



ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

# **Elementos de Máquinas para Automação**

**PMR 3307 – A09**

**Fixação cubo-eixo**

**2023.2**

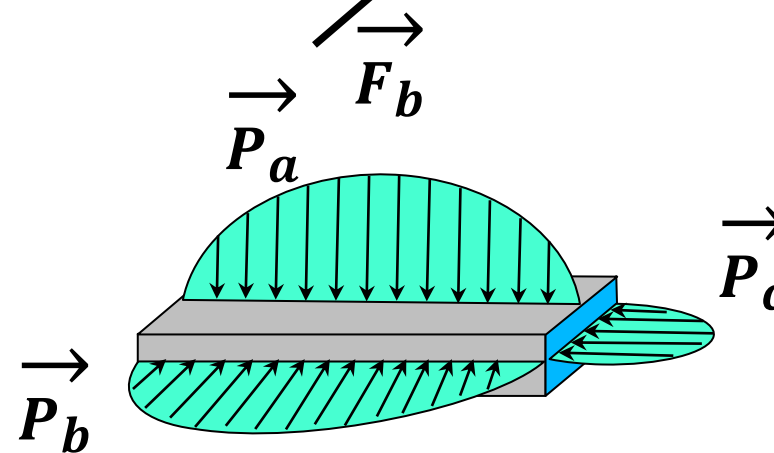
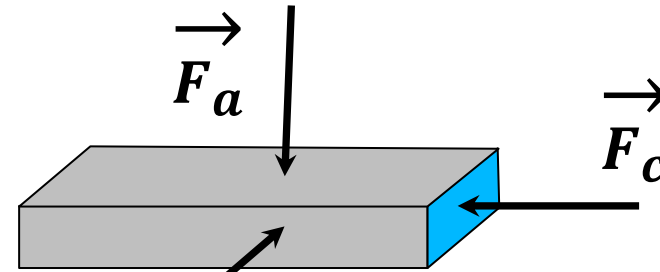


**RELEMBRANDO!**

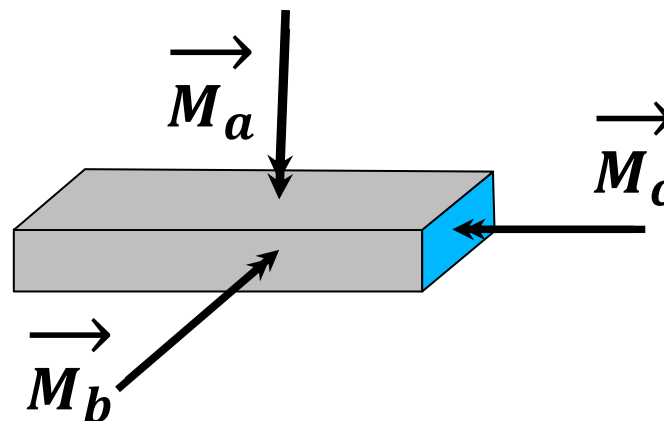
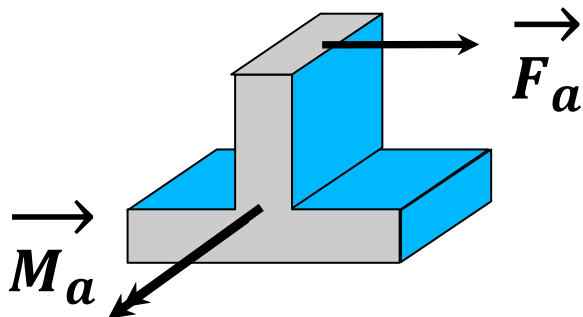
## Carregamentos

### Forças

- Concentrados
- Distribuídos



### Momentos (torques)

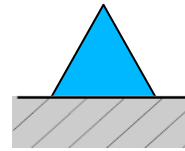




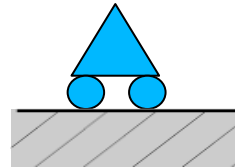
**RELEMBRANDO!**

## Apoios e Reações

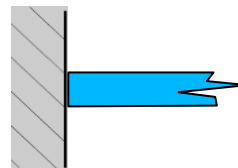
➤ **Fixo**



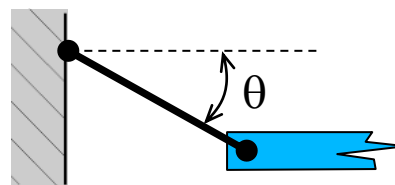
➤ **Deslizante**



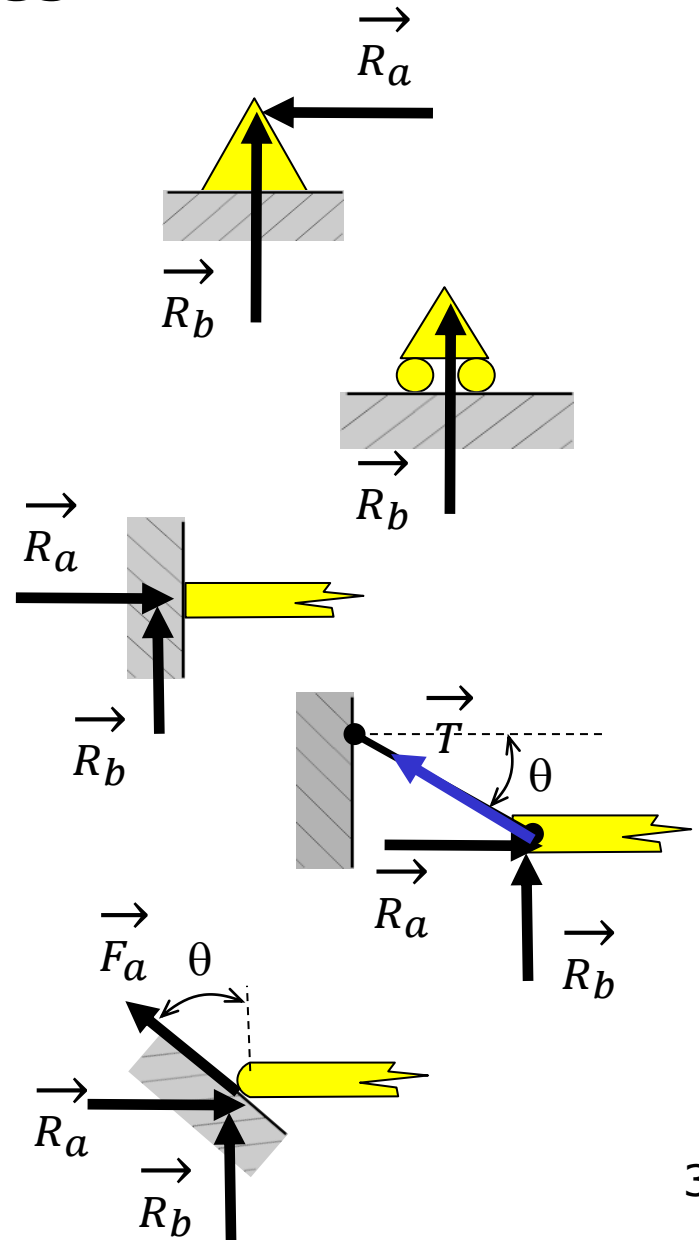
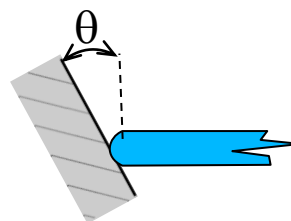
➤ **Engastado**



➤ **Com cabo**



➤ **Com contato**

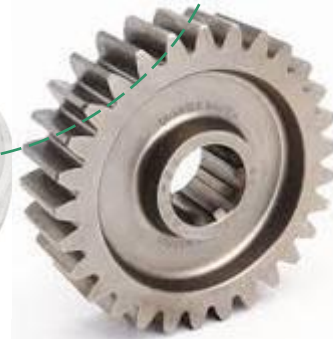
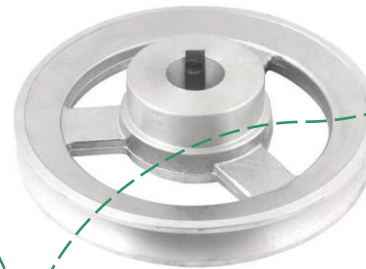




## Fixação cubo eixo

Eixos

Cubos

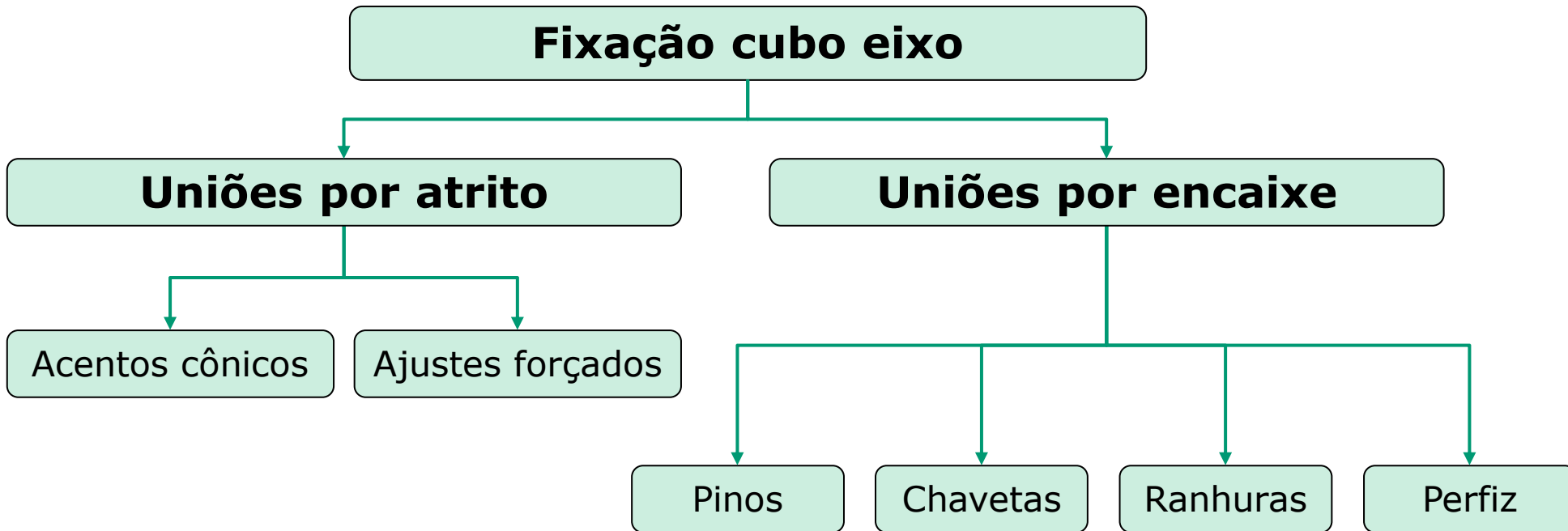


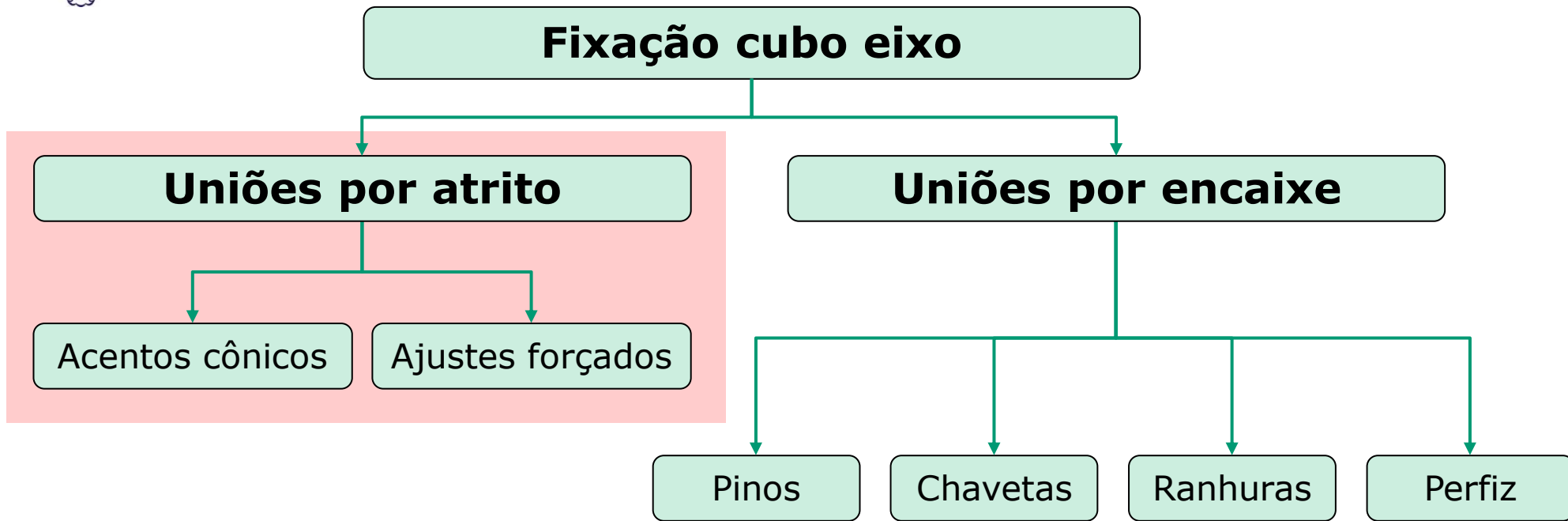
Cubo + Eixo





## Fixação cubo de eixo

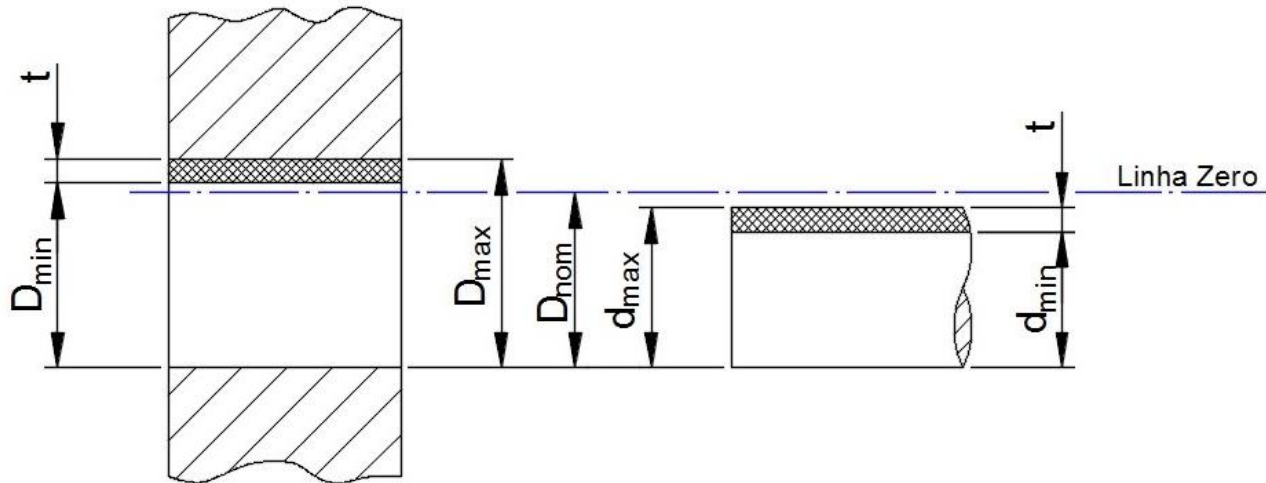




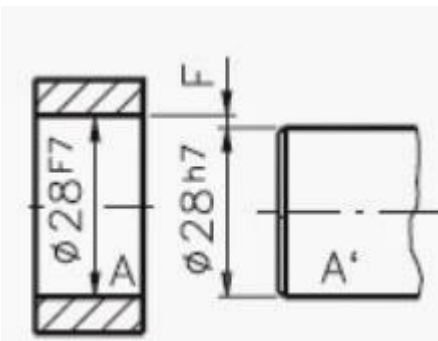


# Uniões por atrito

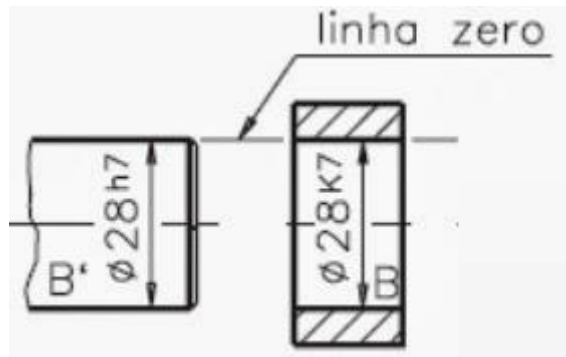
## Ajustes cubo-eixo



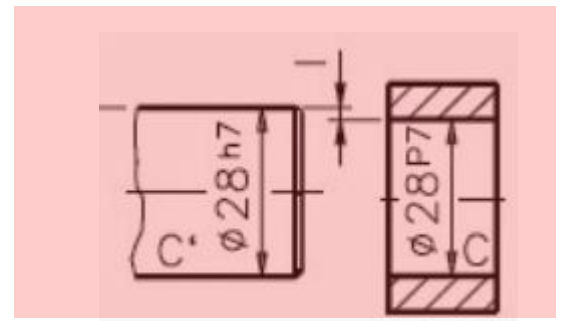
### Ajustes com folga



### Ajustes incertos



### Ajustes forçados





## Uniões por atrito

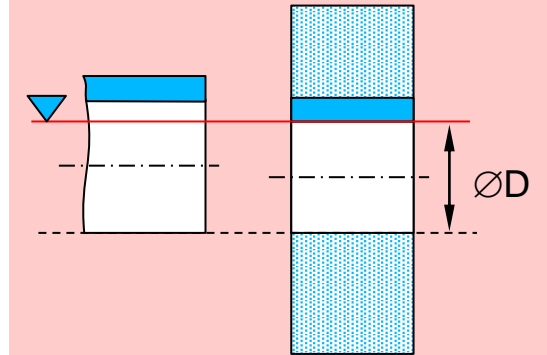
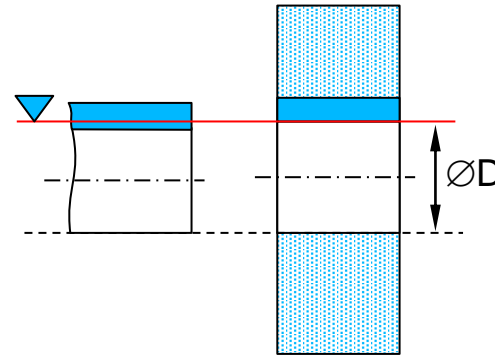
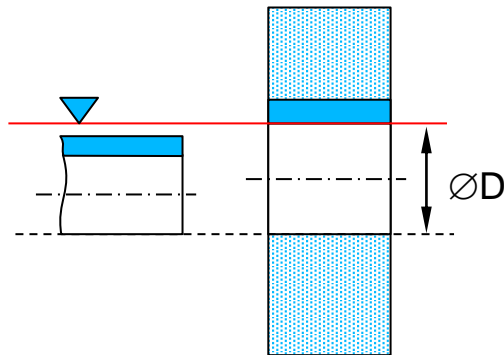
### Ajustes cubo-eixo

Ajustes com folga

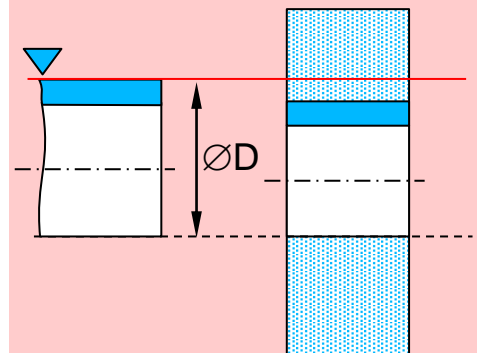
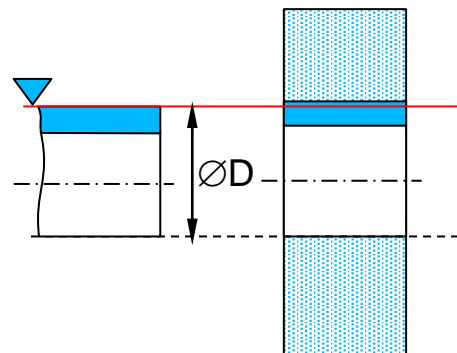
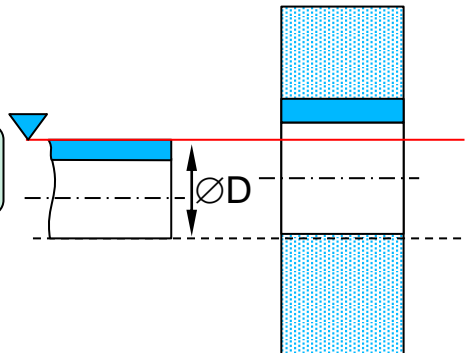
Ajustes incertos

Ajustes forçados

Furo base



Eixo base

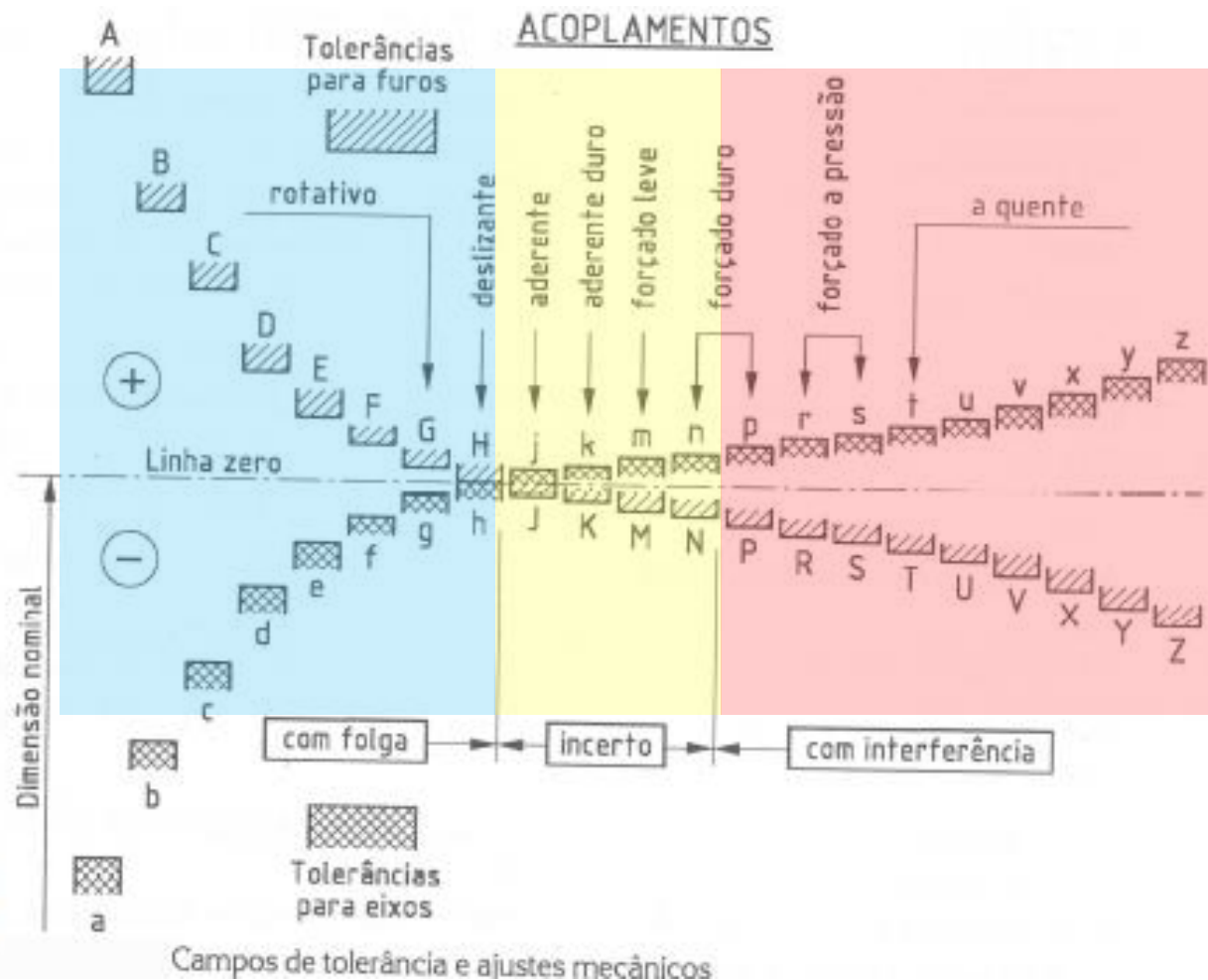






## Uniões por atrito

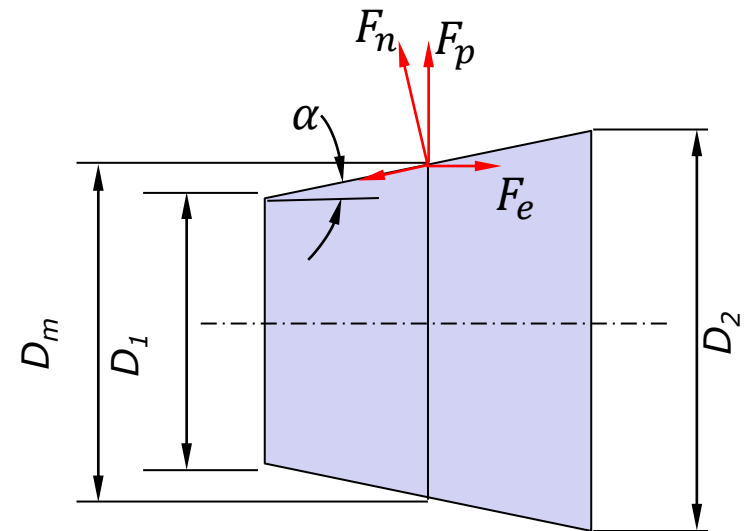
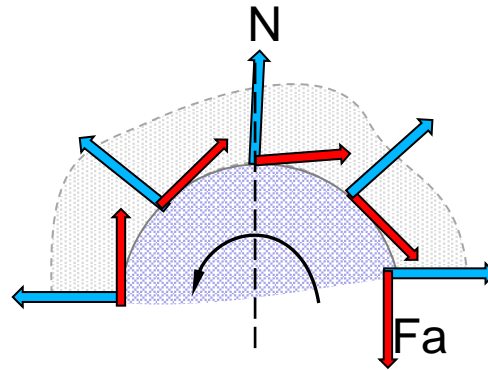
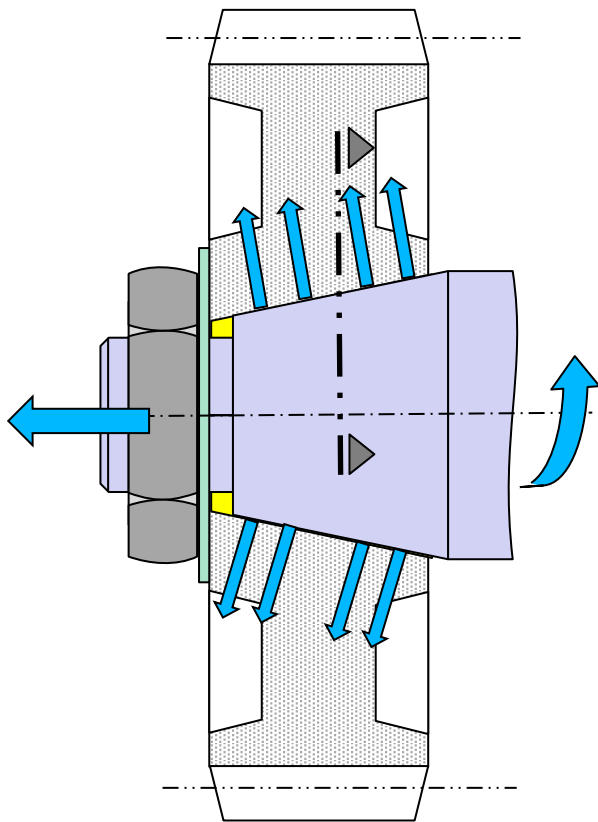
## Ajustes cubo-eixo





## Uniões por atrito

### Acentos cônicos

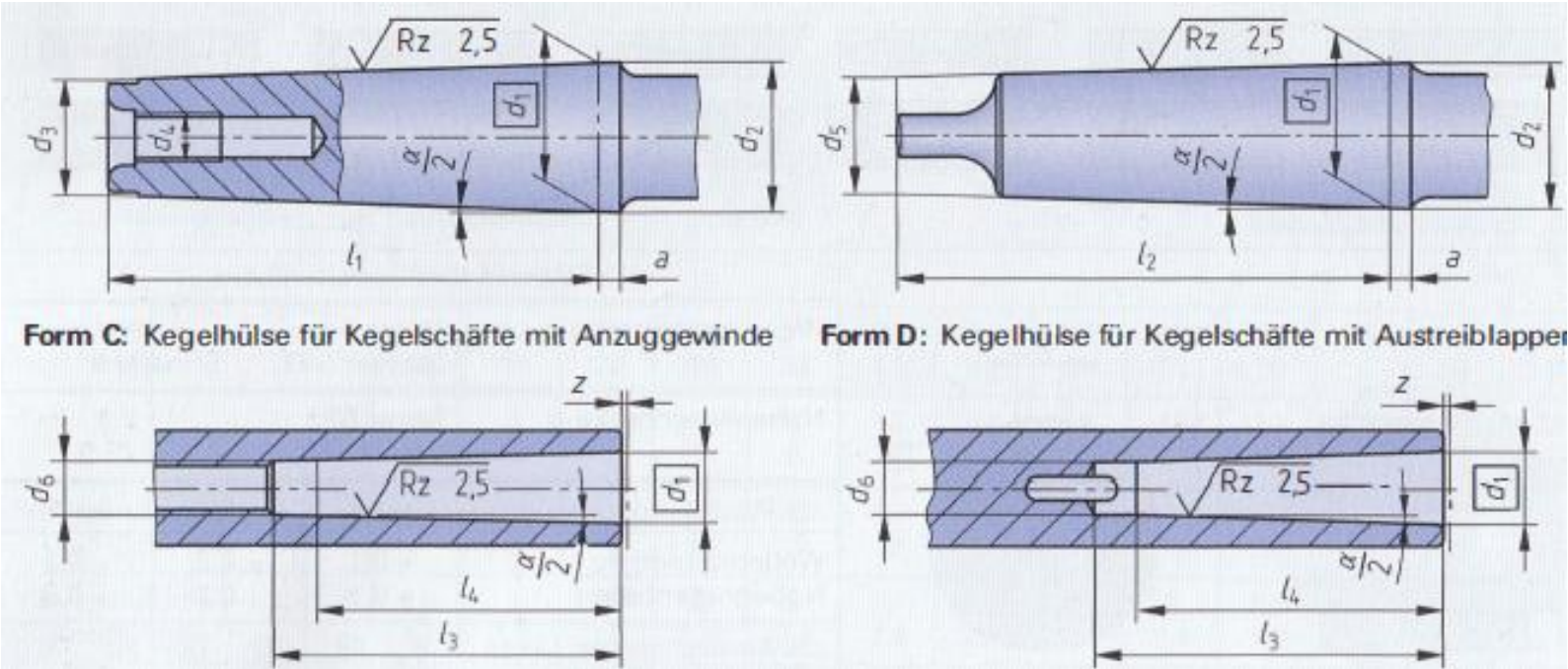


$$F_e = F_n (\sin \alpha - \mu \cdot \cos \alpha)$$



## Uniões por atrito

### Acentos cônicos padronizados



Form C: Kegelhülse für Kegelschäfte mit Anzuggewinde

Form D: Kegelhülse für Kegelschäfte mit Austreiblappen



# Uniões por atrito

## Acentos cônicos padronizados

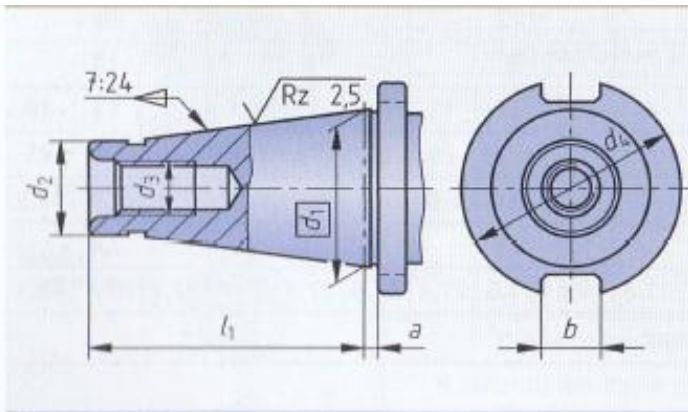
Kegelart	Größe	Kegelschaft								Kegelschaft				Kegel	
		$d_1$	$d_2$	$d_3$	$d_4$	$d_5$	$l_1$	$a$	$l_2$	$d_6$ H11	$l_3$	$l_4$	$z^{1)}$	Verjüngung	$\frac{\alpha}{2}$
Metr. Kegel (ME)	4	4	4,1	2,9	–	–	23	2	–	3	25	20	0,5	1 : 20	1,432°
	6	6	6,2	4,4	–	–	32	3	–	4,6	34	28	0,5		
Morse-Kegel (MK)	0	9,045	9,2	6,4	–	6,1	50	3	56,5	6,7	52	45	1	1 : 19,212	1,491°
	1	12,065	12,2	9,4	M6	9	53,5	3,5	62	9,7	56	47	1	1 : 20,047	1,429°
	2	17,780	18,0	14,6	M10	14	64	5	75	14,9	67	58	1	1 : 20,020	1,431°
	3	23,825	24,1	19,8	M12	19,1	81	5	94	20,2	84	72	1	1 : 19,922	1,438°
	4	31,267	31,6	25,9	M16	25,2	102,5	6,5	117,5	26,5	107	92	1	1 : 19,254	1,488°
	5	44,399	44,7	37,6	M20	36,5	129,5	6,5	149,5	38,2	135	118	1	1 : 19,002	1,507°
	6	63,348	63,8	53,9	M24	52,4	182	8	210	54,8	188	164	1	1 : 19,180	1,493°
Metr. Kegel (ME)	80	80	80,4	70,2	M30	69	196	8	220	71,5	202	170	1,5	1 : 20	1,432°
	100	100	100,5	88,4	M36	87	232	10	260	90	240	200	1,5		
	120	120	120,6	106,6	M36	105	268	12	300	108,5	276	230	1,5		
	160	160	160,8	143	M48	141	340	16	380	145,5	350	290	2		
	200	200	201,0	179,4	M48	177	412	20	460	182,5	424	350	2		
→	Kegelschaft DIN 228 – ME – B 80 AT6: Metr. Kegelschaft, Form B, Größe 80, Kegelwinkel-Toleranzqualität AT6														



# Uniões por atrito

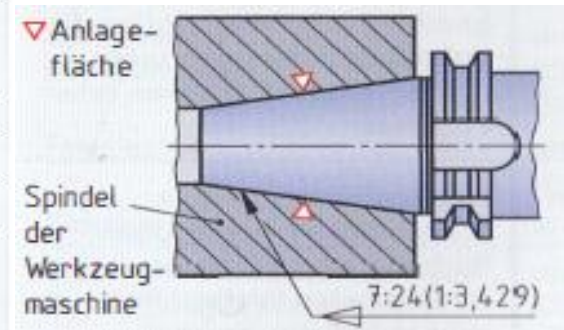
## Acentos cônicos

### Cones SK

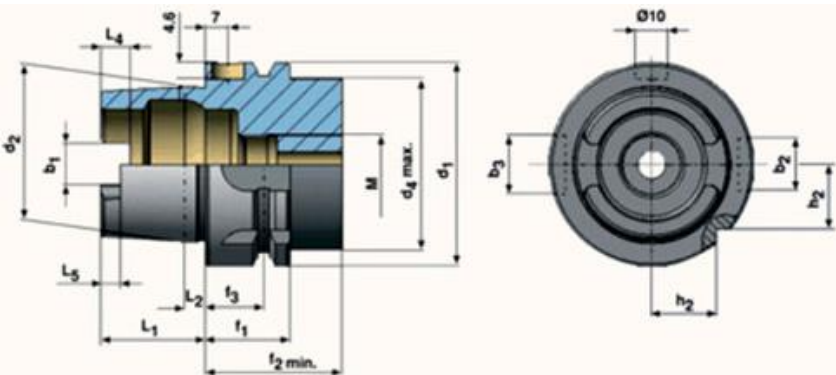


Nr.	$d_1$	$d_2 a_{10}$	$d_3$	$d_4 - 0,4$	$l_1$	$a \pm 0,2$	$b H_{12}$
30	31,75	17,4	M12	50	68,4	1,6	16,1
40	44,45	25,3	M16	63	93,4	1,6	16,1
50	69,85	39,6	M24	97,5	126,8	3,2	25,7
60	107,95	60,2	M30	156	206,8	3,2	25,7
70	165,1	92	M36	230	296	4	32,4
80	254	140	M48	350	469	6	40,5

→ Steilkegelschaft DIN 2080 – A 40 AT4: Form A, Nr. 40, Kegelwinkel-Toleranzqualität AT4

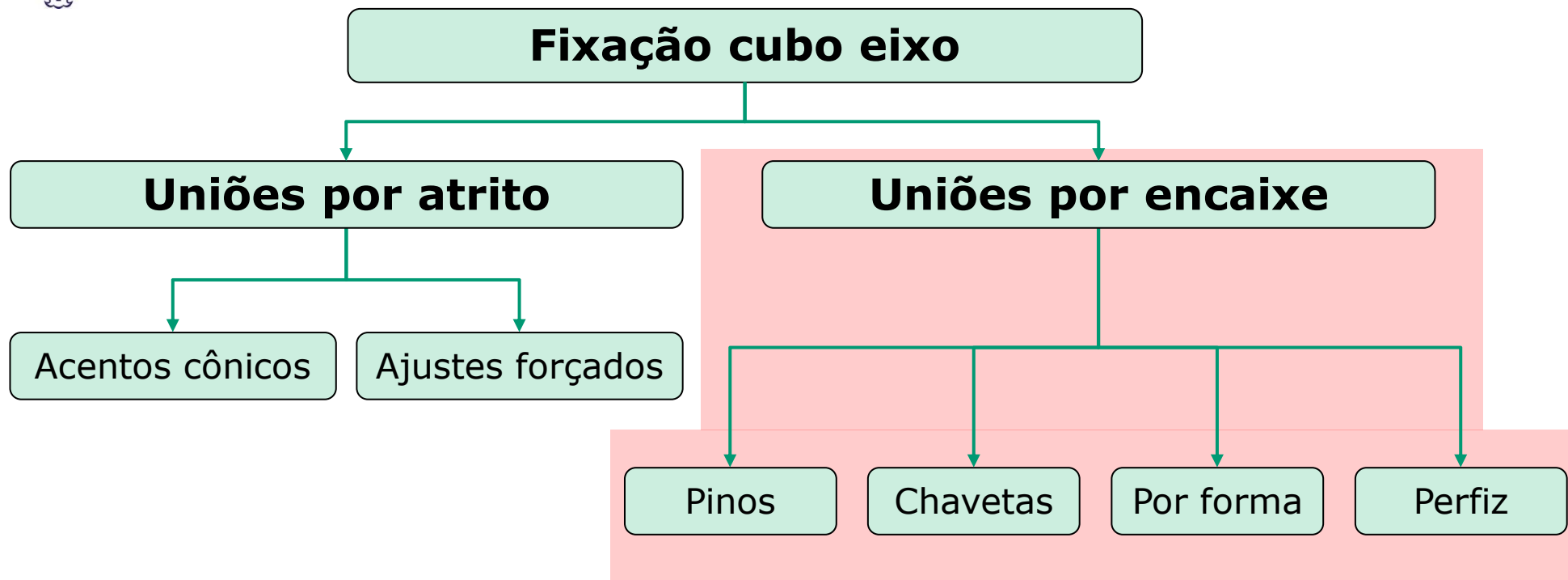


### Cones HSK



HSK-A

d1	d2	d4	L1	L2	L4	L5	M	f1	f2	f3	b1	b2	b3	h2
32	24	26	16	3,2	5,0	3,0	M10x1	20	35	16	7,05	7	9	9,5
40	30	34	20	4,0	6,0	3,5	M12x1	20	35	16	8,05	9	11	12
50	38	42	25	5,0	7,5	4,5	M16x1	26	42	18	10,54	12	14	15,5
63	48	53	32	6,3	10,0	6,0	M18x1	26	42	18	12,54	16	18	20
80	60	67	40	8,0	12,0	8,0	M20x1,5	26	42	18	16,04	18	20	25
100	75	85	50	10,0	15,0	10,0	M24x1,5	29	45	20	20,02	20	25	31,5





## Fixação cubo eixo

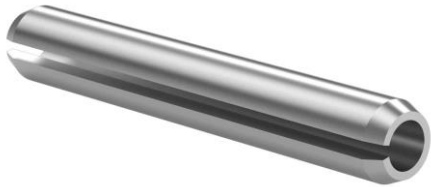
### Unões por encaixe

Pinos

Chavetas

Por forma

Perfiz

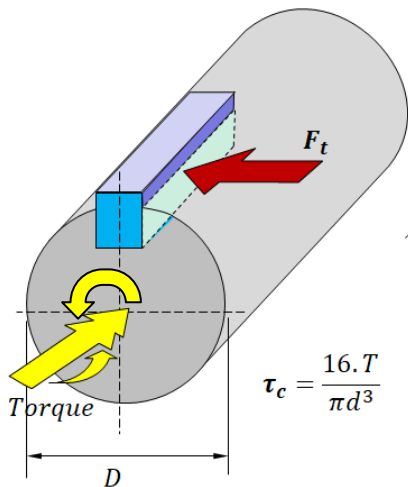
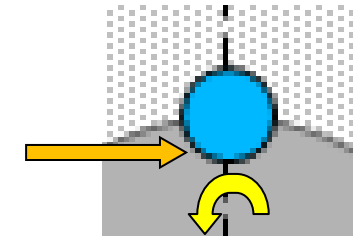
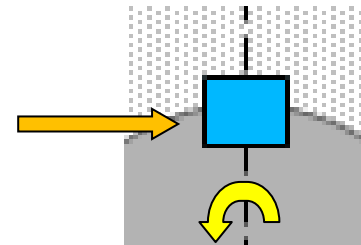
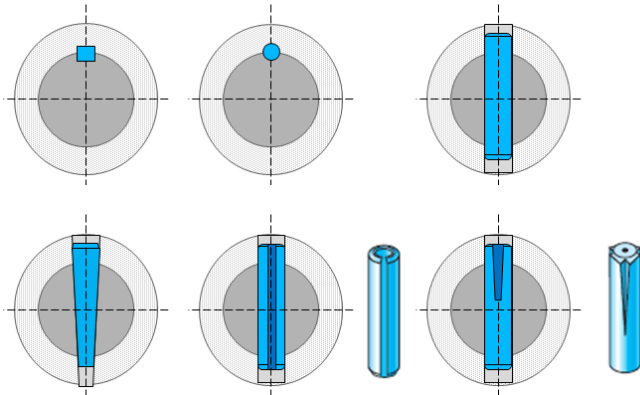




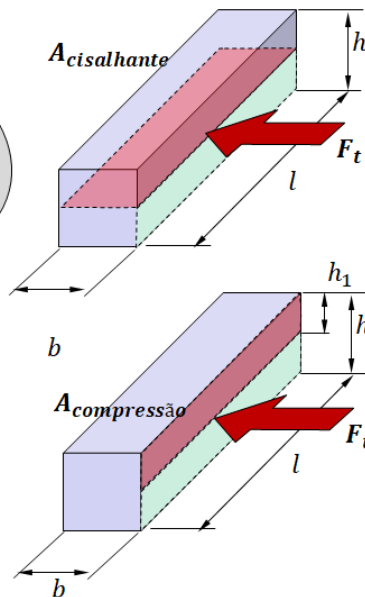
# Unões por encaixe

Pinos

Chavetas



$$\tau_c = \frac{16.T}{\pi d^3}$$



$$A_{\text{cisalhante}} = b \cdot l$$

$$F_t = \tau_c \cdot A_{\text{cisalhante}}$$

$$F_t = \tau_c \cdot a \cdot l$$

$$\tau_c = \frac{F_t}{a \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \tau_c}$$

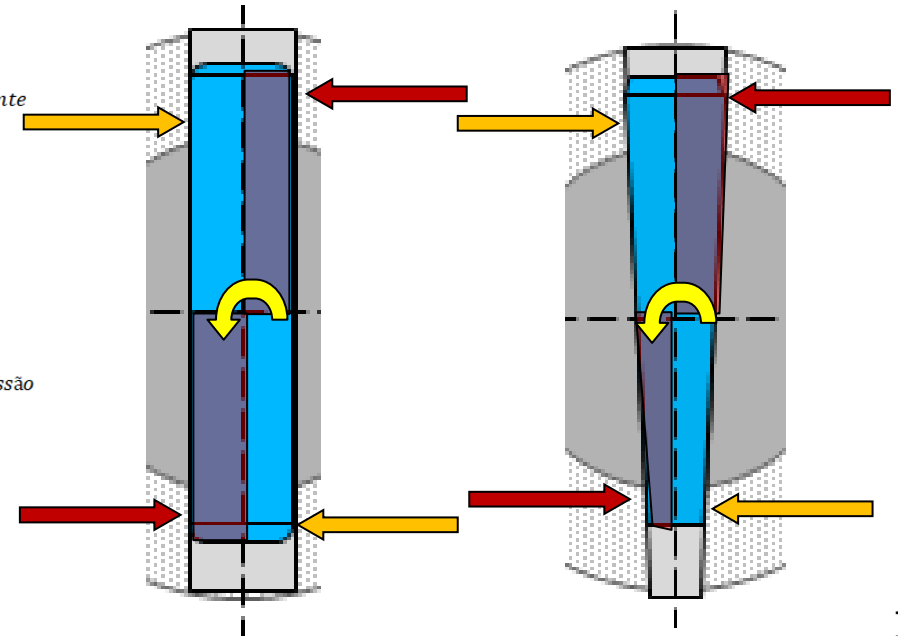
$$A_{\text{compressão}} = l \cdot h_1$$

$$F_t = \sigma_c \cdot A_{\text{compressão}}$$

$$F_t = \sigma_c \cdot h_1 \cdot l$$

$$\sigma_c = \frac{F_t}{h_1 \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \sigma_c}$$

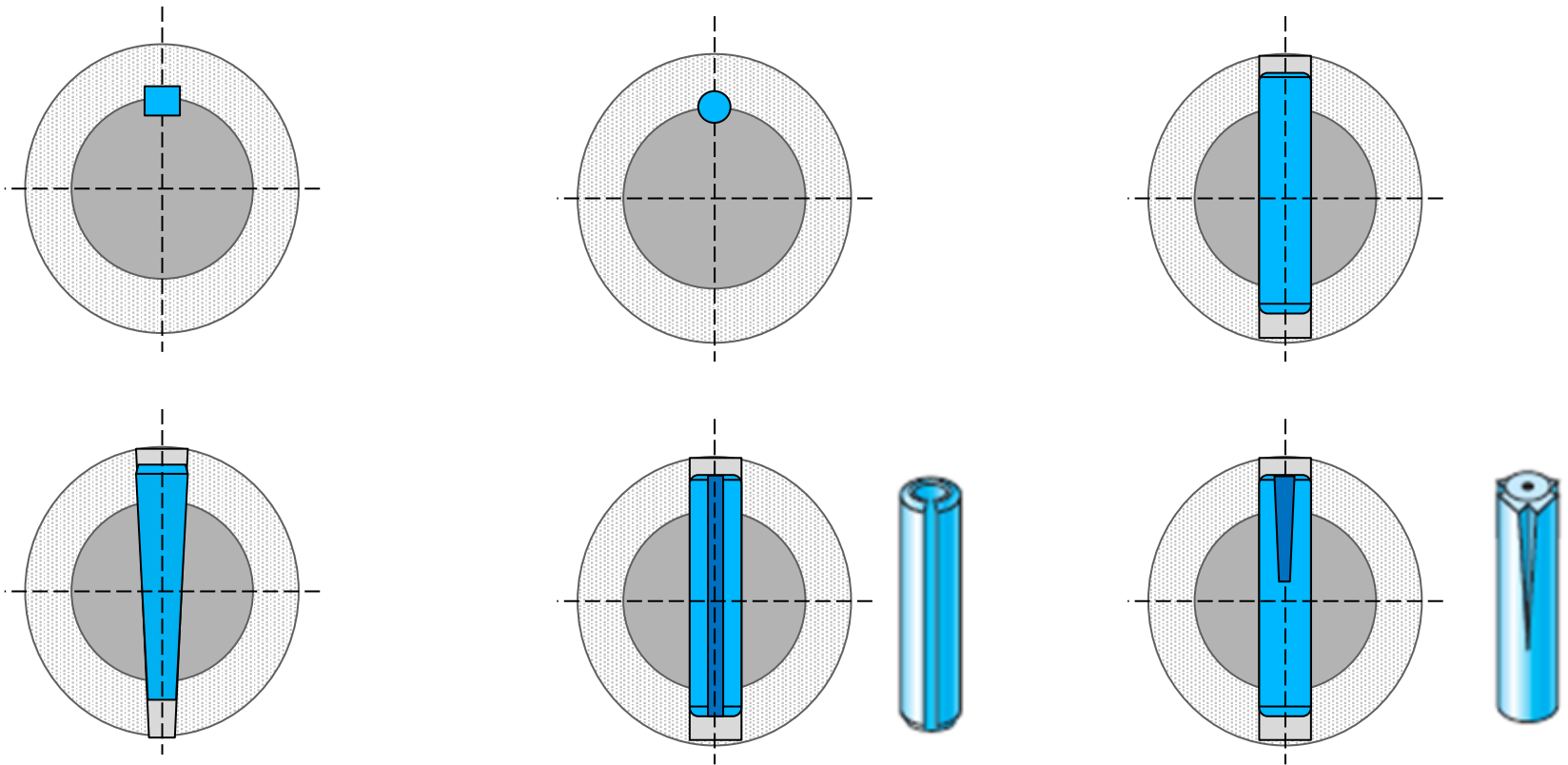






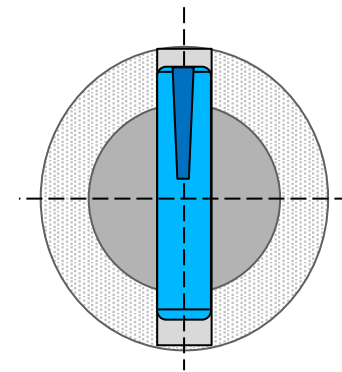
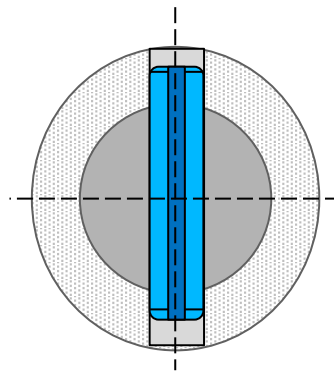
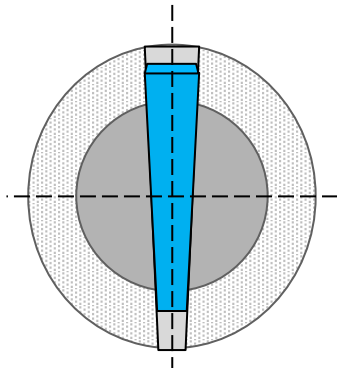
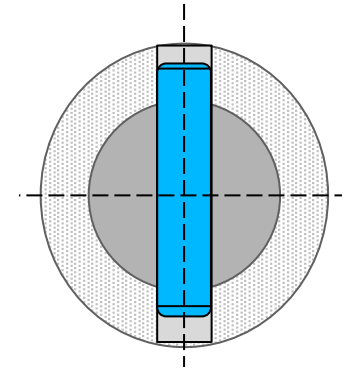
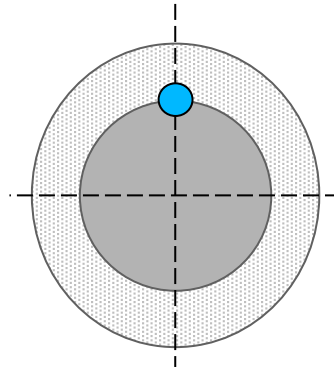
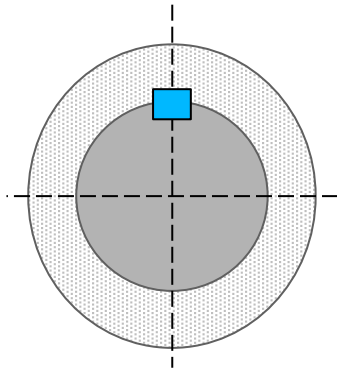
## Uniões por encaixe

### Pinos



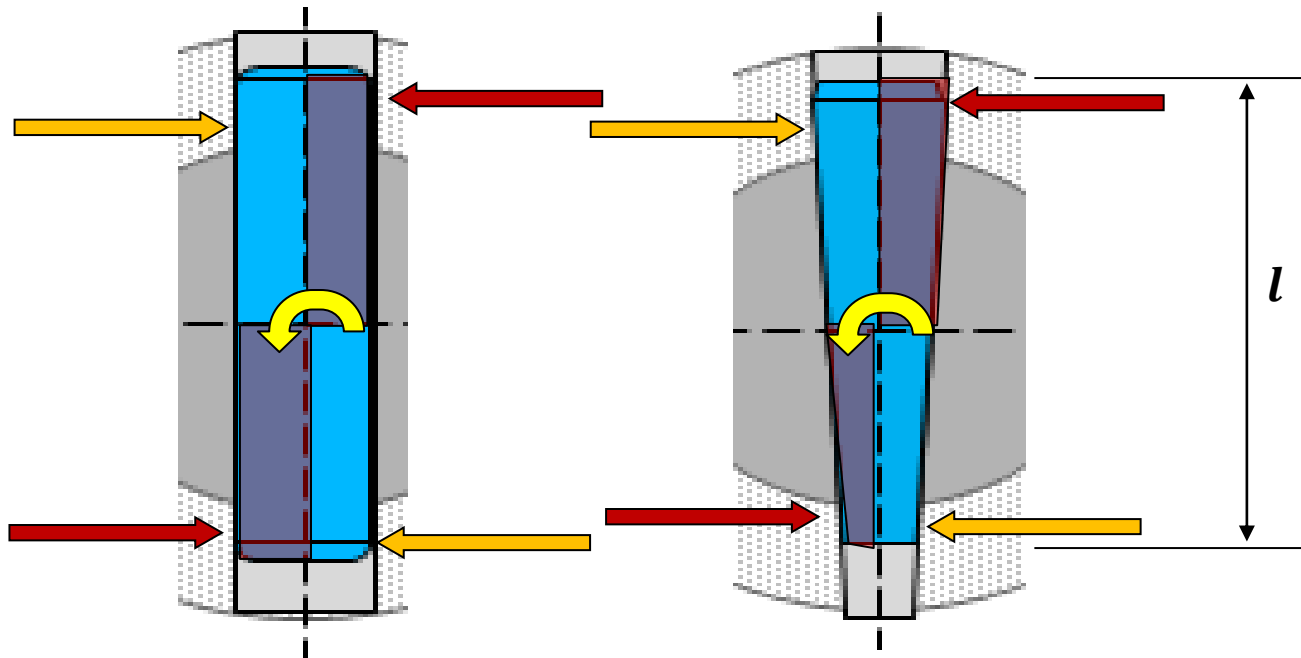


## Pinos



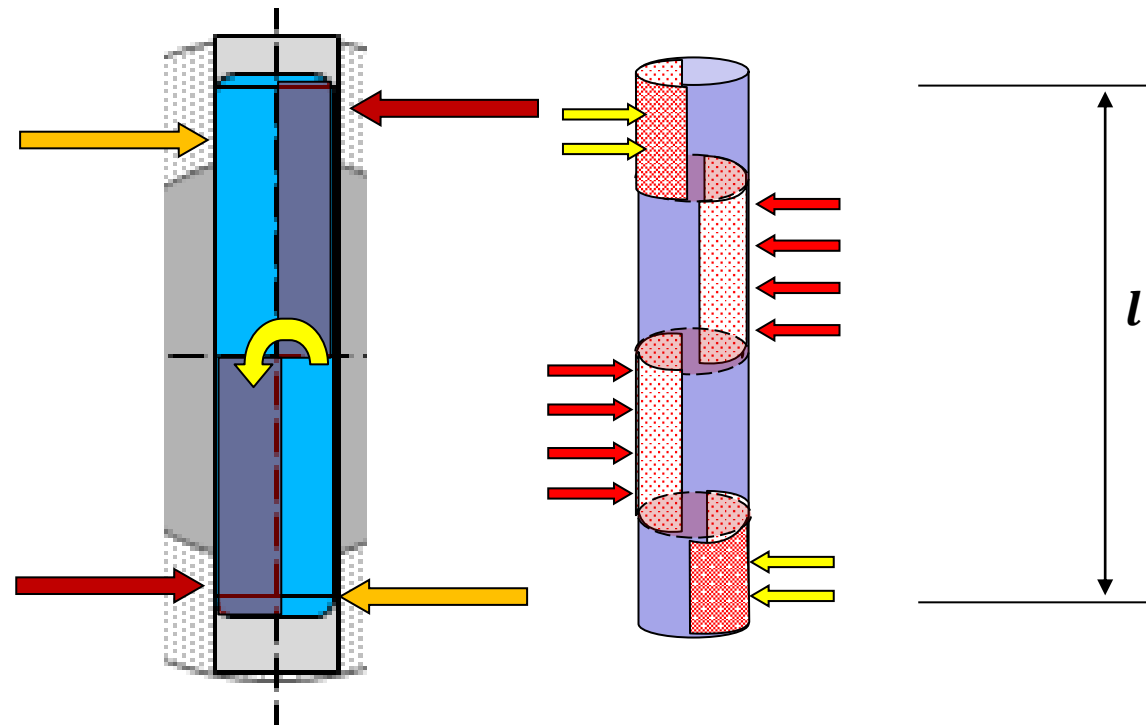


## Pinos



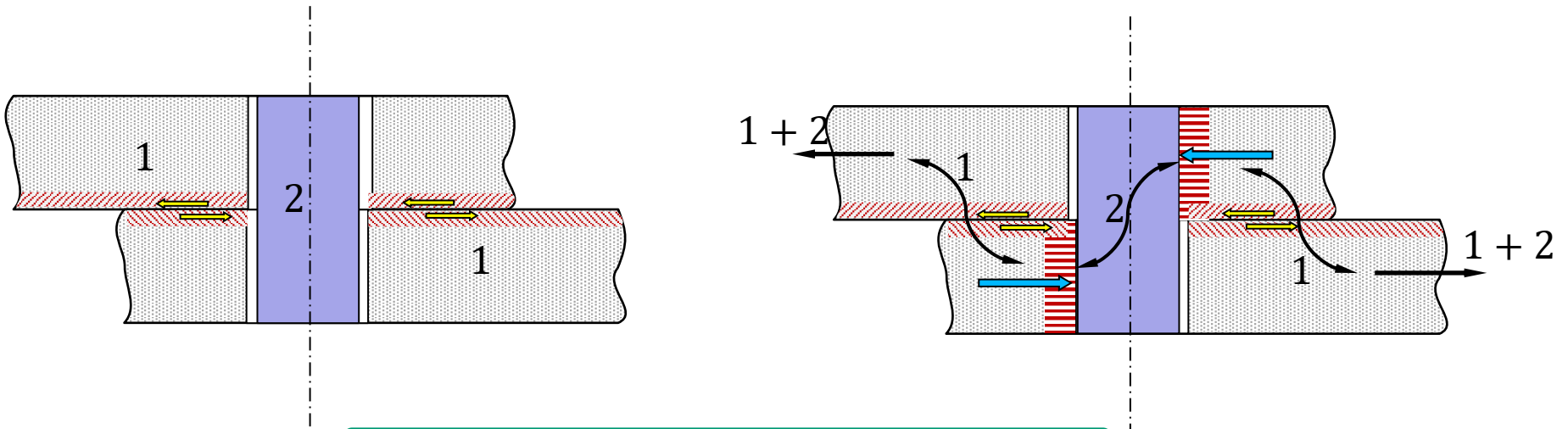


## Pinos

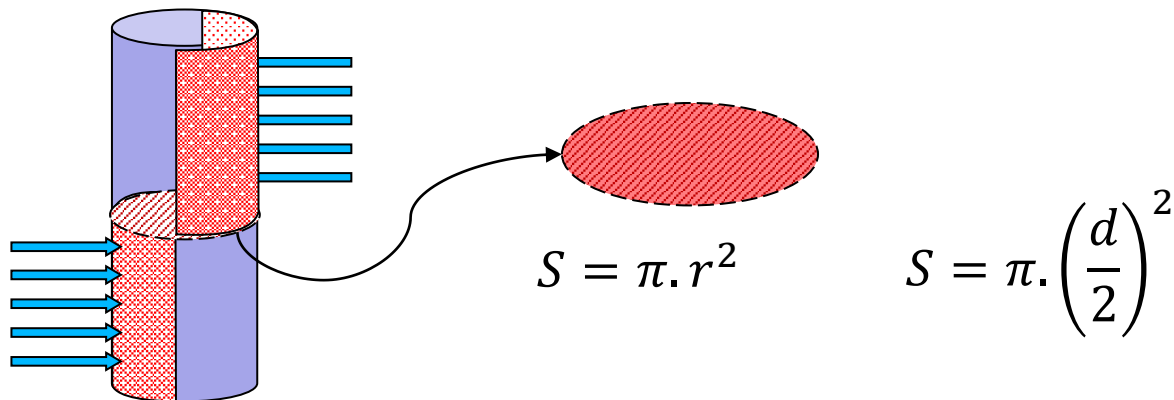




# Pinos

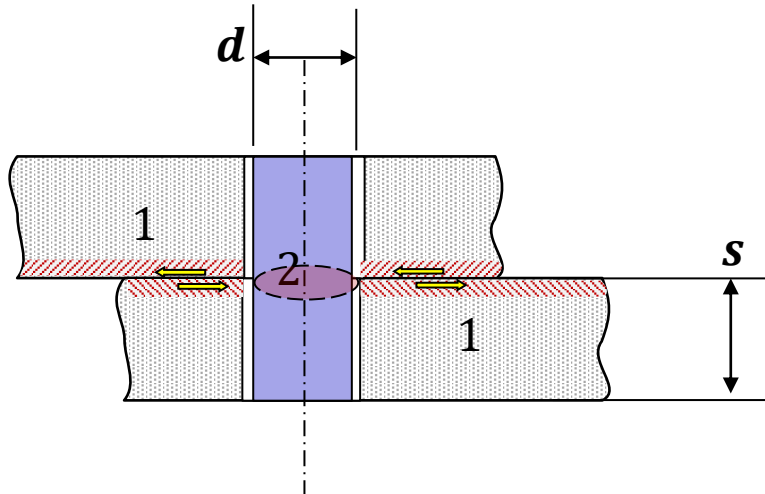


Seção transversal resistente do pino





## Pinos



secção resistente ao cisalhamento

$$d = \frac{4 \sigma_l \cdot s}{\pi \tau_r}$$

como:  $\sigma_l \leq 2,5 \cdot \tau_r$  (experimental)

temos:  $d \leq 3,2 \cdot s$

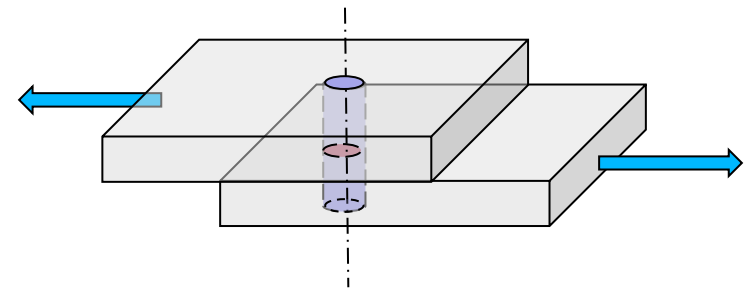
Força Normal transmitida (N) de uma chapa para outra através do pino

$$N = \tau_r \cdot s$$

$\tau_r \rightarrow$  tensão de cisalhamento

$$N = \sigma_l \cdot d \cdot s$$

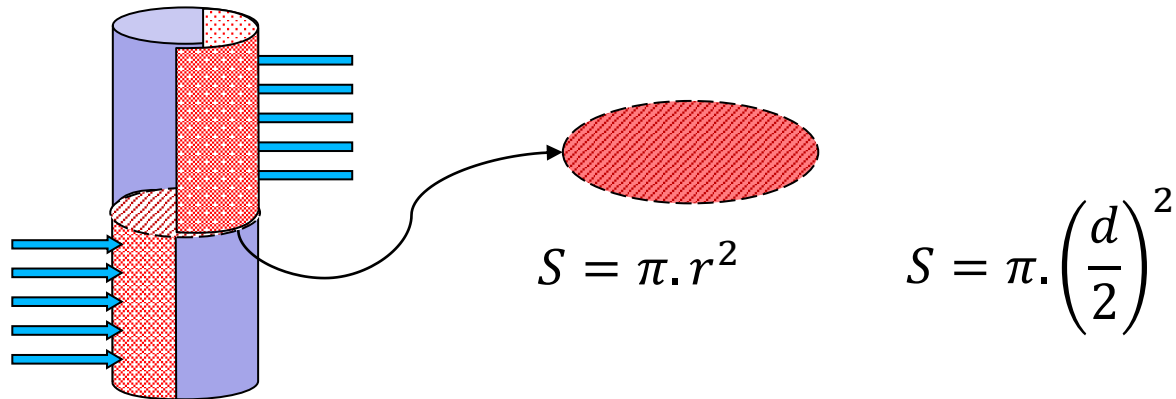
$s \rightarrow$  espessura da chapa  
 $d \rightarrow$  diâmetro do pino  
 $\sigma_l \rightarrow$  tensão média





## Pinos

Seção transversal resistente do pino



$$A_{\text{cisalhante}} = b \cdot l$$

$$F_t = \tau_c \cdot A_{\text{cisalhante}}$$

$$F_t = \tau_c \cdot a \cdot l$$

$$\tau_c = \frac{F_t}{a \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \tau_c}$$

$$A_{\text{compressão}} = l \cdot h_1$$

$$F_t = \sigma_c \cdot A_{\text{compressão}}$$

$$F_t = \sigma_c \cdot h_1 \cdot l$$

$$\sigma_c = \frac{F_t}{h_1 \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \sigma_c}$$



## Uniões por encaixe

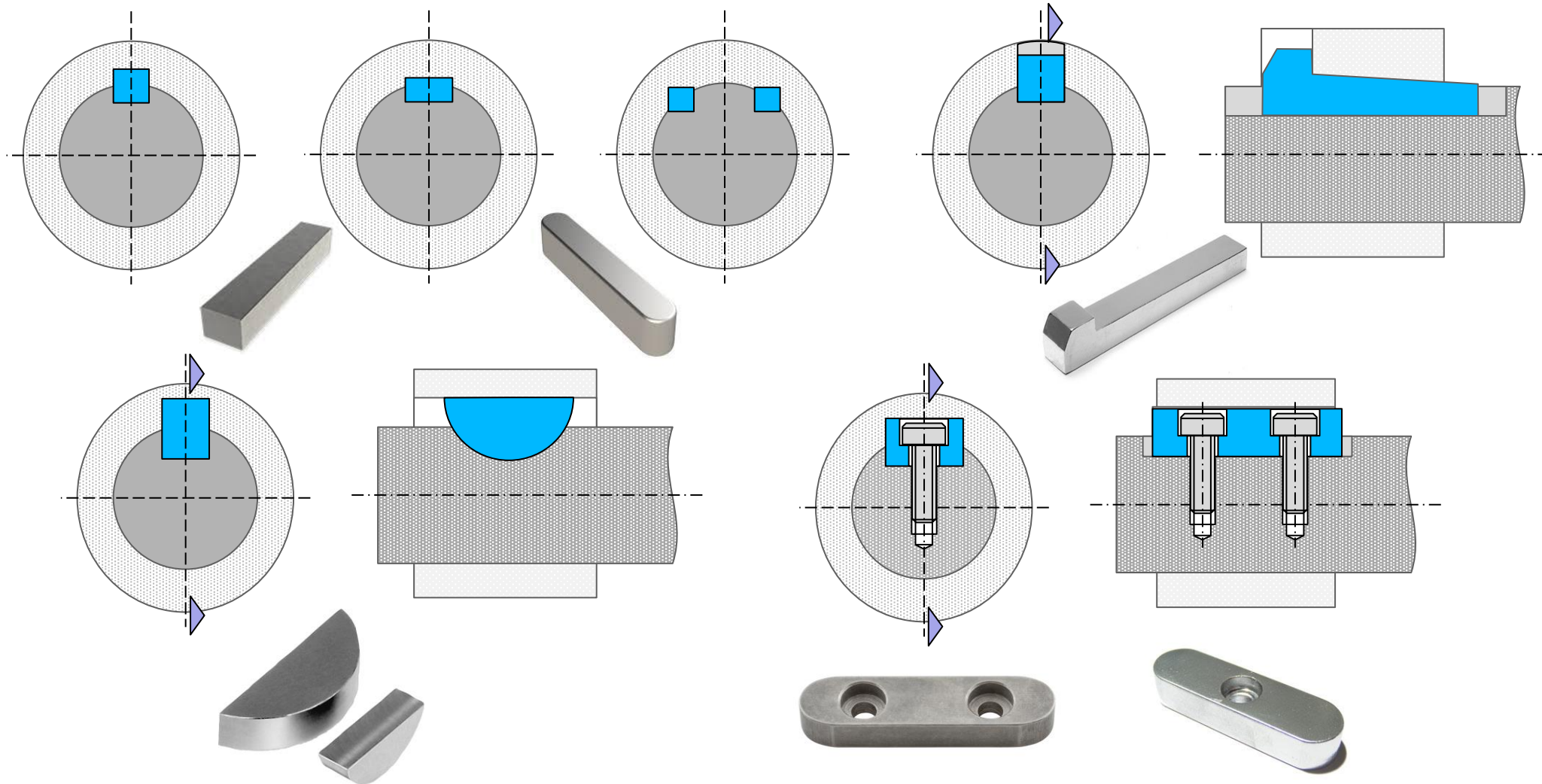
### Chavetas





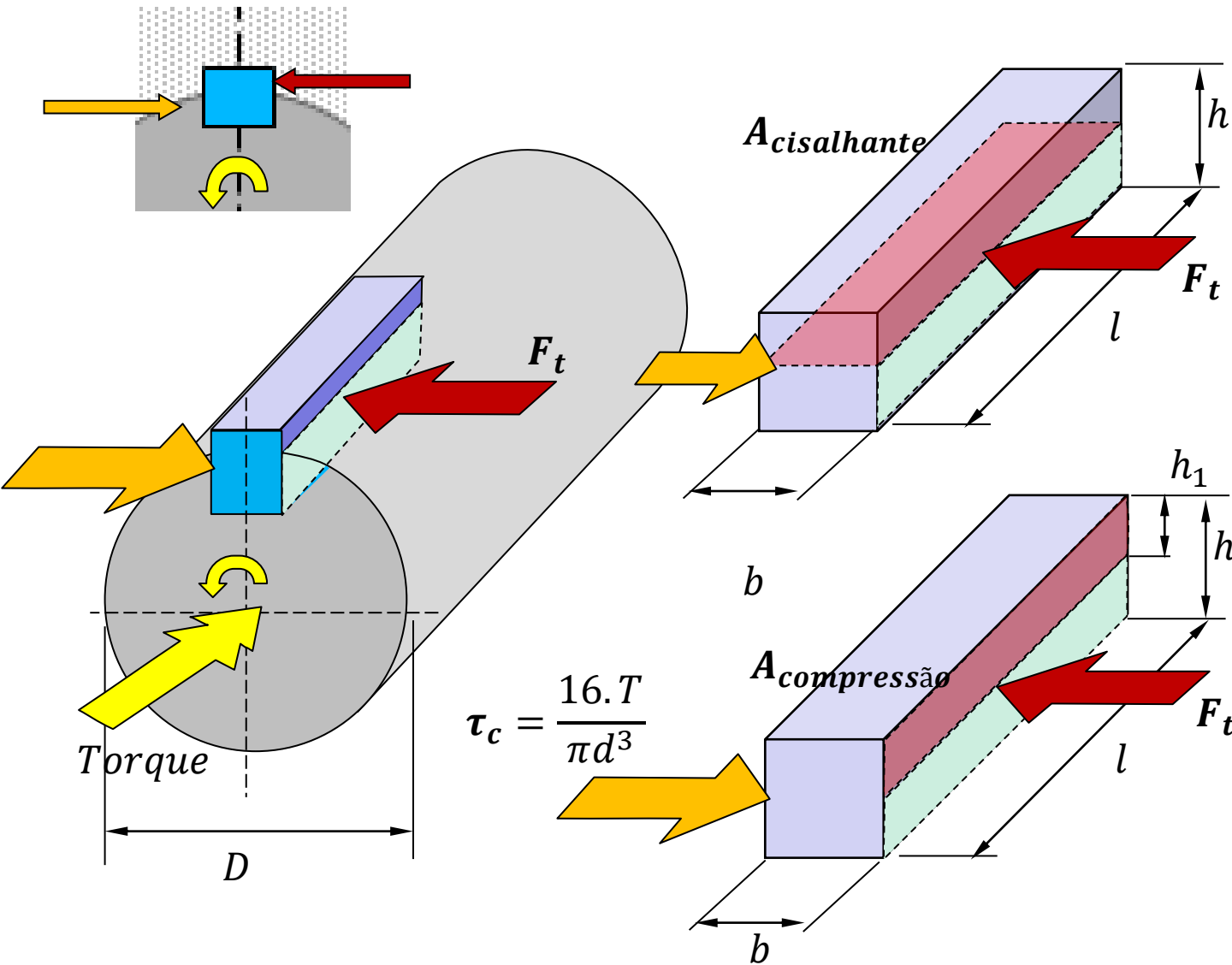


# Chavetas





## Chavetas



$$A_{cisalhante} = b \cdot l$$

$$F_t = \tau_c \cdot A_{cisalhante}$$

$$F_t = \tau_c \cdot a \cdot l$$

$$\tau_c = \frac{F_t}{a \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \tau_c}$$

$$A_{compressão} = l \cdot h_1$$

$$F_t = \sigma_c \cdot A_{compressão}$$

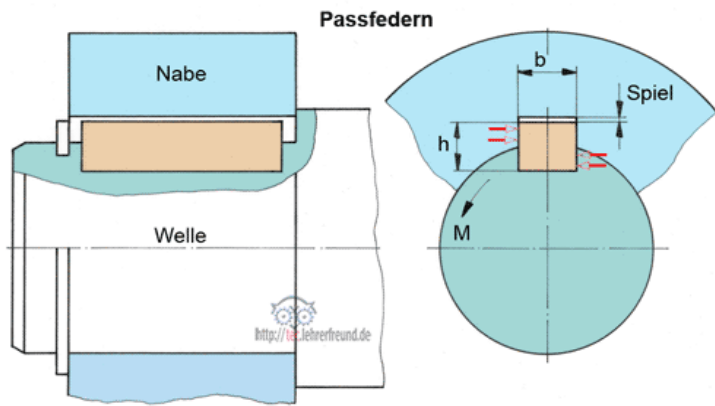
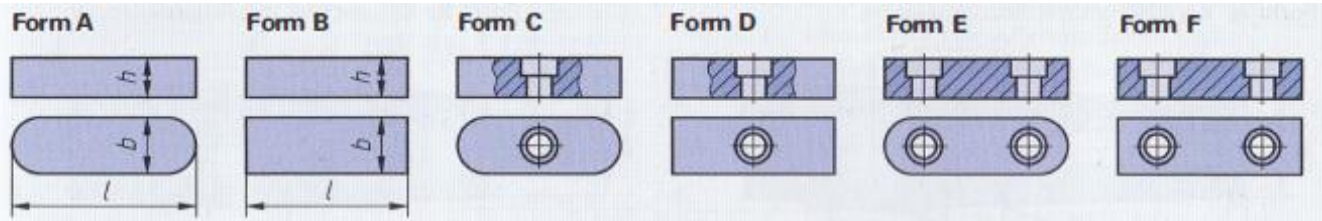
$$F_t = \sigma_c \cdot h_1 \cdot l$$

$$\sigma_c = \frac{F_t}{h_1 \cdot l}$$

$$l \geq \frac{F_t}{h_1 \cdot \sigma_c}$$



# Chavetas



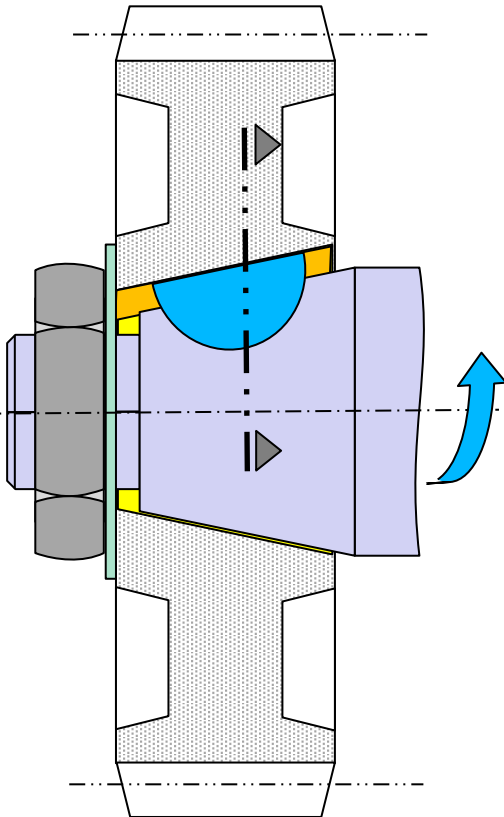
Toleranzen für Passfedernuten			
Wellennutenbreite $b$	fester Sitz	P 9	
	leichter Sitz	N 9	
Nabennutenbreite $b$	fester Sitz	P 9	
	leichter Sitz	JS 9	
zul. Abweichung bei $d_1$	$\leq 22$	$\leq 130$	$> 130$
Wellennutentiefe $t_1$	+ 0,1	+ 0,2	+ 0,3
Nabennutentiefe $t_2$	+ 0,1	+ 0,2	+ 0,3
zul. Abweichung bei Länge $l$	6 ... 28	32 ... 80	90 ... 400
Längentoleranzen für	Feder	- 0,2	- 0,3
	Nut	+ 0,2	+ 0,3

$d_1$ über	6	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	
bis	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	130	
$b$	2	3	4	5	6	8	10	12	14	16	18	20	22	25	28	32	
$h$	2	3	4	5	6	7	8	8	9	10	11	12	14	14	16	18	
$t_1$	1,2	1,8	2,5	3	3,5	4	5	5	5,5	6	7	7,5	9	9	10	11	
$t_2$	1	1,4	1,8	2,3	2,8	3,3	3,3	3,3	3,8	4,3	4,4	4,9	5,4	5,4	6,4	7,4	
$l$ von	6	6	8	10	14	18	20	28	36	45	50	56	63	70	80	90	
bis	20	36	45	56	70	90	110	140	160	180	200	220	250	280	320	360	
Nennlängen $l$	6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 70, 80, 90, 100, 110, 125, 140, 160, 180, 200, 220, 250, 280, 320 mm																

→ Passfeder DIN 6885 - A - 12 x 8 x 56: Form A,  $b = 12$  mm,  $h = 8$  mm,  $l = 56$  mm



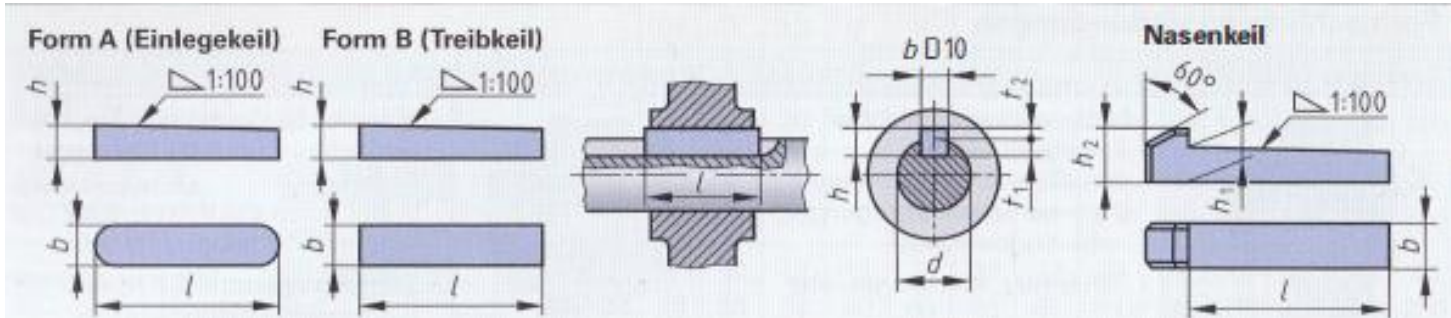
**Chavetas**



		Tolerâncias für Scheibfedernuten																			
Wellennutenbreite $b$		fester Sitz		P 9 (P 8) <sup>1)</sup>																	
		leichter Sitz		N 9 (N 8) <sup>1)</sup>																	
Nabennutenbreite $b$		fester Sitz		P 9 (P 8) <sup>1)</sup>																	
		leichter Sitz		J 9 (J 8) <sup>1)</sup>																	
zul. Abweich. bei $b$ und $h$		$\leq 5$	$5 > 7,5$	$6 \leq 9$	$6 > 9$	8	10														
Wellennutentiefe $t_1$		+0,1	+0,2	+0,1	+0,2	+0,2	+0,2														
Nabennutentiefe $t_2$		+0,1	+0,1	+0,1	+0,1	+0,1	+0,2														
$d_1$	über bis	8 10		10 12		12 17		17 22		22 30		30 38									
$b$	h9	2,5	3	4		5		6		8		10									
$h$	h12	3,7	3,7	5	6,5	5	6,5	7,5	6,5	7,5	9	7,5	9	11	9	11	13	11	13	16	
$d_2$		10	10	13	16	13	16	19	16	19	22	19	22	28	22	28	32	28	32	45	
$t_1$		2,9	2,5	3,8	5,3	3,5	5	6	4,5	5,5	7	5,1	6,6	8,6	6,2	8,2	10,2	7,8	9,8	12,8	
$t_2$		1	1,4		1,7		2,2		2,6		3		3,4								
$l \approx$		9,7	9,7	12,7	15,7	12,7	15,7	18,6	15,7	18,6	21,6	18,6	21,6	27,4	21,6	27,4	31,4	27,4	31,4	43,1	
⇒		Scheibfeder DIN 6888 - 6 x 9 $b = 6$ mm, $h = 9$ mm																			



**Chavetas**



Für Wellen- durchmesser $d$	über bis	10 12	12 17	17 22	22 30	30 38	38 44	44 50	50 58	58 65	65 75	75 85	85 95	95 110	
Keile	$b$ D10	4	5	6	8	10	12	14	16	18	20	22	25	28	
	$h$	4	5	6	7	8	8	9	10	11	12	14	14	16	
Nasenkeile	$h_1$	4,1	5,1	6,1	7,2	8,2	8,2	9,2	10,2	11,2	12,2	14,2	14,2	16,2	
	$h_2$	7	8	10	11	12	12	14	16	18	20	22	22	25	
Wellennuttiefe	$t_1$	2,5	3	3,5	4	5	5	5,5	6	7	7,5	9	9	10	
Nabennuttiefe	$t_2$	1,2	1,7	2,2	2,4	2,4	2,4	2,9	3,4	3,4	3,9	4,4	4,4	5,4	
Zul. Abweichung	$t_1, t_2$	+0,1			+0,2										
Keillänge $l$	von	10 <sup>1)</sup>	12 <sup>1)</sup>	16	20	25	32	40	45	50	56	63	70	80	
	bis	45	56	70	90	110	140	160	180	200	220	250	280	320	
Nennlängen $l$		6, 8 ... 20, 22, 25, 28, 32, 40, 45, 50, 56, 63, 70, 80 ... 100, 110, 125, 140, 160 ... 200, 220, 250, 280, 320, 360, 400 mm													
Längentoleranzen		Keillänge $l$ , von ... bis			6 ... 28				32 ... 80				90 ... 400		
Toleranzen für		Keillänge			- 0,2				- 0,3				- 0,5		
		Nuttlänge (Einlegekeil)			+ 0,2				+ 0,3				+ 0,5		

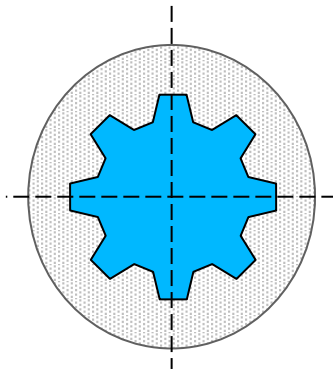
⇒ Keil A 20 x 12 x 125 DIN 6886: Form A,  $b = 20$  mm,  $h = 12$  mm,  $l = 125$  mm



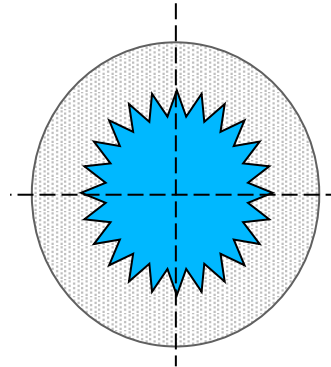
# Uniões por encaixe

## Por forma

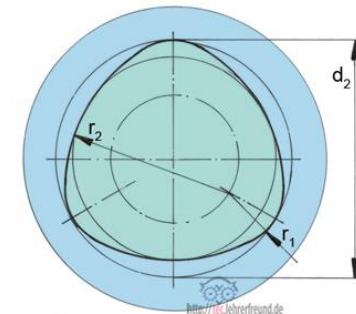
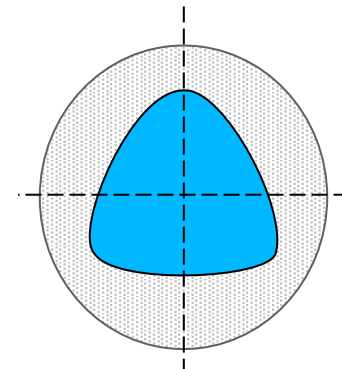
Ranhuras



Dentes



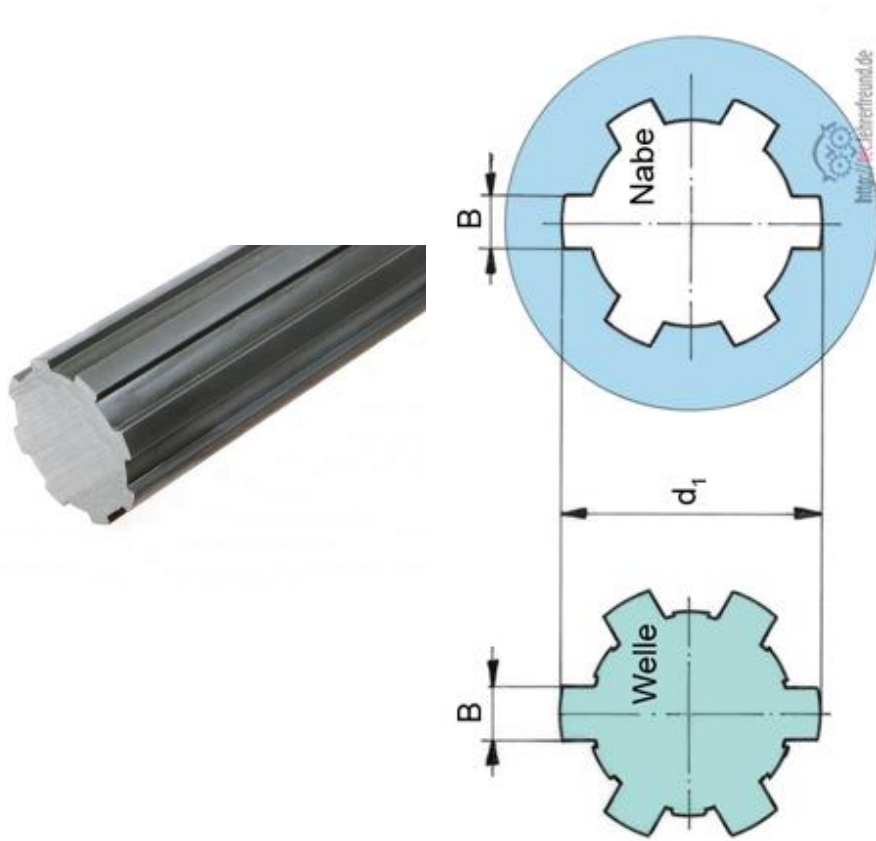
Poligonal





# Uniões por encaixe

## Ranhuras



d	Leichte Reihe			Mittlere Reihe			d	Leichte Reihe			Mittlere Reihe		
	N <sup>1)</sup>	D	B	N <sup>1)</sup>	D	B		N <sup>1)</sup>	D	B	N <sup>1)</sup>	D	B
11	-	-	-	6	14	3	42	8	46	8	8	48	8
13	-	-	-	6	16	3,5	46	8	50	9	8	54	9
16	-	-	-	6	20	4	52	8	58	10	8	60	10
18	-	-	-	6	22	5	56	8	62	10	8	65	10
21	-	-	-	6	25	5	62	8	68	12	8	72	12
23	6	26	6	6	28	6	72	10	78	12	10	82	12
26	6	30	6	6	32	6	82	10	88	12	10	92	12
28	6	32	7	6	34	7	92	10	98	14	10	102	14
32	8	36	6	8	38	6	102	10	108	16	10	112	16
36	8	40	7	8	42	7	112	10	120	18	10	125	18

Toleranzklassen für die Nabe						Toleranzklassen für die Welle			
nicht wärme-behandelt Maße			wärme-behandelt Maße			Maße	Einbauart		
B	D	d	B	D	d		Spiel-passung	Über-gangspass.	Übermaß-passung
H9	H10	H7	H11	H10	H7	B	d10	f9	h10
						D	a11	a11	a11
						d	f7	g7	h7

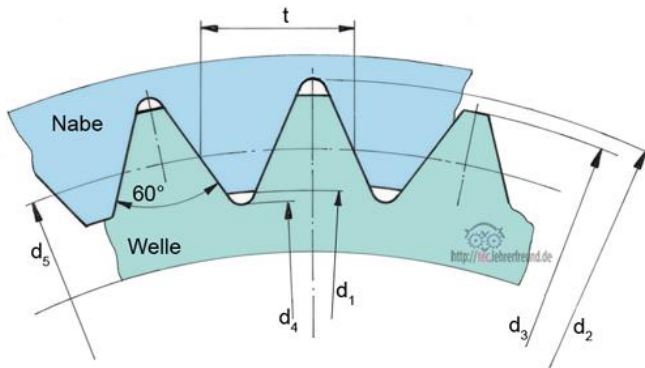
⇒ Welle (oder Nabe) ISO 14 – 6 x 23 x 26: N = 6, d = 23 mm, D = 26 mm

<sup>1)</sup> N Anzahl der Keile



# Uniões por encaixe

## Dentes



DIN 5481 SERRATION - 60° INCLUDED

Nom. Dia.	D1			D2 Calc.	D3			D4 Calc.	D5	R1 =	R2 =	T Calc. for D5	Inc Angle $\gamma$	Z No. of Teeth
	Nom. Dim.	Max.	Min.		Nom. Dim.	Max.	Min.							
8X7	6.9	7.27	7.18	8.21	8.1	7.82	7.73	8.91	7.5	0.08	0.08	0.842	47°8'35"	28
10X8	8.1	8.47	8.38	9.8	10.1	9.81	9.70	10.26	8	0.08	0.08	1.010	47°8'35"	28
12X10	10.1	10.5	10.39	12	12	11.71	11.60	12.2	11	0.1	0.1	1.152	48°	30
14X12	12	12.4	12.29	14.18	14.2	13.91	13.80	14.4	13	0.1	0.1	1.317	48°23'14"	31
17X15	14.9	15.3	15.19	17.28	17.2	16.91	16.80	17.4	16	0.15	0.15	1.571	48°45'	32
20X17	17.3	17.7	17.59	20	20	19.7	19.57	20.2	18.5	0.15	0.2	1.761	49°5'27"	33
24X21	20.8	21.23	21.1	23.78	23.9	23.6	23.47	24.0	22	0.15	0.25	2.030	49°24'42"	34
30X28	26.5	26.93	26.8	30.08	30	29.7	29.57	30.4	28	0.25	0.3	2.513	49°42'52"	35
34X30	30.5	30.97	30.81	34.17	34	33.69	33.53	34.2	32	0.3	0.4	2.792	50°	36
40X36	36	36.47	36.31	40.16	39.9	39.59	39.43	40.4	38	0.5	0.4	3.226	50°16'13"	37
45X40	40	40.47	40.31	44.42	44	43.68	43.52	44.6	42	0.5	0.4	3.472	50°31'36"	38
50X45	45	45.48	45.32	50.2	50	49.68	49.52	50.8	47.5	0.5	0.4	3.472	50°46'9"	39
55X50	50	50.48	50.32	55.25	54.9	54.56	54.37	55.2	52.5	0.6	0.4	4.123	51°	40
60X55	55	55.53	55.34	60.39	60	59.66	59.47	60.6	57.5	0.6	0.5	4.301	51°25'43"	42

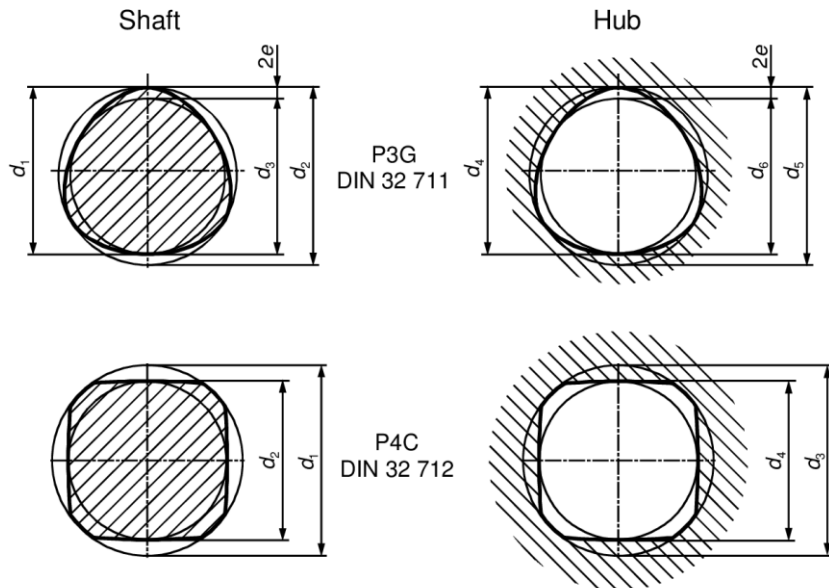




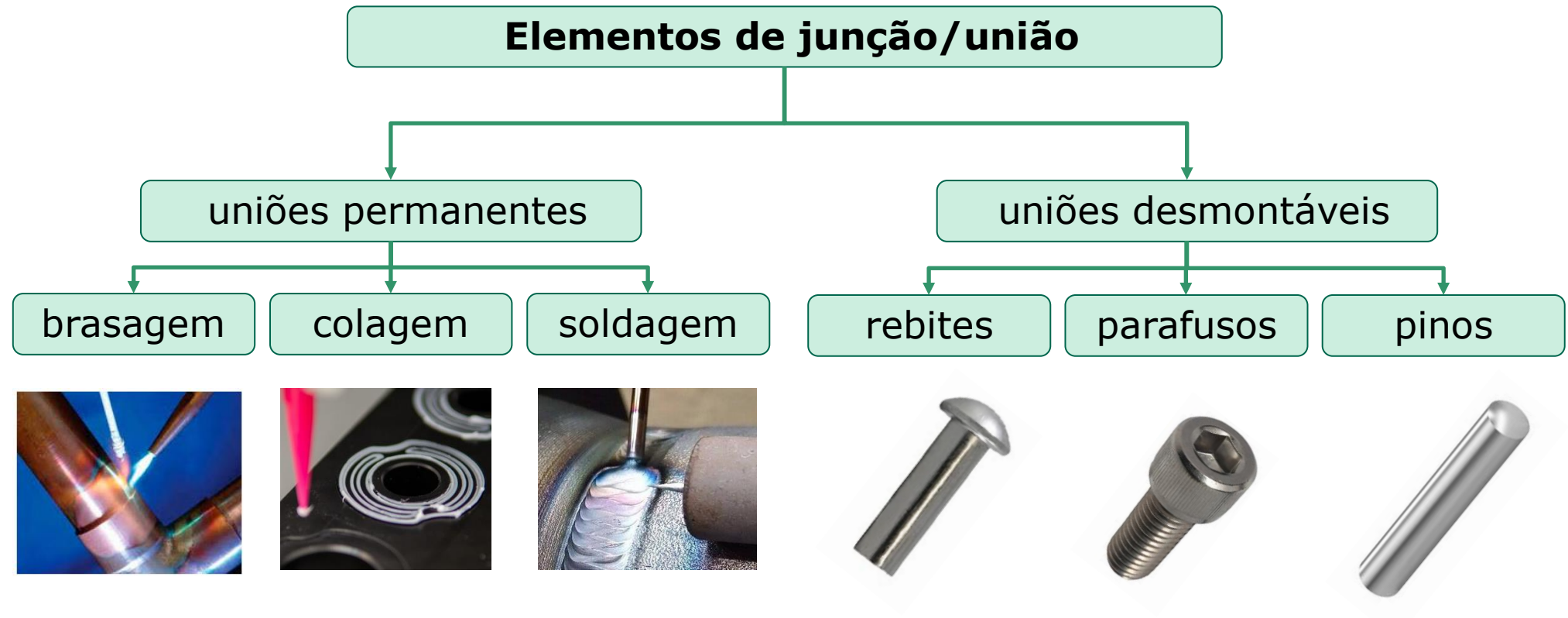


# Uniões por encaixe

## Poligonal



		P3G 18→25	P3G 100→25	P4C 14→25	P4C 100→25
$d_1$	mm	25.00	25.00	25.00	25.00
$d_2$	mm	26.56	27.25	19.64	22.50
$d_3$	mm	23.44	22.75	---	---
$d_m$	mm	25.00	25.00	25.36	26.50
$e$	mm	0.7778	1.1250	2.86	2.00
$W_p$	cm <sup>3</sup>	2.62	2.42	1.52	2.28
$W_x$	cm <sup>3</sup>	1.41	1.34	1.14	1.71

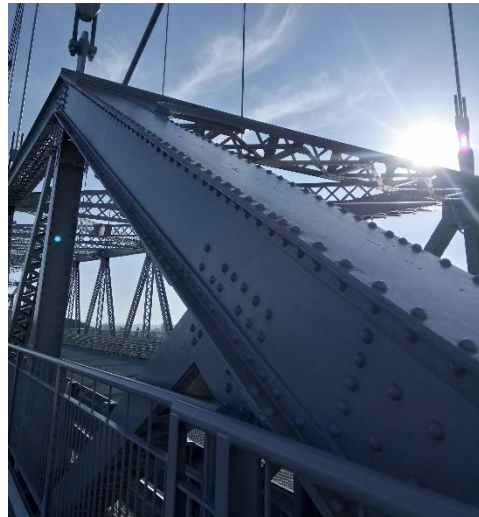
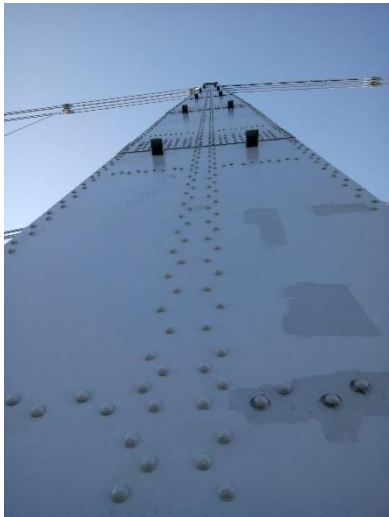






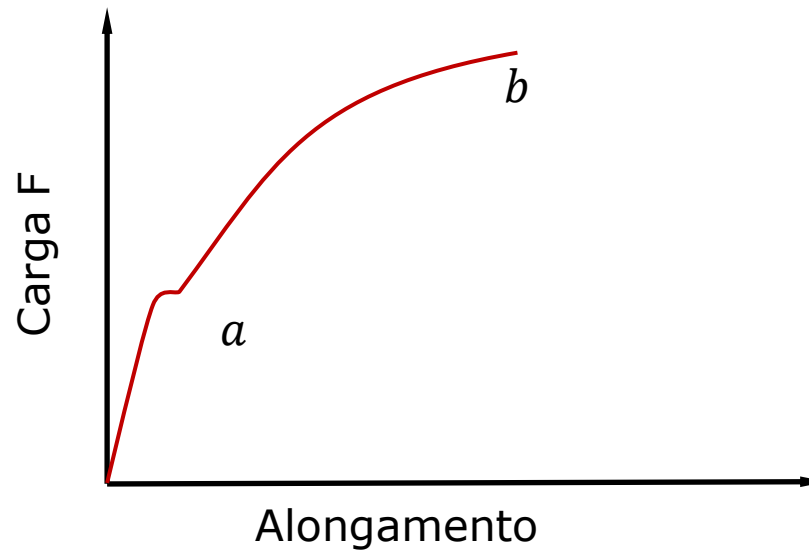
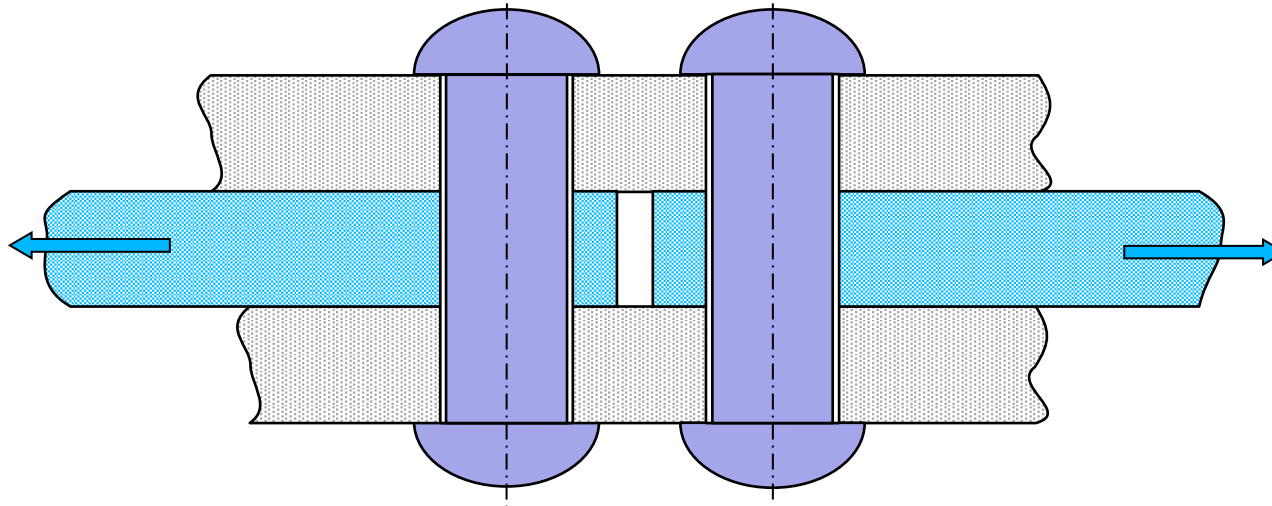


## Rebites



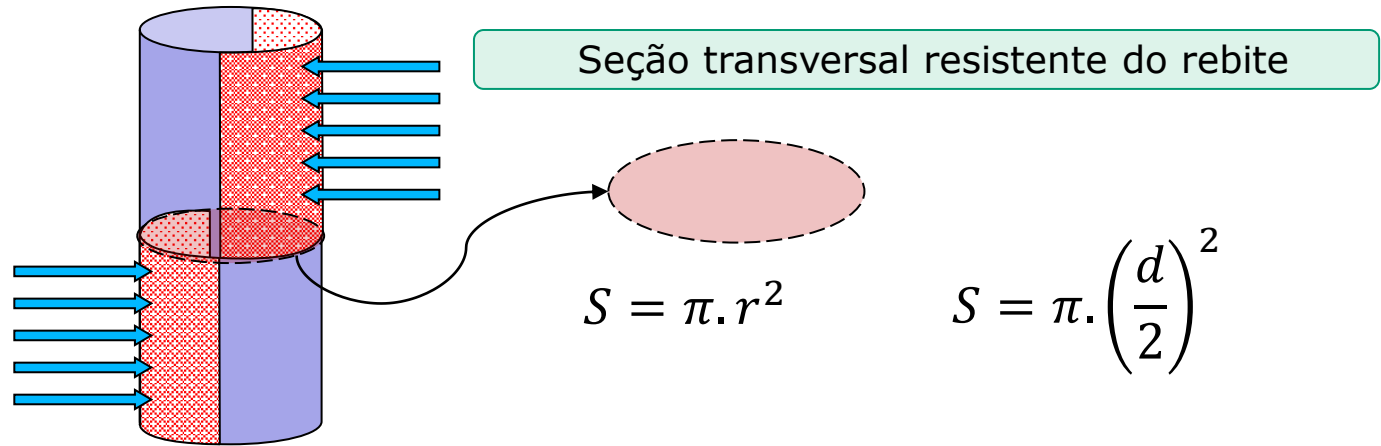
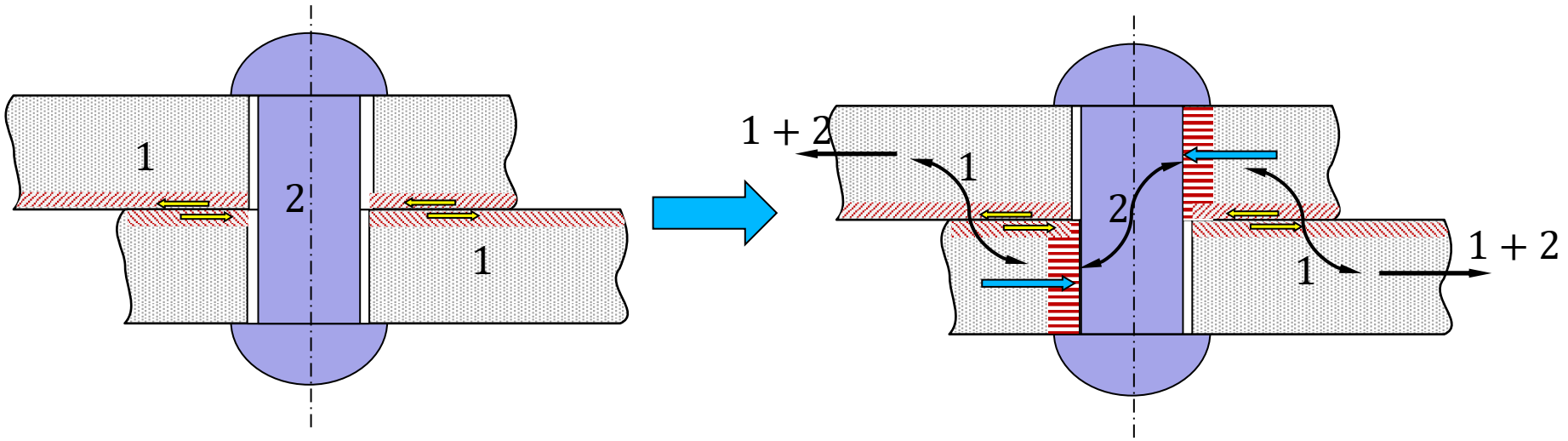


**Rebites**



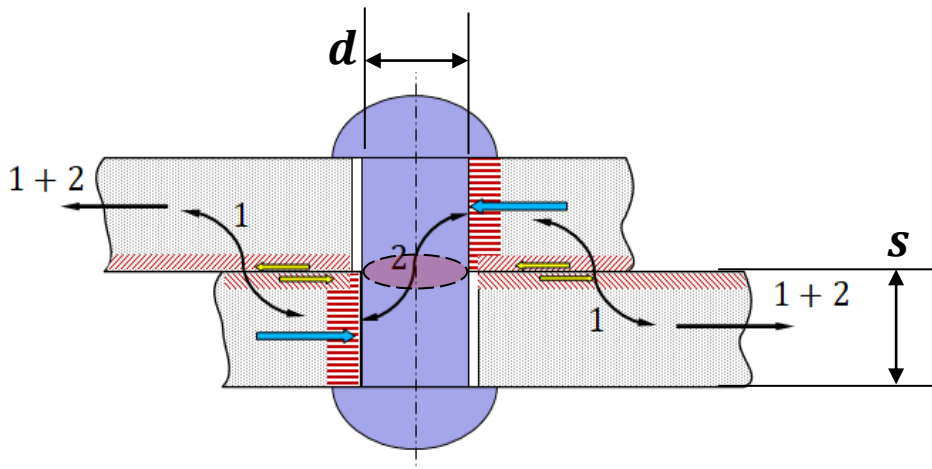


# Rebites





# Rebites



secção resistente ao cisalhamento

$$d = \frac{4 \sigma_l \cdot s}{\pi \tau_r}$$

como:  $\sigma_l \leq 2,5 \cdot \tau_r$  (experimental)

temos:  $d \leq 3,2 \cdot s$

Força Normal transmitida (N) de uma chapa para outra através do rebite

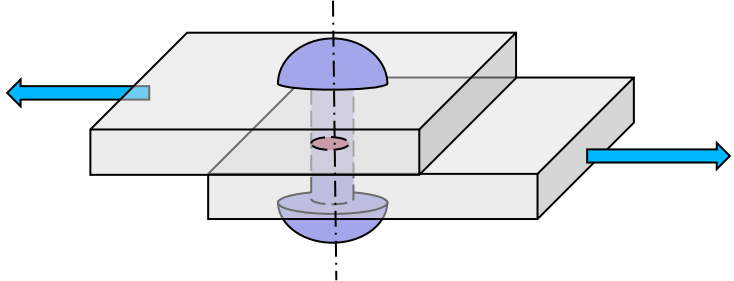
$$N = \mu \cdot \sigma_r \cdot S + \tau_r \cdot S$$

$$N = \tau_r \cdot S$$

$\tau_r \rightarrow$  tensão de cisalhamento

$$N = \sigma_l \cdot d \cdot s$$

$s \rightarrow$  espessura da chapa  
 $d \rightarrow$  diâmetro do rebite  
 $\sigma_l \rightarrow$  tensão média



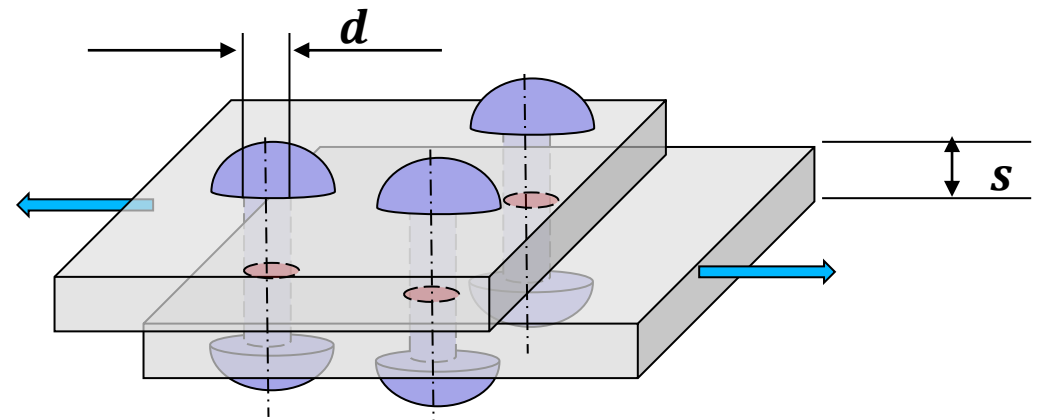
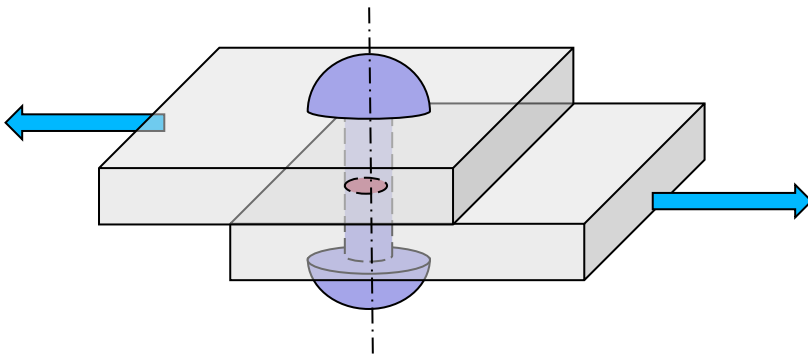




## Rebites

Número mínimo de rebite necessários

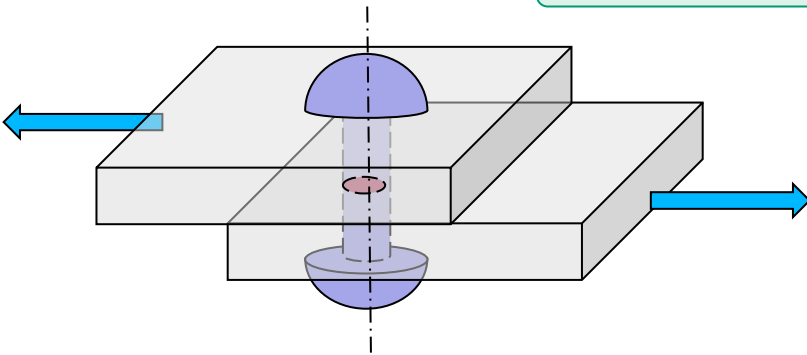
$$z = \frac{P}{N} = \frac{P}{\tau_r \cdot S}$$



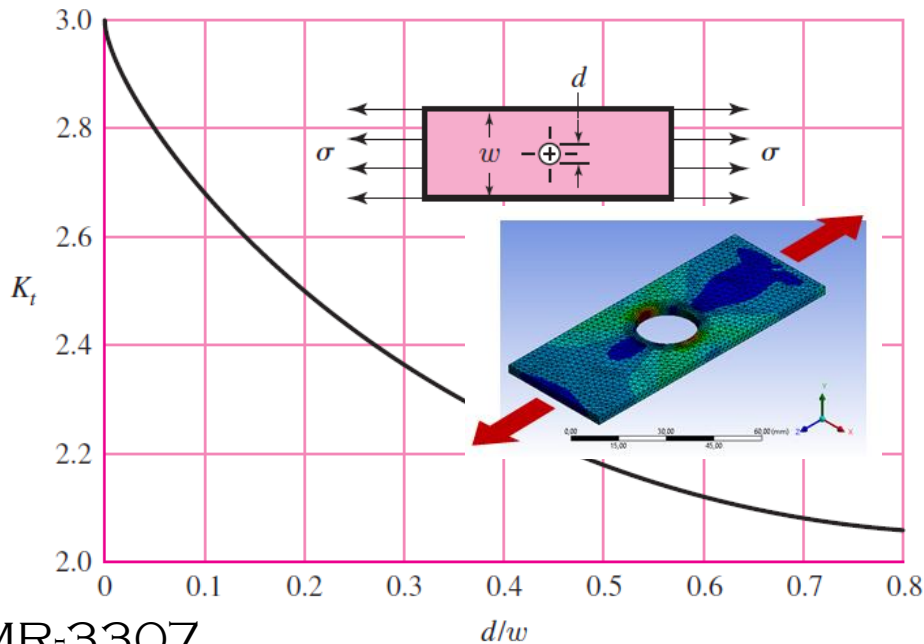


## Rebites

Os furos para os rebites



são concentradores de tensões



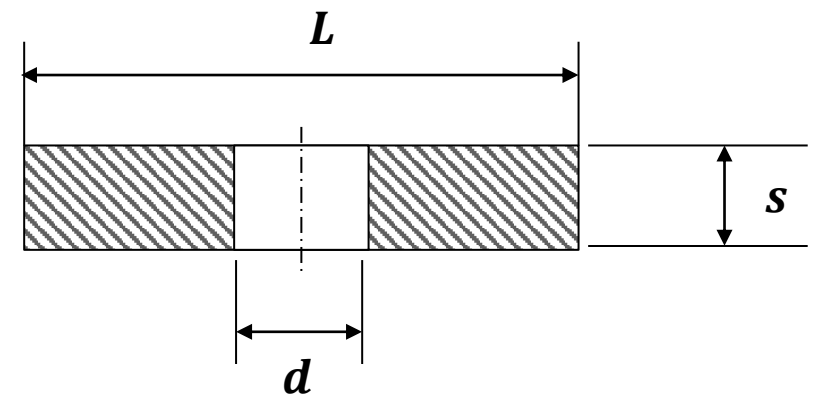
reduzem a seção transversal

então:  $P = z \cdot N$

$$S_n = S - z_g \cdot d \cdot s \text{ [cm}^2\text{]}$$

$z_g \rightarrow$  quantidade total de rebites

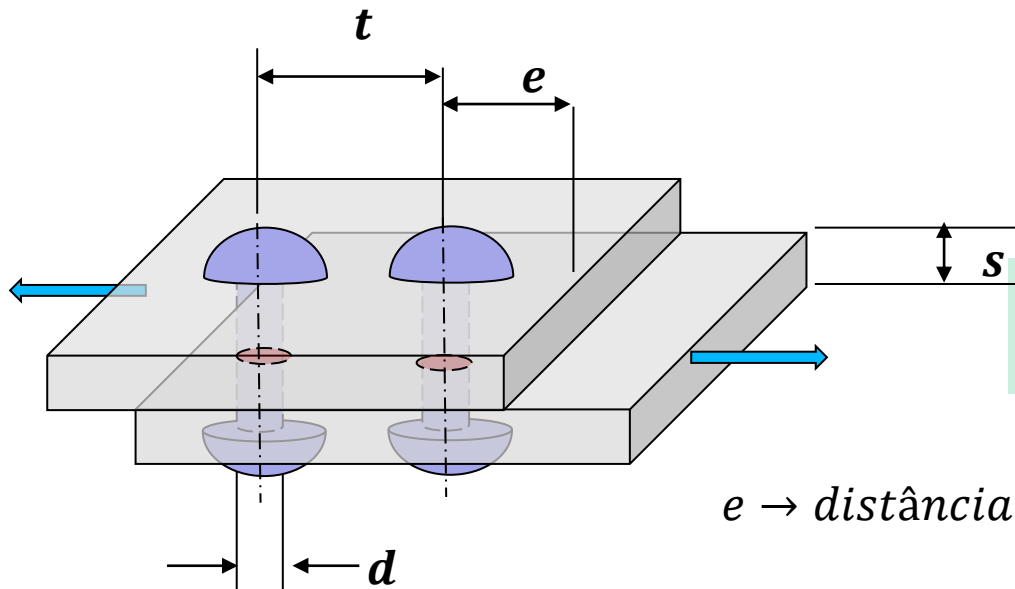
$s \rightarrow$  seção transversal útil da chapa





## Rebites

### Costuras rebitadas



$$N = \sigma_r \cdot (t - d) s'$$

$t \rightarrow$  passo dos rebites

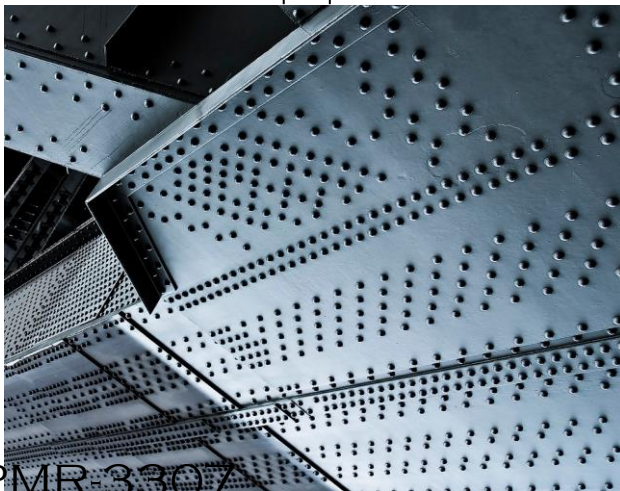
$$N = 2 \cdot \left( e - \frac{d}{s} \right) s \cdot \tau$$

$e \rightarrow$  distância do centro do furo até a borda da chapa

$$e' = \frac{\sigma_l \cdot d}{2 \cdot \tau} + \frac{d}{2}$$

$e' \rightarrow$  distância mínima do centro do furo até a borda da chapa

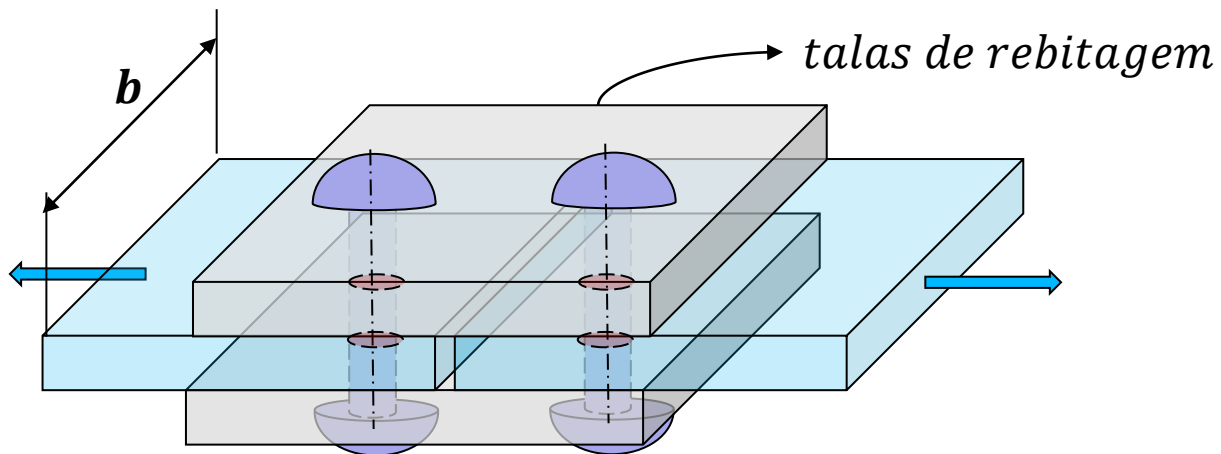
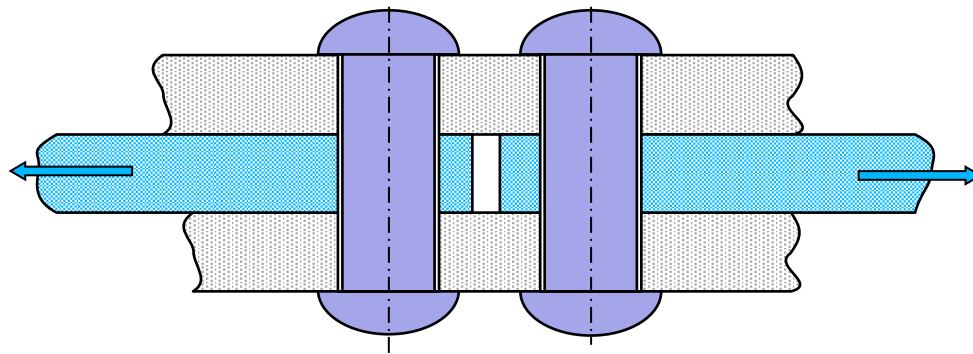
como:  $\sigma_l \leq 2,5 \cdot \tau_r \rightarrow e \geq 1,75 \cdot d$





## Rebites

junção de chapas múltiplas



Força aplicada por rebite

$$N = 2 \cdot \tau_r \cdot S$$

para:

$$\sigma_l \leq 2,5 \cdot \tau_r$$

$$d \geq 1,6 \cdot s$$

$$e \geq 1,75 \cdot d$$



## Rebites

### Considerações práticas

- Em estruturas rebitadas não se deve observar grandes deformações (escoamento) nas junções
- Quanto maior a rugosidade das chapas em contato melhor
- A união de duas ou mais chapas por rebites também estão sujeitas a flexão.
- A união de duas ou mais chapas por rebites com auxílio de talas de junção a resistência ao deslizamento é menor, principalmente se as chapas forem de espessura diferente. A menor pressão deve ser aplicada a menor chapa.



## Rebites

### Considerações práticas

- Havendo várias fileiras de rebites o limite de deslizamento é atingido primeiro nas fileiras mais externas

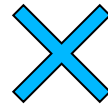


- A altura da haste do rebite é proporcional a espessura das chapas que estão sendo unidas
- A rebitagem feita por máquinas é melhor do que a feita manualmente



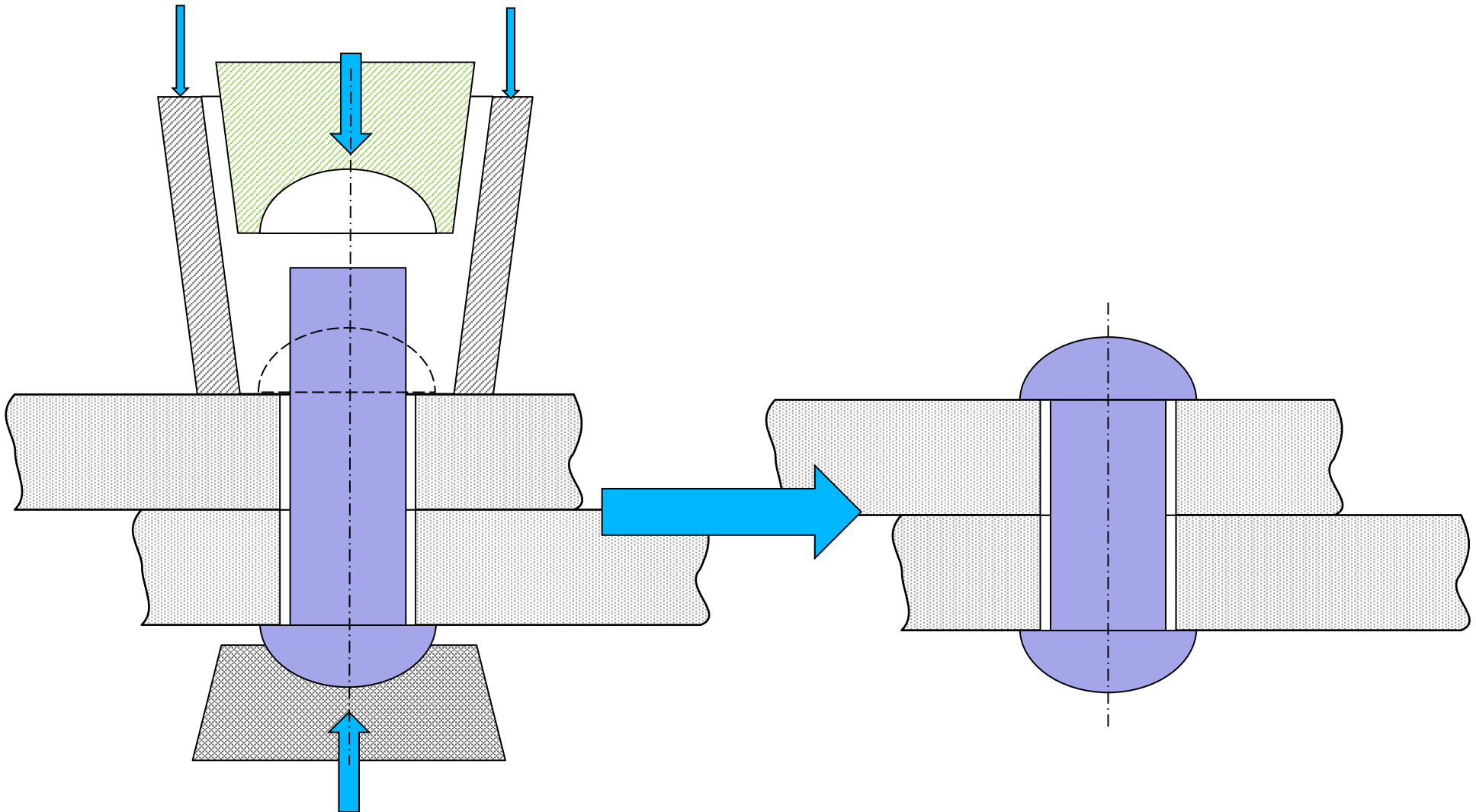
## Rebites

### Considerações práticas





## Rebites







## Rebitagem

<https://www.youtube.com/watch?v=5aTL0Jvrf4I>

<https://www.youtube.com/watch?v=WC5BAp2xvDc>



## Rebites

### Exemplos





**FIM**