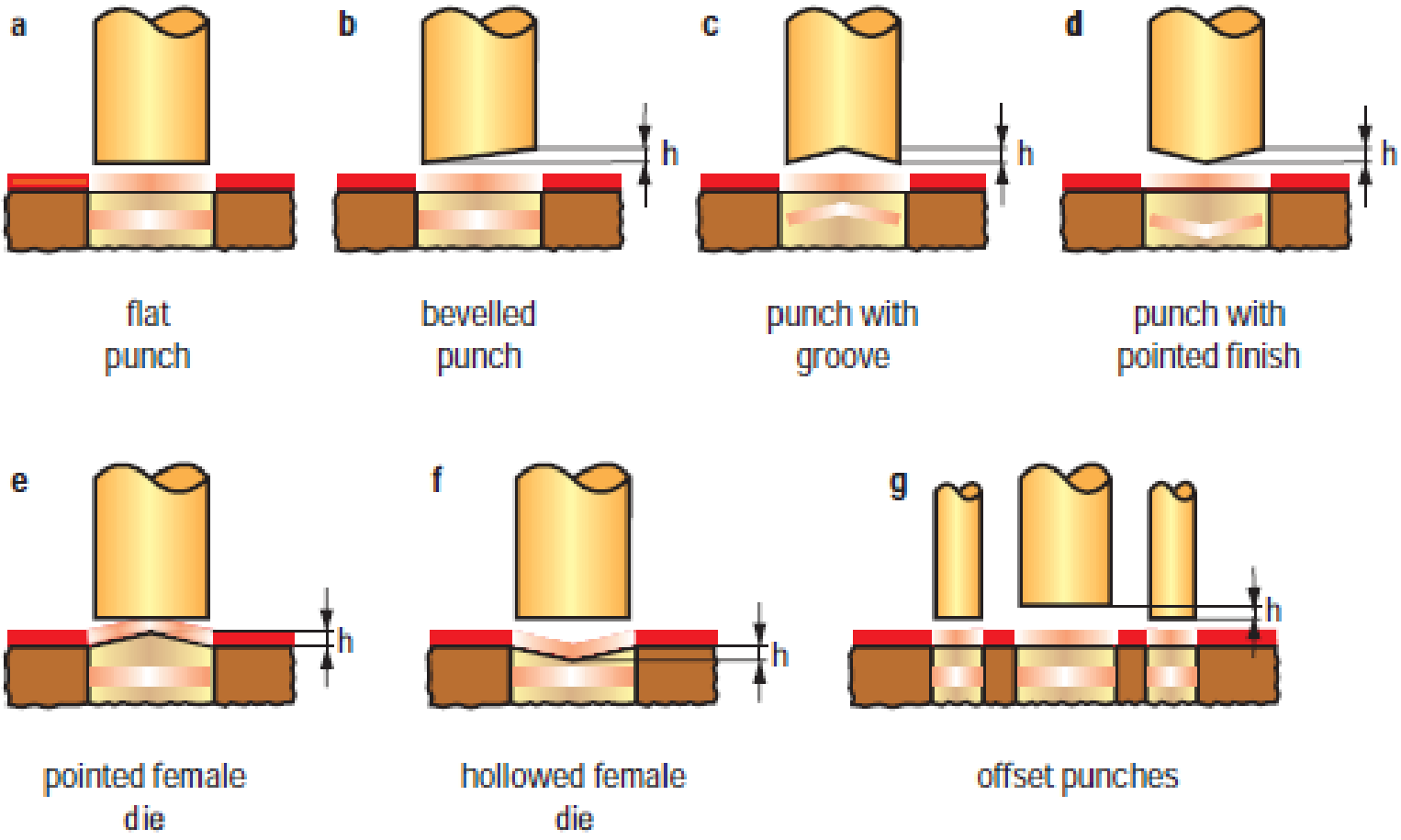
		Recozido	Cru
Aço laminado	0,1% C	25	32
	0,2% C	32	40
	0,3% C	36	48
	0,4% C	45	56
	0,6% C	56	72
	0,8% C	72	90
	1,0% C	80	105
	inoxidável	52	60
	silício	45	56
Alumínio		7 ÷ 9	13 ÷ 16
Alpaca (Cu — Ni — Zn)		28 ÷ 36	45 ÷ 46
Amianto em folha		3,15	
Prata		23,5	
Bronze fosforoso		32 ÷ 40	40 ÷ 60
Papel	1 folha de 0,25 mm de espessura	16	
	5 folhas de 0,25 mm de espessura	4,5	
	10 folhas de 0,25 mm de espessura	2,3	
	20 folhas de 0,25 mm de espessura	1,4	

Pressão específica de corte

$$k_c \cong 0,75\sigma_r$$

Estampos III Pro-tec -1985

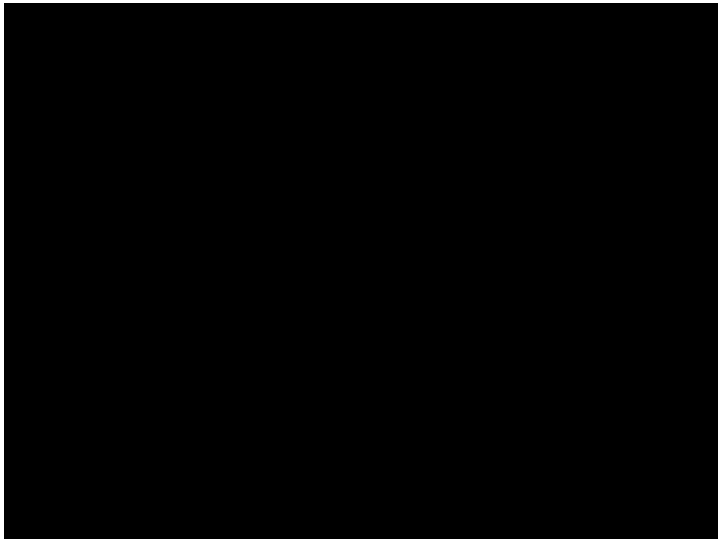
Técnicas para reduzir a força de corte por cisalhamento



Processo de Dobra de chapas

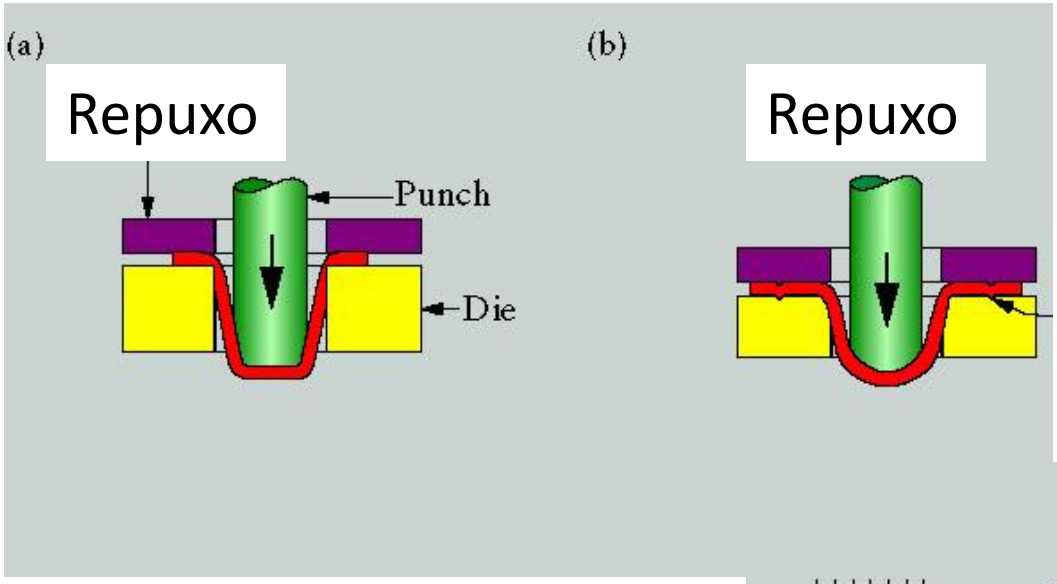
Dobras simples

Dobras com CNC

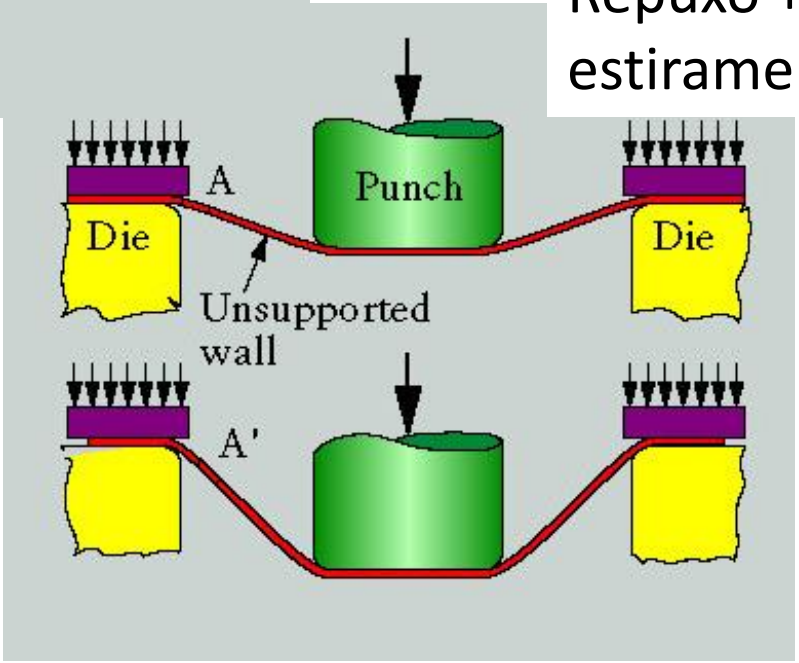


Dobras com matriz rotativa

Operações de dobra de chapas

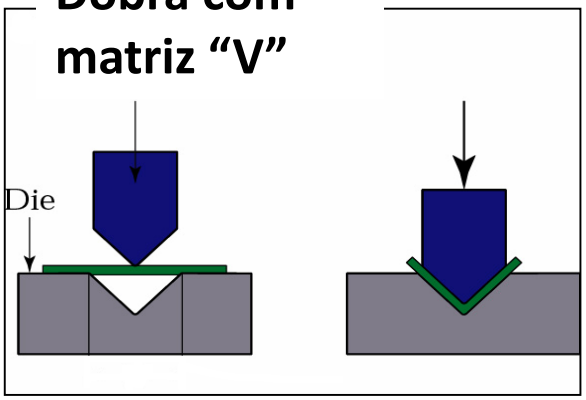


Repuxo + estiramento

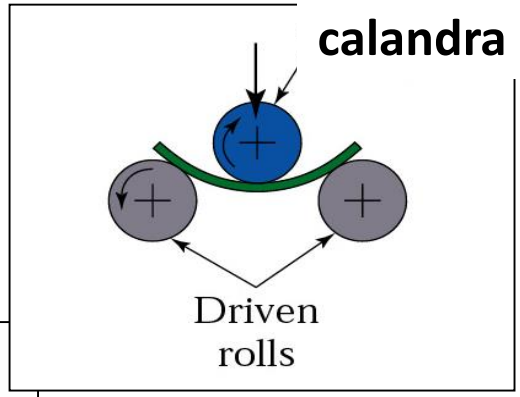


Operações de dobra de chapas

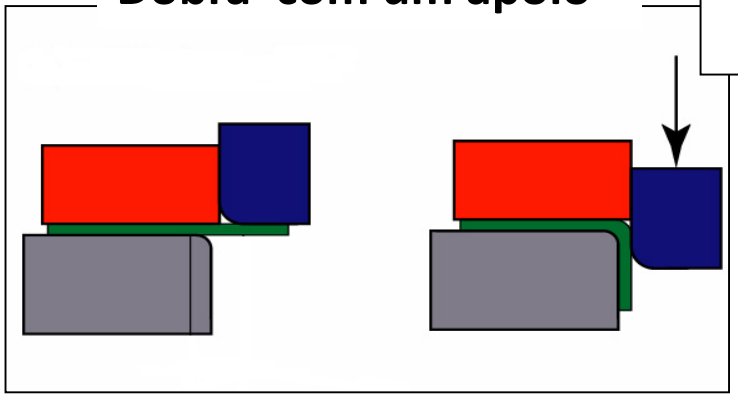
Dobra com matriz "V"



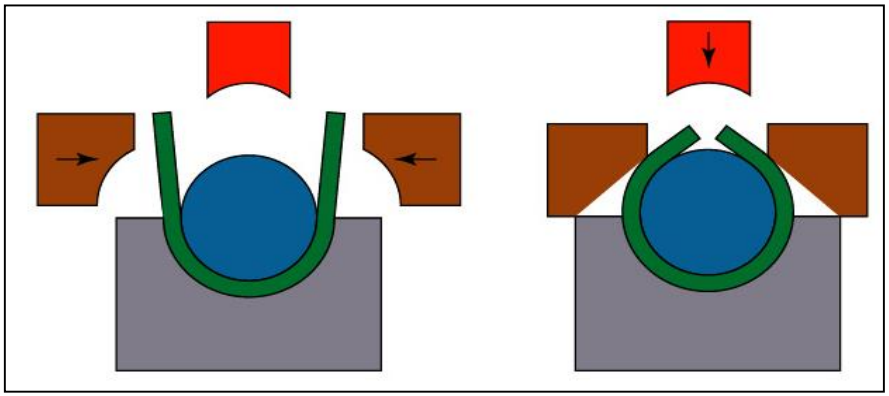
calandra



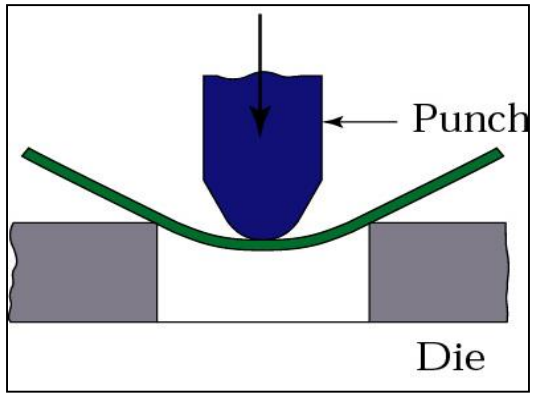
Dobra com um apoio



Dobra com dupla ação



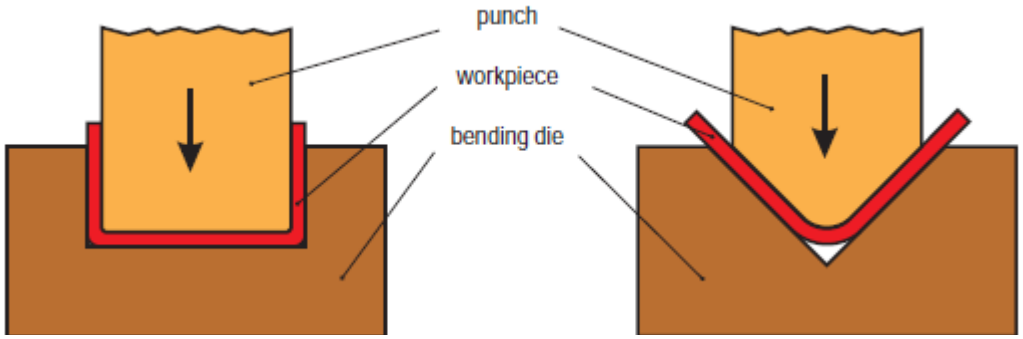
Dobra em matriz aberta

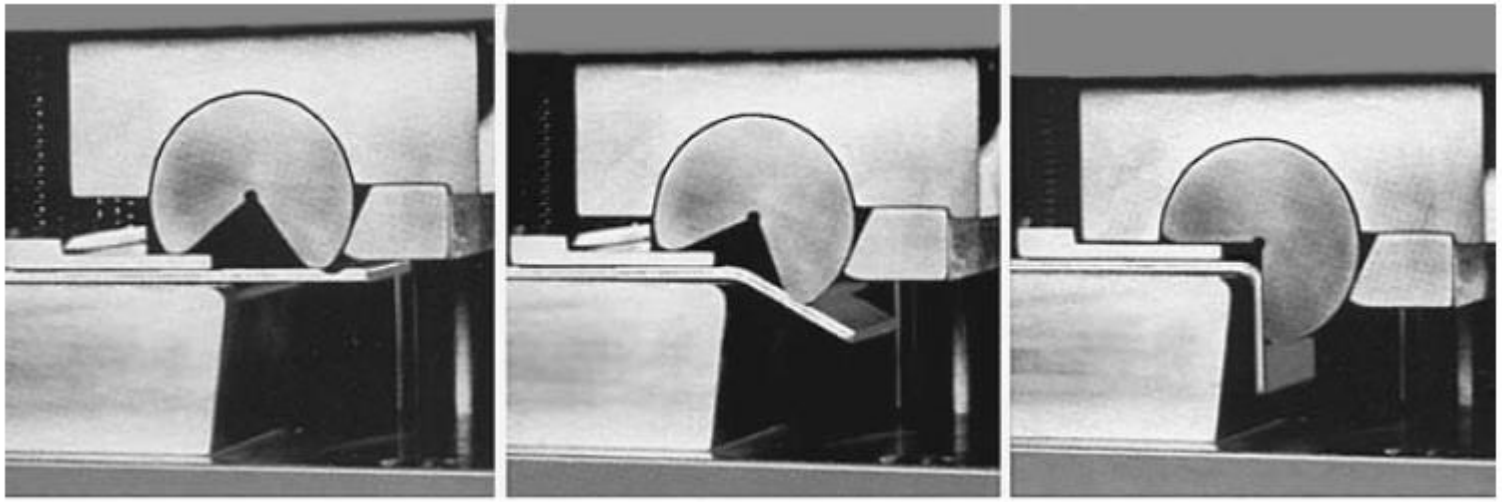


Operações de dobra de chapas

Dobra em “U”

Dobra em “V”

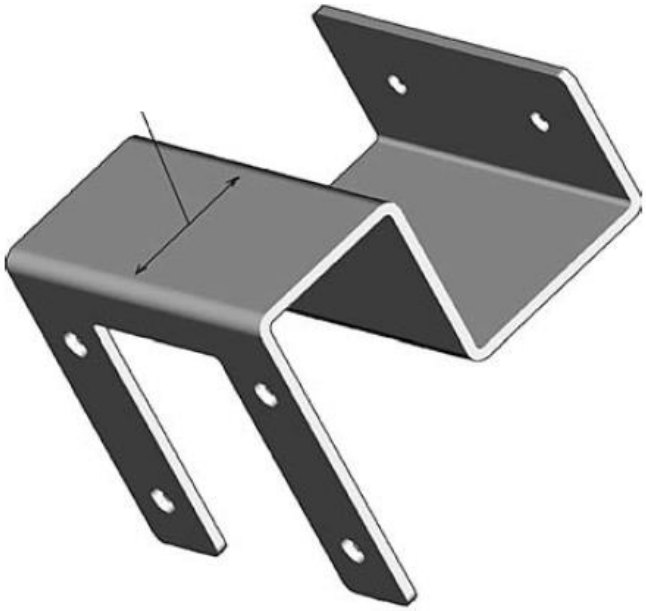


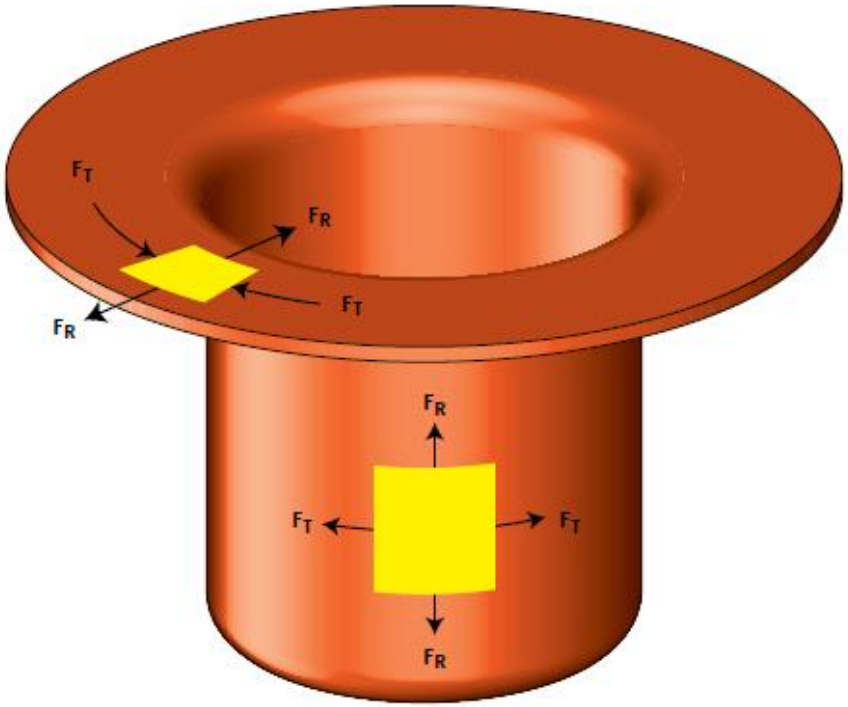


Dobra com punção rotativo

CORTE E DOBRA DE DE CHAPAS

Exemplos de peças com dobra de chapas





CORTE E DOBRA DE DE CHAPAS

Raio mínimo para a dobra

Table 4.8.1: Minimum bending radius $r_{i\,min}$ for bending angles α under 120°

		Smallest admissible bending radius $r_{i\,min}$ for sheet metal thickness s [mm]							
Steel sorts with a minimum tensile strength [N/mm²]	Bending direction compared to roller direction of sheet	1	> 1 to 1,5	> 1,5 to 2,5	> 2,5 to 3	> 3 to 4	> 4 to 5	> 5 to 6	> 6 to 7
to 390	transverse	1	1.6	2.5	3	5	6	8	10
	longitudinal	1	1.6	2.5	3	6	8	10	12
over 390 to 490	transverse	1.2	2	3	4	5	8	10	12
	longitudinal	1.2	2	3	4	6	10	12	16
over 400 to 640	transverse	1.6	2.5	4	5	6	8	10	12
	longitudinal	1.6	2.5	4	5	8	10	12	16

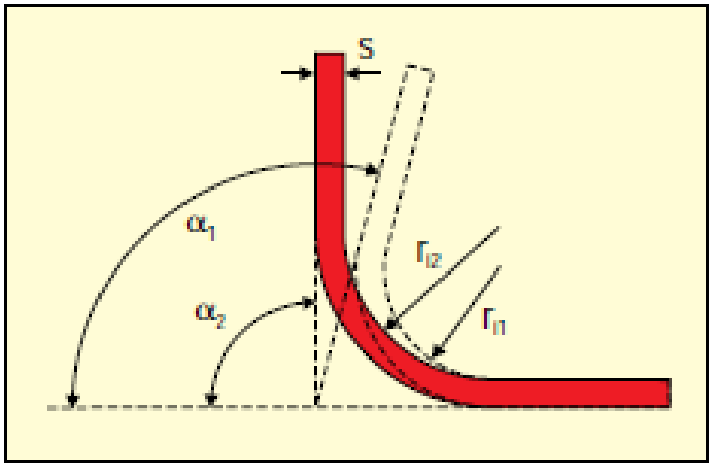
		Smallest admissible bending radius $r_{i\,min}$ for sheet metal thickness s [mm]						
Steel sorts with a minimum tensile strength [N/mm²]	Bending direction compared to roller direction of sheet	> 7 to 8	> 8 to 10	> 10 to 12	> 12 to 14	> 14 to 16	> 16 to 18	>18 to 20
to 390	transverse	12	16	20	25	28	36	40
	longitudinal	16	20	25	28	32	40	45
over 390 to 490	transverse	16	20	25	28	32	40	45
	longitudinal	20	25	32	36	40	45	50
over 400 to 640	transverse	16	20	25	32	36	45	50
	longitudinal	20	25	32	36	40	50	63

CORTE E DOBRA DE DE CHAPAS

Retorno elástico (spring back)

Table 4.8.2: Springback factor k_R

Material	Springback factor k_R	
	$r_{i2}/s = 1$	$r_{i2}/s = 10$
St 0-24, St 1-24	0.99	0.97
St 2-24, St 12	0.99	0.97
St 3-24, St 13	0.985	0.97
St 4-24, St 14	0.985	0.96
stainless austenitic steels	0.96	0.92
high temperature ferritic steels	0.99	0.97
high temperature austenitic steels	0.982	0.955
nickel w	0.99	0.96
Al 99 5 F 7	0.99	0.98
Al Mg 1 F 13	0.98	0.90
Al Mg Mn F 18	0.985	0.935
Al Cu Mg 2 F 43	0.91	0.65
Al Zn Mg Cu 1.5 F 49	0.935	0.85

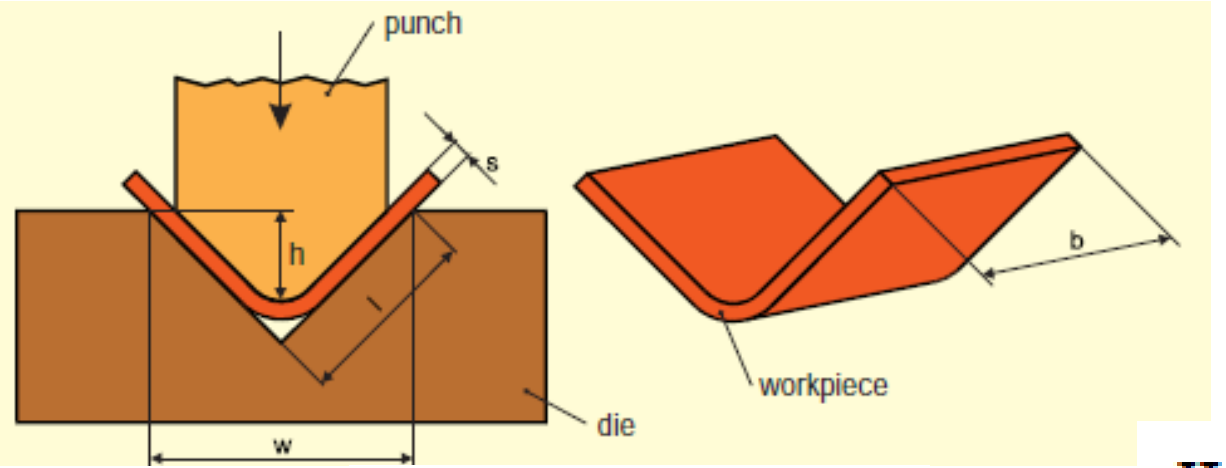


$$k_R = \frac{\alpha_2}{\alpha_1} = \frac{r_{i1} + 0.5 \cdot s}{r_{i2} + 0.5 \cdot s} \; [-],$$

With α_1: angle at the die (required bending angle) [°],
α_2 : desired angle at the workpiece (after springback) [°],
s: sheet metal thickness [mm],
r_{i1} : inside radius at the die [mm],
r_{i2} : inside radius at the workpiece [mm].

CORTE E DOBRA DE DE CHAPAS

Força e trabalho para dobrar em matriz “V”



$$l = 6 \cdot s \quad [\text{mm}]$$

$$F_b = \frac{b_s \cdot s^2 \cdot R_m}{w} \quad [\text{N}] \qquad \text{for } w/s \geq 10$$

or

$$F_b = \left(1 + \frac{4 \cdot s}{w}\right) \cdot \frac{b_s \cdot s^2 \cdot R_m}{w} \quad [\text{N}] \qquad \text{for } w/s < 10$$

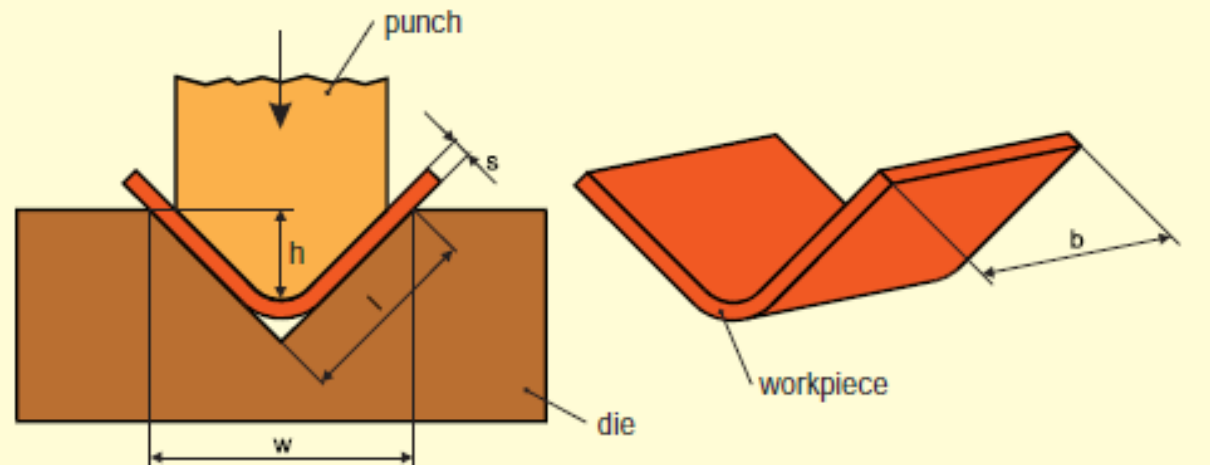
$$W_b = x \cdot F_b \cdot h \quad [\text{Nm}],$$

x = 0,3 a 0,6

R_m = Tabela

Metal Forming Handbook / Schuler (c) Springer-Verlag Berlin Heidelberg 1998

Força para dobrar em matriz "V"



$$r \geq ks$$

$$k = 0{,}85\frac{\sigma_r}{\delta} + 0{,}5$$

$$F_b = \frac{2}{3}\frac{bs^2\sigma_b}{w}$$

r = raio min. de dobra

δ = alongamento (%)

σ_b = tensão de dobra dada por

$$\sigma_b = 2\sigma_r$$

Para $w/s \geq 10$

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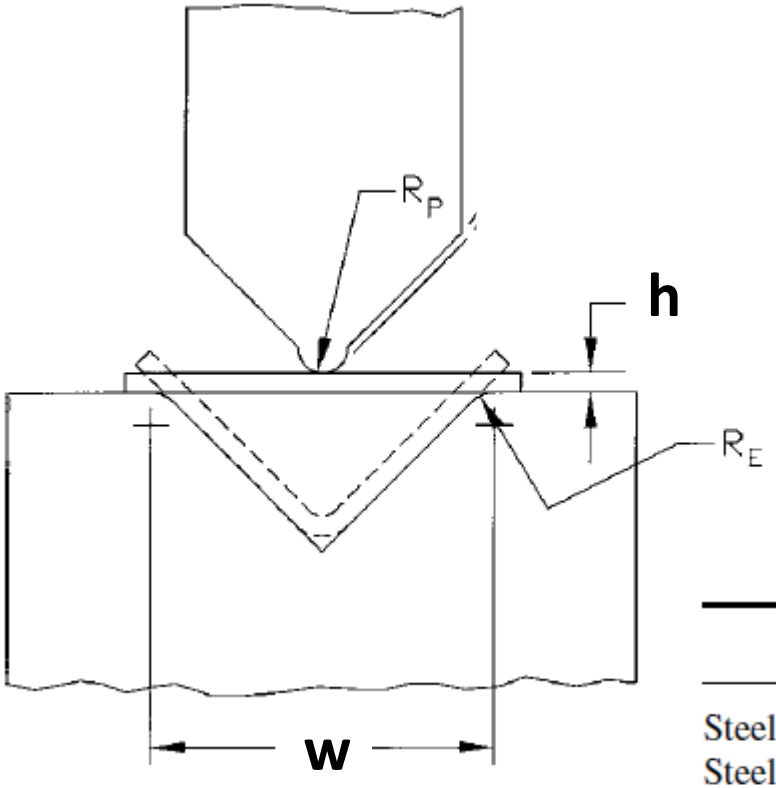
CORTE E DOBRA DE DE CHAPAS

Força para dobrar em matriz "V"



$$F_b = k_v \frac{bh^2 \sigma_d}{w}$$

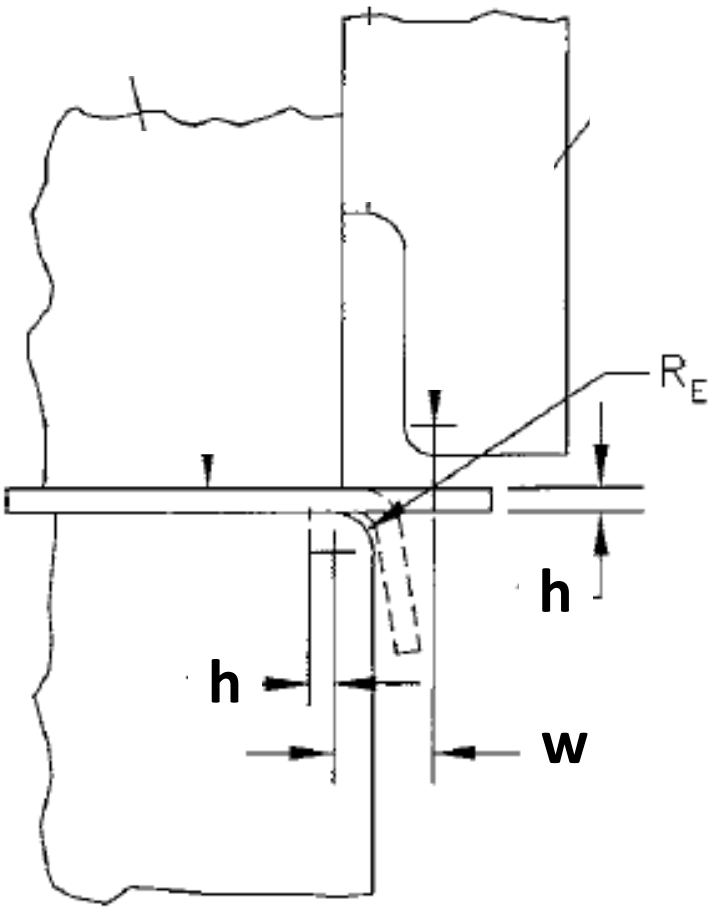
k_v = 0,75 a 2,5 (valores maiores para menores razões ***Rp/h***). O valor de 1,33 é usado se ***W >8h***

	Tons/In.^{2}	MPa [N/mm^2]
Steel, low carbon, 1025	30–51.5	410–710
Steel, medium carbon, 1045	40–91	550–1,250
Steel, high carbon, 1095	45–106.5	620–1,470
Steel, stainless, 303	42.5–62.5	585–860
Aluminum alloy, cold worked	6.0–31.5	80–435
Aluminum alloy, heat treated	11.0–41.5	150–570
Copper	16–28.5	220–390
Phosphor bronze	20–64	275–880
Zinc	9.75–15.5	135–215

Handbook of Die Design -2nd ed. 2006

CORTE E DOBRA DE DE CHAPAS

Força para dobrar em matriz com um ponto de apoio



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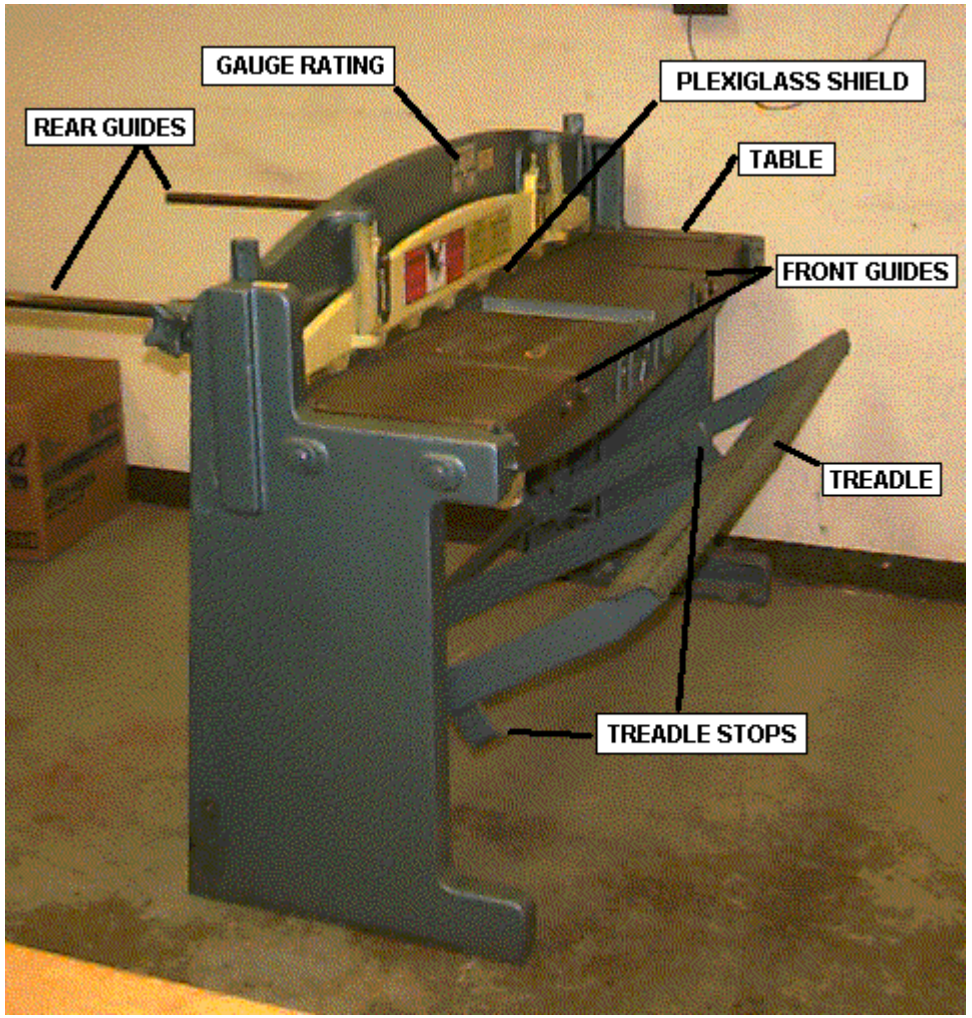
Máquinas para corte de chapas

Máquina manual de cortar



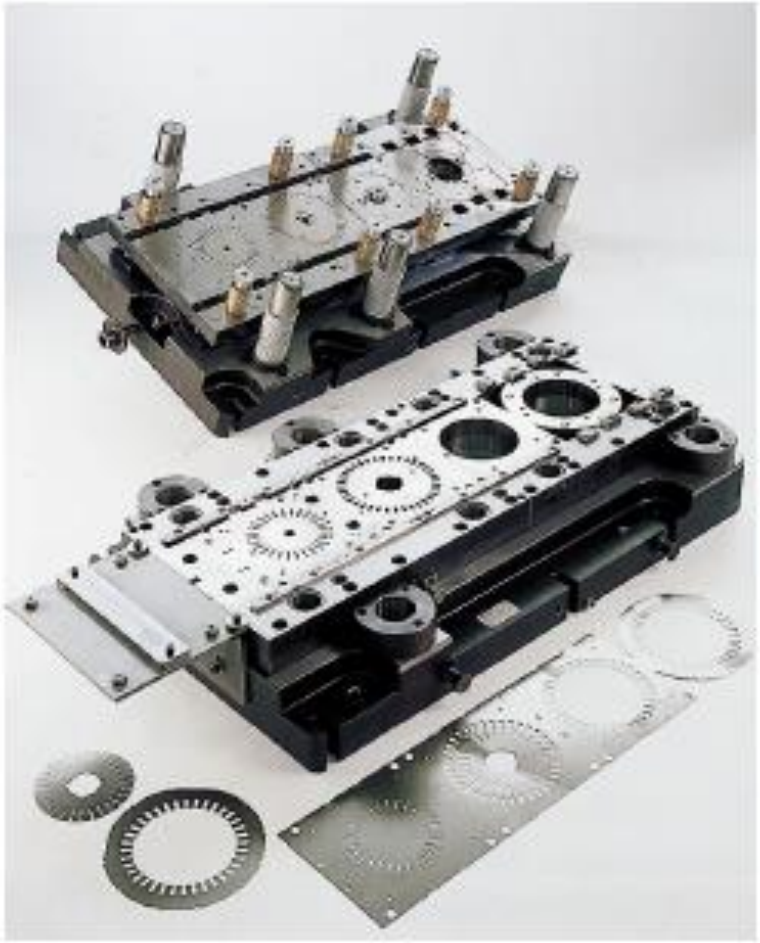
CORTE E DOBRA DE DE CHAPAS

Ferramentas e prensas para corte e dobra de chapas

Estampo de corte com 4 guias

CORTE E DOBRA DE DE CHAPAS

Ferramentas e prensas para corte e dobra de chapas



Estampo de corte progressivo

Prensa com alimentador automático

CORTE E DOBRA DE DE CHAPAS

Prensas de corte e dobra de chapas