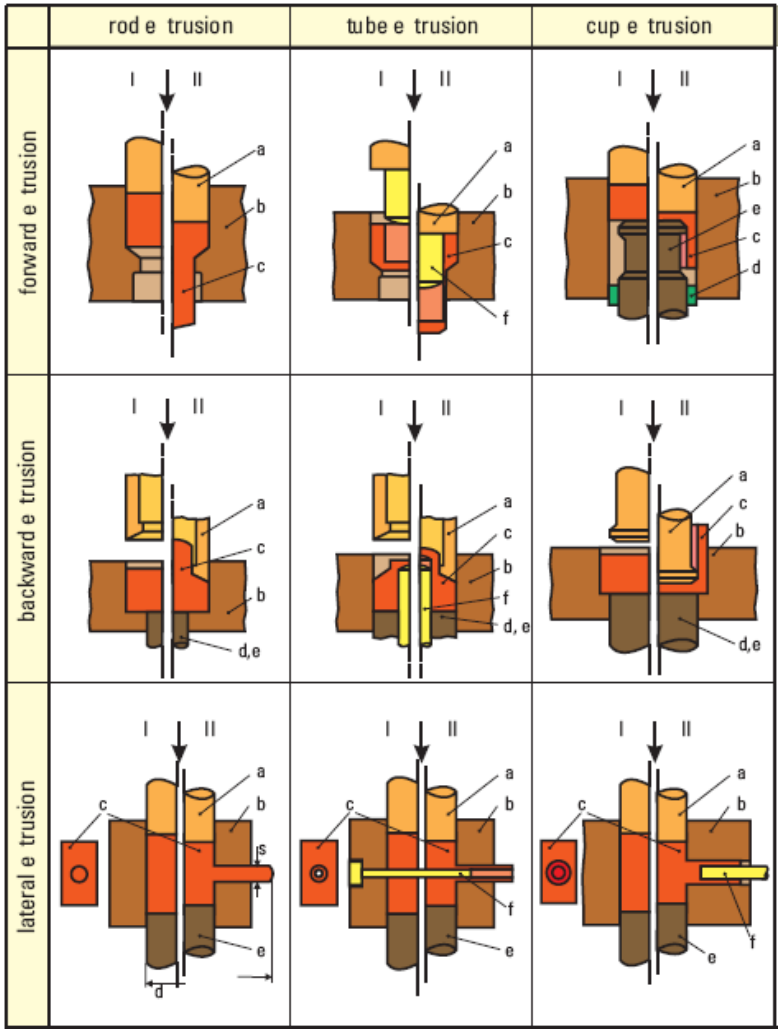
ISTISKIVANJE

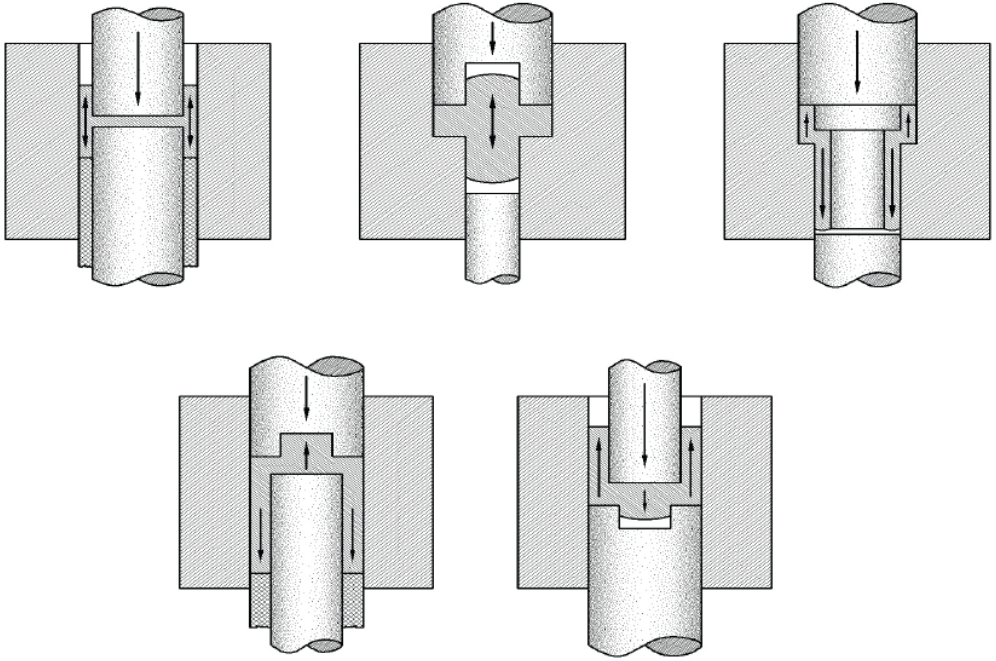
Istiskivanje je proces zapreminskog deformisanja pri kojem se materijal, pod dejstvom pritisnog opterećenja, dovodi u plastično stanje i primorava da ističe kroz otvore u alatu.

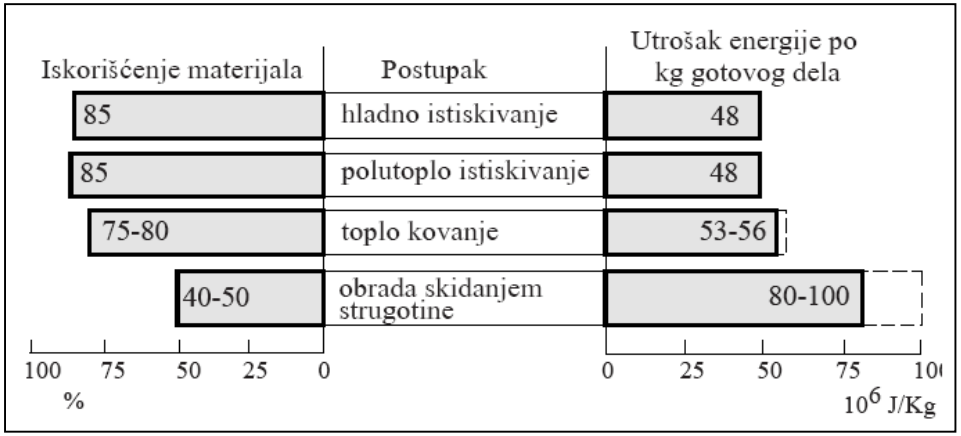
- hladno
- polu-toplo
- toplo

Osnovne vrste istiskivanja:

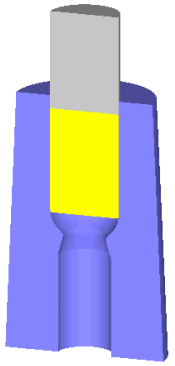
- istosmerno,
- suprotnosmerno
- radijalno
- kombinovano



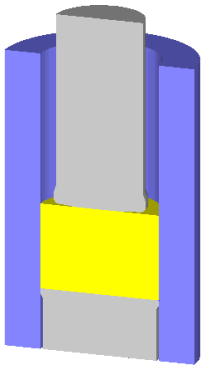




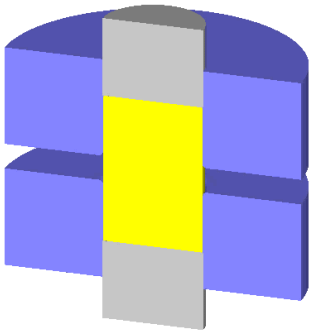
Open Die Extrusion



Backward Cup Extrusion



Lateral Extrusion



$D_{max} \approx 160$ mm

$L_{max} \approx 1200$ mm

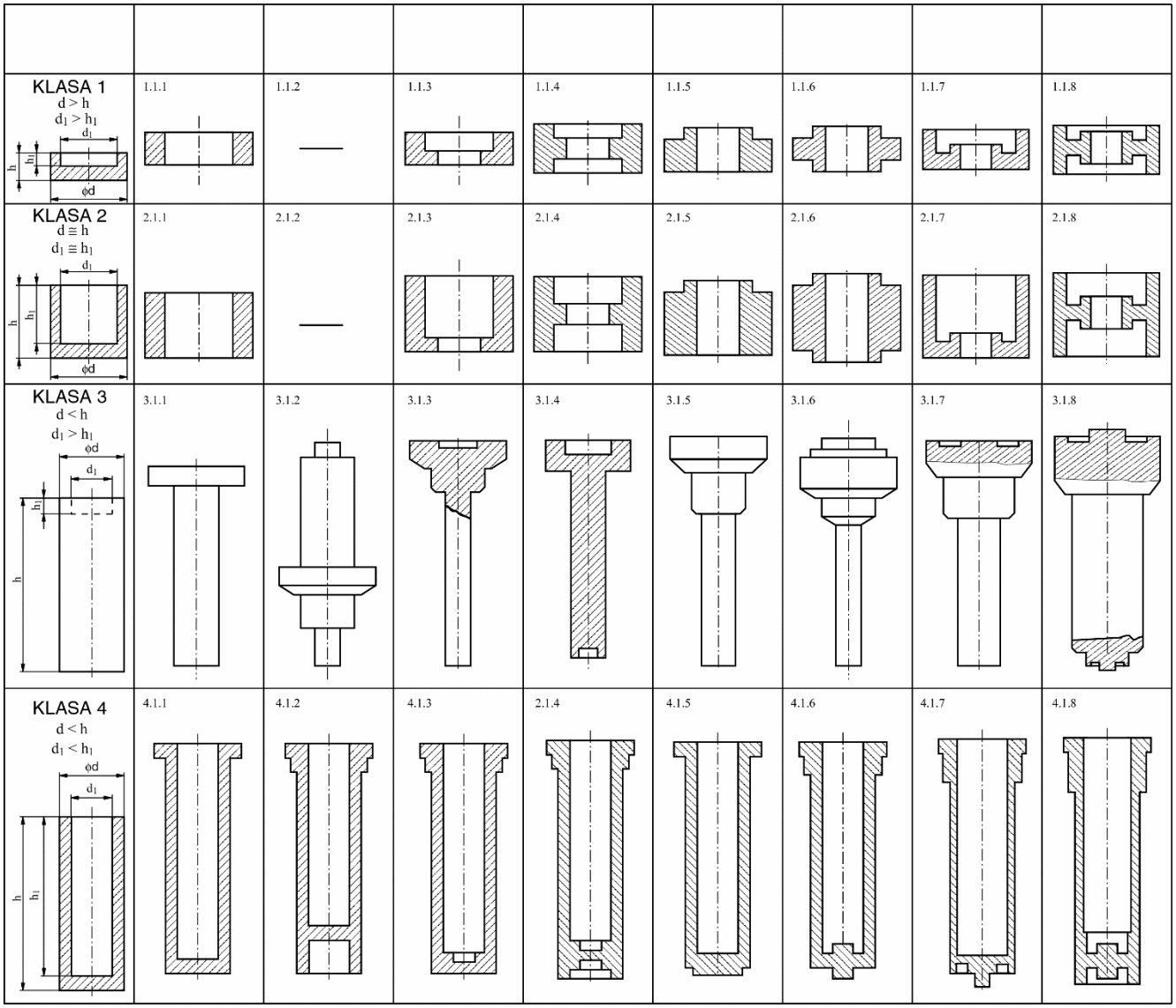
$D \leq 50$ mm; $L \leq 100$ mm

M=1g do 50 kg.

<u>Limitirajući faktori</u> :

- geometrijsko-konstruktivni
- obradivost materijala
- opterećenje alata
- ekonomski faktori

$p \leq 2500$ MPa



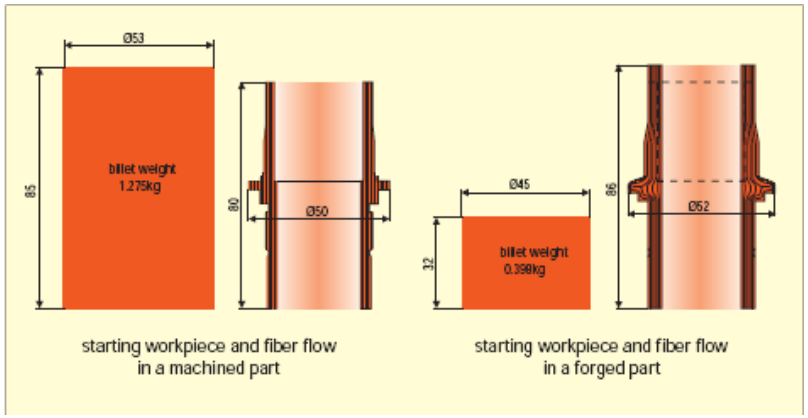


Table 6.4.1: Minimum economical batch sizes for solid forming when compared with machining

Weight	Production quantity per year	
	Cold forming	Warm forming
0.10 – 0.25 kg	200,000	300,000
0.25 – 0.75 kg	150,000	200,000
0.75 – 2.50 kg	25,000	100,000

Hladnim istiskivanjem se najčešće obrađuju:

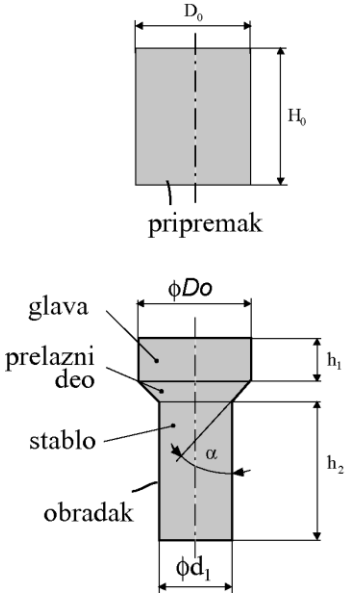
•čelici za cementaciju (Č 1121, Č 1221, Č 1321, Č 4120, Č 4320, Č 4321, Č 4721)

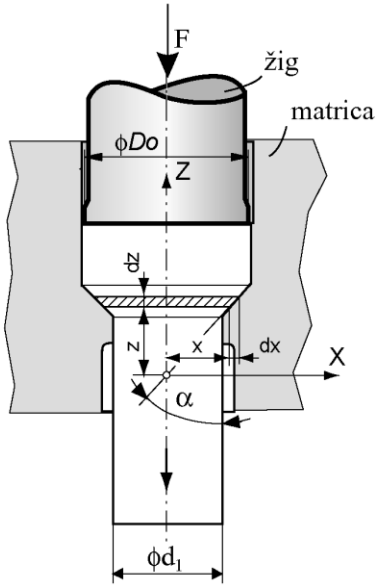
•čelici za poboljšanje (Č 1431, Č 1531, Č 4130, Č 4131, Č 4732)

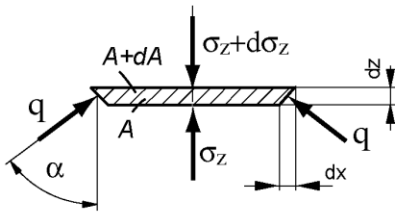
•niskougljenični čelici za hladnu obradu namenjeni termičkoj obradi (Č 0246, Č 0248…;) . Ovi čelici se koriste za zakovice, zavrtnjeve i sl.

•nerđajući čelici Č 4170, Č 4580

Istosmerno istiskivanje punih obradaka



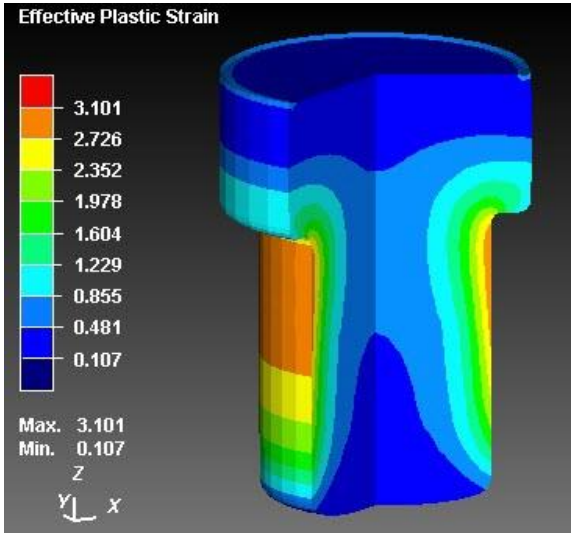




$$\varphi = \ln\frac{A_0}{A_1};$$

gde su $A_0 = \frac{\pi \cdot D_0^2}{4}$; $A_1 = \frac{\pi \cdot d_1^2}{4}$

$$\varphi = \ln\left(\frac{D_0}{d_1}\right)^2 = 2\ln\frac{D_0}{d_1}$$



$$F = F_{id} + F_{t1} + F_{t2} + F_{t3}$$

F_{id} – deformaciona sila idealne deformacije – bez učešća trenja na kontaktnim površinama i bez unutrašnjeg trenja

F_{t1} – komponenta deformacione sile koja je potrebna za savladavanje otpora trenja na kontaktnim površinama u konusnom delu matrice

F_{t2} – komponenta deformacione sile koja je potrebna za savladavanje otpora unutrašnjeg (intermolekularnog) trenja usled promene pravca toka vlakana materijala

F_{t3} – komponenta deformacione sile potrebna za savlađivanje otpora trenja na kontaktnim površinama u cilindričnom delu matrice

Diferencijalna jednačina ravnoteže

$$(\sigma_z + d\sigma_z)(A + dA) - \sigma_z A - 2\pi x \frac{dz}{\sin\alpha} q \sin\alpha = 0$$

$A = \pi x^2$ i $dA = 2\pi x\, dx$

$z = x\,tg\alpha$ i $dz = dx\,tg\alpha$

$$\pi x^2 d\sigma_z + 2\pi \cdot x \cdot dx \cdot \sigma_z - 2\pi x\, dx\, q = 0$$

$$x\, d\sigma_z + 2dx(\sigma_z - q) = 0$$

$$q - \sigma_z = K; \quad q = K + \sigma_z$$

$$x\, d\sigma_z - 2dx\, K = 0$$

$$\frac{\sigma_z}{K} = 2\ln x + C$$

$x = \frac{d_1}{2}$; $\sigma_z = 0$

$$c = -2\ln\frac{d_1}{2} = -2\ln r_1$$

$$\sigma_z = 2K\ln\frac{x}{r_1} = K\ln\left(\frac{x}{r_1}\right)^2$$

$$F_{id} = A_0 \cdot \sigma_z = A_0 \cdot K_{sr} \ln\frac{D_0^2}{d_1^2} = A_0 \cdot K_{sr} \cdot \varphi$$

$$K_{sr} = \frac{K_0 + K_1}{2}$$

$$F_{t_1} = F_{id} \cdot \frac{\mu}{\alpha}$$

$$F_{t_2} = \frac{2}{3}\frac{\alpha}{\varphi} \cdot F_{id}$$

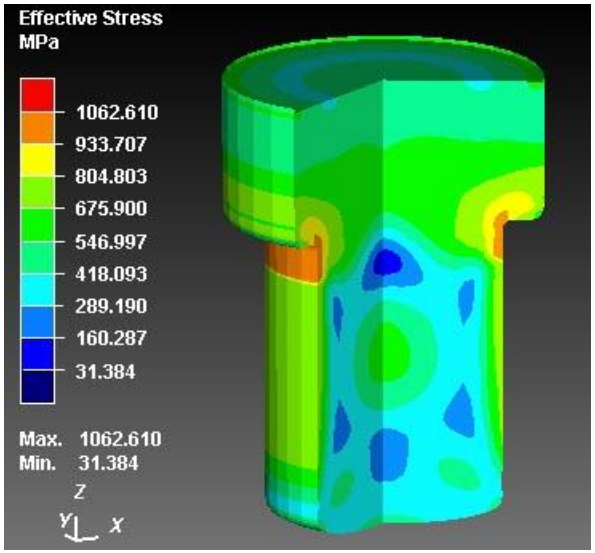
$$F_{t_3} = A \cdot \tau_k = A \cdot \mu \cdot K_0 = 4 \cdot \mu \cdot K_0 \frac{h_0}{D_0} A_0$$

$A = \pi \cdot D_0 \cdot l_0$ $\quad \tau_k = \mu \cdot K_0$ $\quad A_0 = \frac{\pi \cdot D_0}{4}$

Ukupna sila kod istosmernog istiskivanjae

$$F_{uk} = A_0 \cdot K_{sr} \cdot \varphi + A_0 \cdot K_{sr} \cdot \varphi \left(\frac{\mu}{\alpha} + \frac{2}{3} \frac{\alpha}{\varphi} \right) + 4 \cdot \mu \cdot K_0 \frac{h_0}{D_0} A_0 =$$

$$= A_0 \cdot K_{sr} \cdot \varphi \left(1 + \frac{\mu}{\alpha} + \frac{2}{3} \frac{\alpha}{\varphi} \right) + 4 \cdot \mu \cdot K_0 \frac{h_0}{D_0} A_0$$



Srednji specifični pritisak

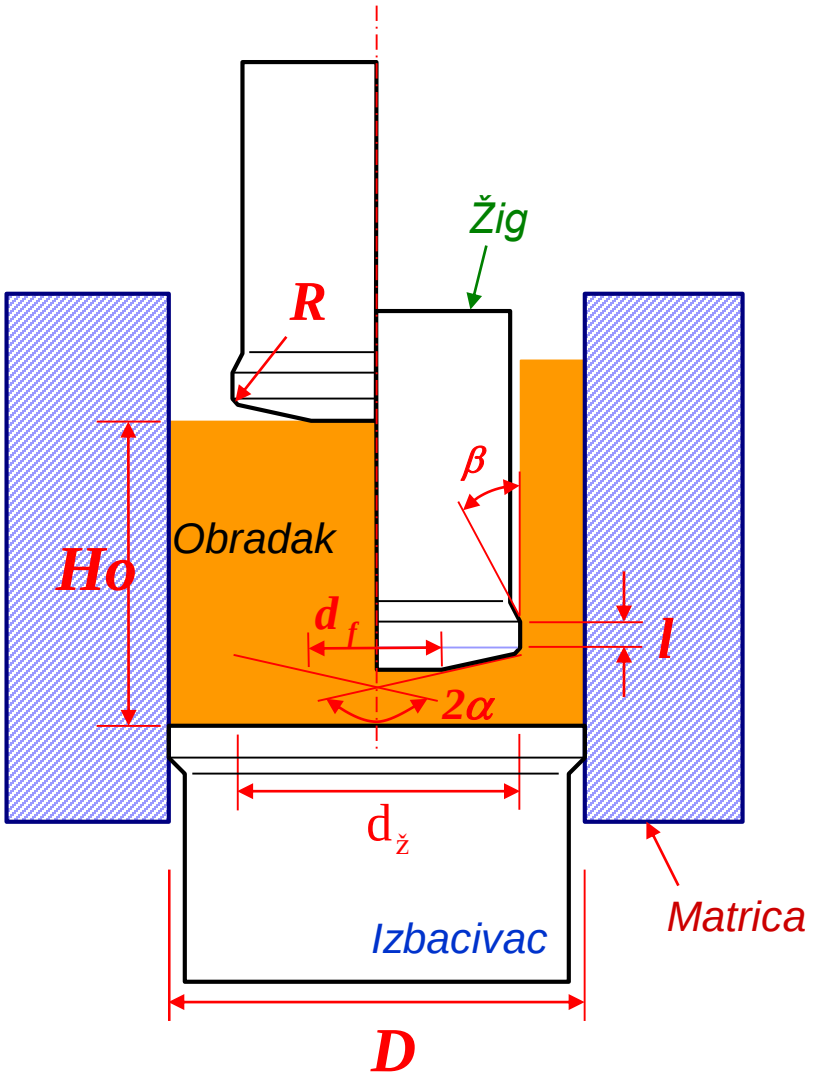
$$p = \frac{F_{uk}}{A_0}$$

Deformacioni rad

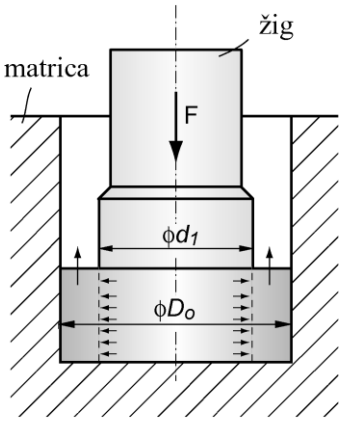
$$W = F_{uk} \left(h_0 - h_1 \right)$$

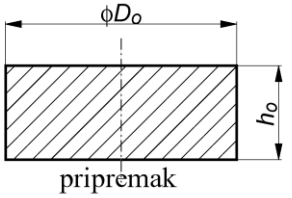
SUPROTNOSMERNO ISTISKIVANJE

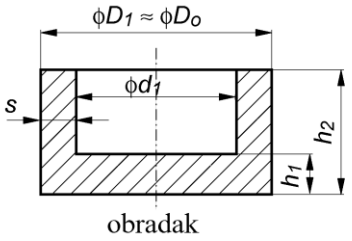
- *Unutrašnji prečnik matrice,* D
- *Visina obratka,* Ho
- *Prečnik žiga,* $d_{ž}$
- *Prečnik ravnog dela čela ,* d_f
- *Ugao čela žiga,* 2α
- *Dužina glave žiga,* l
- *Radijus žiga,* R
- *Izlazni ugao,* β



Suprotnosmerno istiskivanje



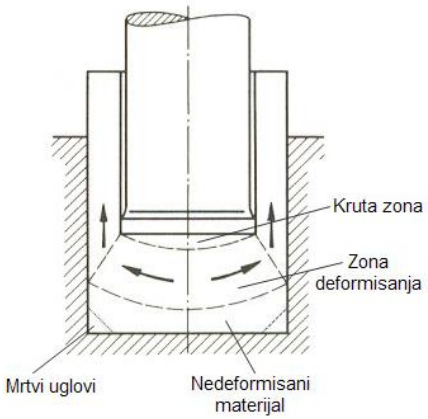


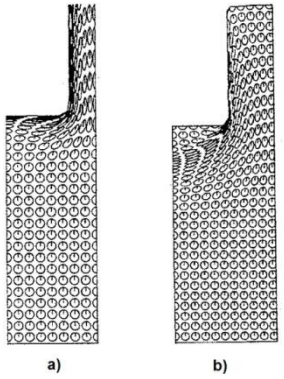


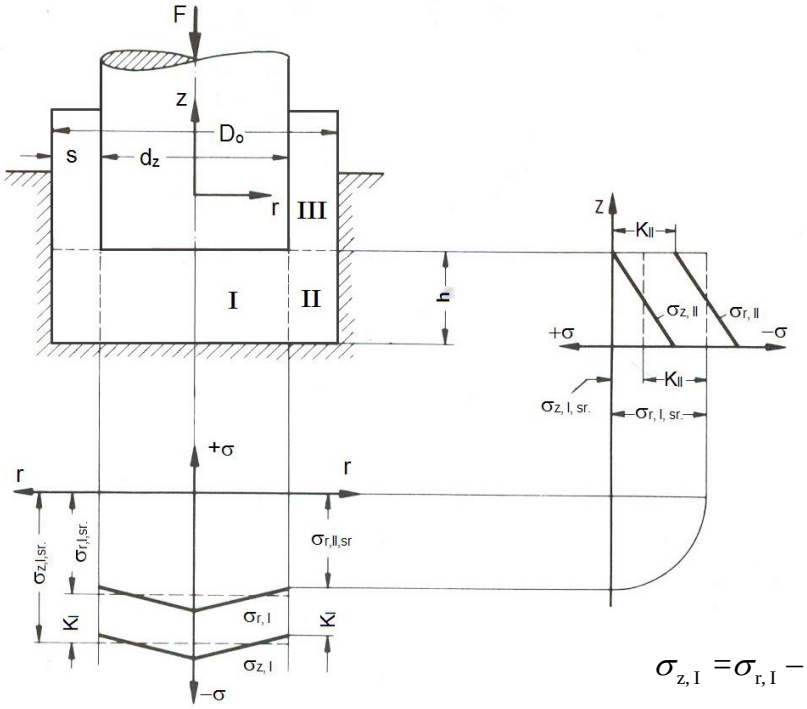
$$\varphi_1 = \ln\frac{h_0}{h_1} \qquad \varphi_2 = \frac{d_1}{8s}\ln\frac{h_0}{h_1}$$

$$\varphi = \varphi_1 + \varphi_2 = \left(1+\frac{d_1}{8s}\right)\ln\frac{h_0}{h_1}$$

$$\varphi = \ln\frac{A_0}{A_1} = \ln\frac{D_0^2}{D_0^2 - d_1^2}$$





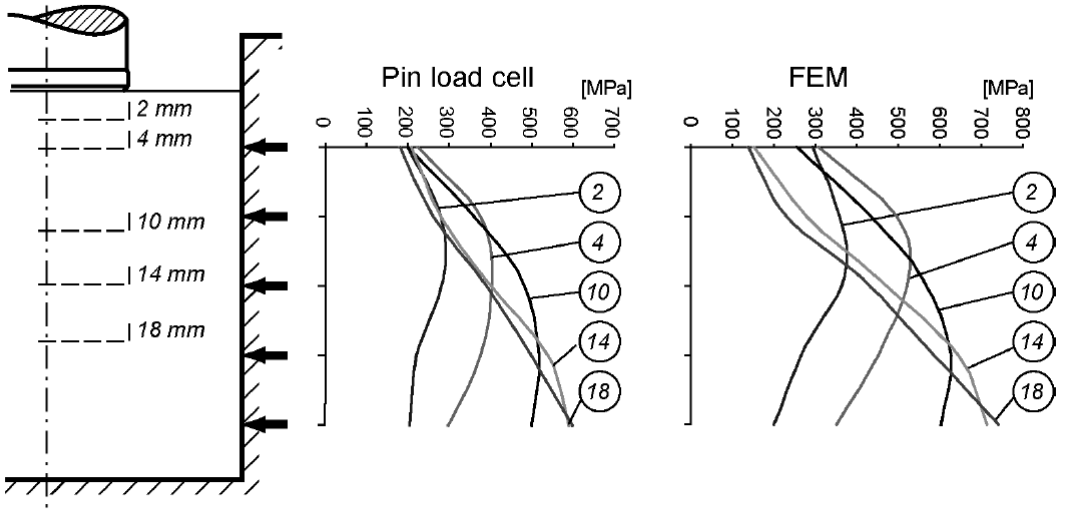


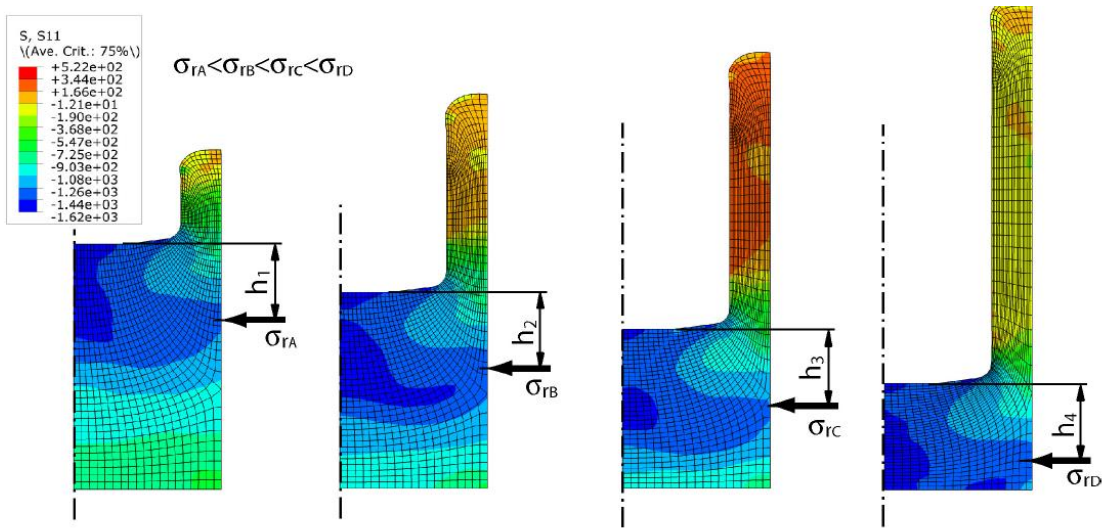
$$\sigma_{z,II} = -\frac{2\cdot\mu_2\cdot K_2}{s}(h-z)$$

$$\sigma_{r,II} = \sigma_{z,II} - K_2 = -K_2\left[\frac{2\cdot\mu_2}{s}(h-z)+1\right]$$

$$\sigma_{r,I} = -\frac{\mu_1\cdot K_1}{h}\left(\frac{d_z}{2}-r\right)+K_2\left(1+\mu_2\cdot\frac{h}{s}\right)$$

$$\sigma_{z,I} = \sigma_{r,I} - K_1 = -K_1\left[\frac{\mu_1\cdot}{h}\left(\frac{d_z}{2}-r\right)+1\right]-K_2\left(1+\mu_2\cdot\frac{h}{s}\right)$$


2 mm
4 mm
10 mm
14 mm
18 mm
Pin load cell
[MPa]
0
100
200
300
400
500
600
700
2
4
10
14
18
FEM
[MPa]
0
100
200
300
400
500
600
700
800
2
4
10
14
18


S, S11
\(Ave. Crit.: 75%\)
+5.22e+02
+3.44e+02
+1.66e+02
-1.21e+01
-1.90e+02
-3.68e+02
-5.47e+02
-7.25e+02
-9.03e+02
-1.08e+03
-1.26e+03
-1.44e+03
-1.62e+03
σrA<σrB<σrC<σrD
h1
σrA
h2
σrB
h3
σrC
h4
σrD

Ukupni srednji specifični pritisak na žig pri suprotnosmernom istiskivanju

$$p_1 = K_1\left(1+\frac{\mu}{3}\frac{d_1}{h_1}\right)$$

$$p = p_1 + p_2 = K_1\left(1+\frac{\mu}{3}\frac{d_1}{h_1}\right)+K_2\left[1+\frac{h_1}{s}\left(0.25+\frac{\mu}{2}\right)\right]$$

$$p_2 = K_2\left[1+\frac{h_1}{s}\left(0.25+\frac{\mu}{2}\right)\right]$$

$$K_1 = f(\varphi_1) \qquad \varphi_1 = \ln\frac{h_0}{h_1} \qquad K_1 \approx K_0$$

$$K_2 = f(\varphi_2) \qquad \varphi_2 = \frac{d_1}{8s}\ln\frac{h_0}{h_1} \qquad K_2 = K(\varphi)$$

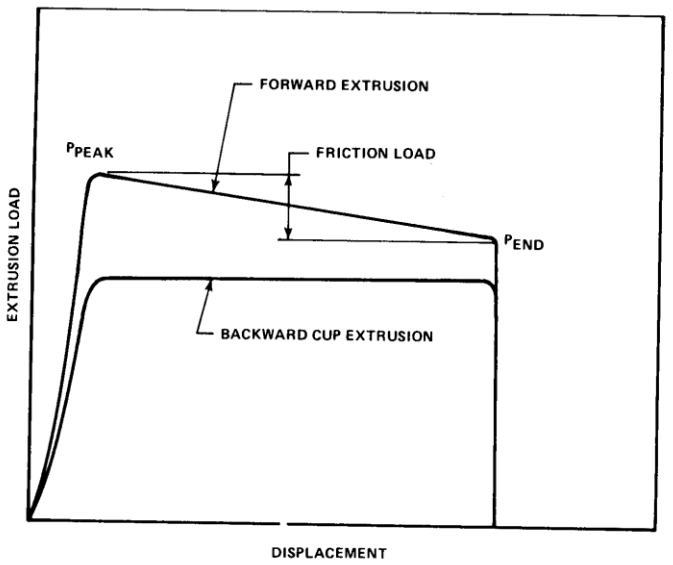
$$\varphi = \ln\frac{A_0}{A_1} = \ln\frac{D_0^2}{D_0^2 - d_1^2}$$

Ukupna deformaciona sila

$$F = A\cdot p = \frac{d_1^2\cdot\pi}{4}\left[K_0\left(1+\frac{\mu}{3}\frac{d_1}{h_1}\right)+K_1\left[1+\frac{h_1}{s}\left(0.25+\frac{\mu}{2}\right)\right]\right]$$

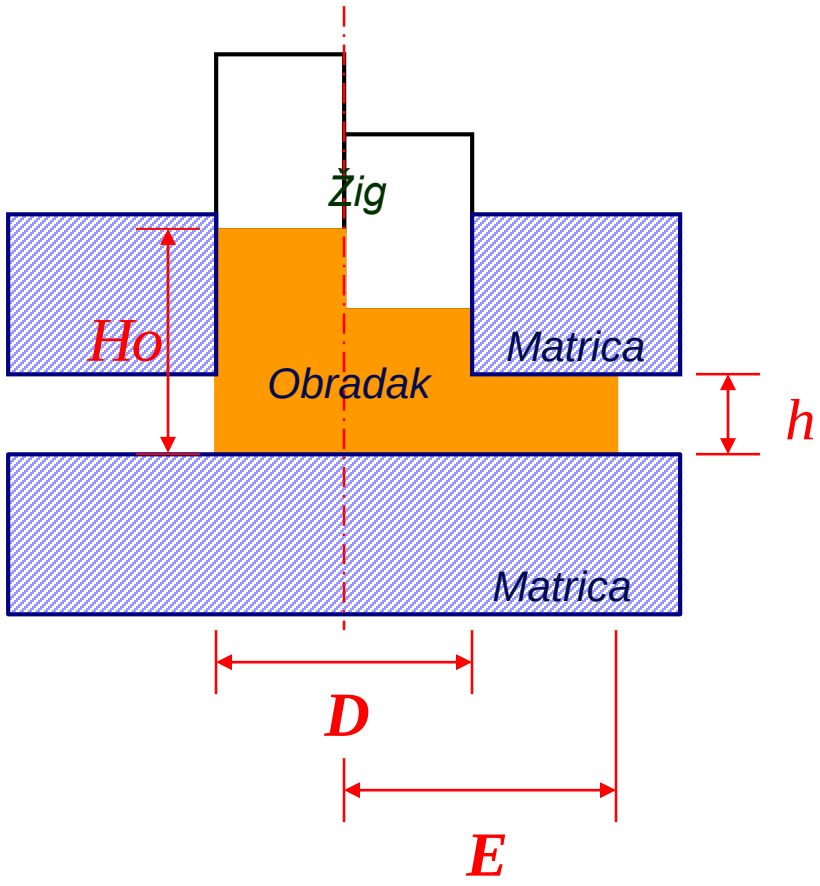
Deformacioni rad

$$W = F_{uk}\left(h_0 - h_1\right)$$



RADIJALNO ISTISKIVANJE

- *Prečnik matrice,* D
- *Visina pripremka,* Ho
- *Visina istisnutog dela,* h
- *Prečnik istisnutog dela,* E



Faktori koji utiču na deformacionu silu u procesu suprotnosmernog istiskivanja

- Napon tečenja

$$\bar{\sigma} = f\left(\bar{\varepsilon}, \dot{\bar{\varepsilon}}, T, S\right)$$

$\bar{\varepsilon}$ Efektivna deformacija
$\dot{\bar{\varepsilon}}$ Brzina deformacije
T Temperatura
S Mikrostruktura

→ Materijal

- Redukcija površine

$$\%\mathrm{R.P.} = \mathrm{f}\left(\mathrm{D}, \mathrm{d}\right)$$

- Ugao čela žiga 2α

→ Geometrija alata

- Visina pripremka Ho
- Prečnik D

→ Dimenzije pripremka

- *Max & Min Redukcija površine:*

$$20 \sim 25\% \leq \%\boldsymbol{R.P.} \leq 70 \sim 75\%$$

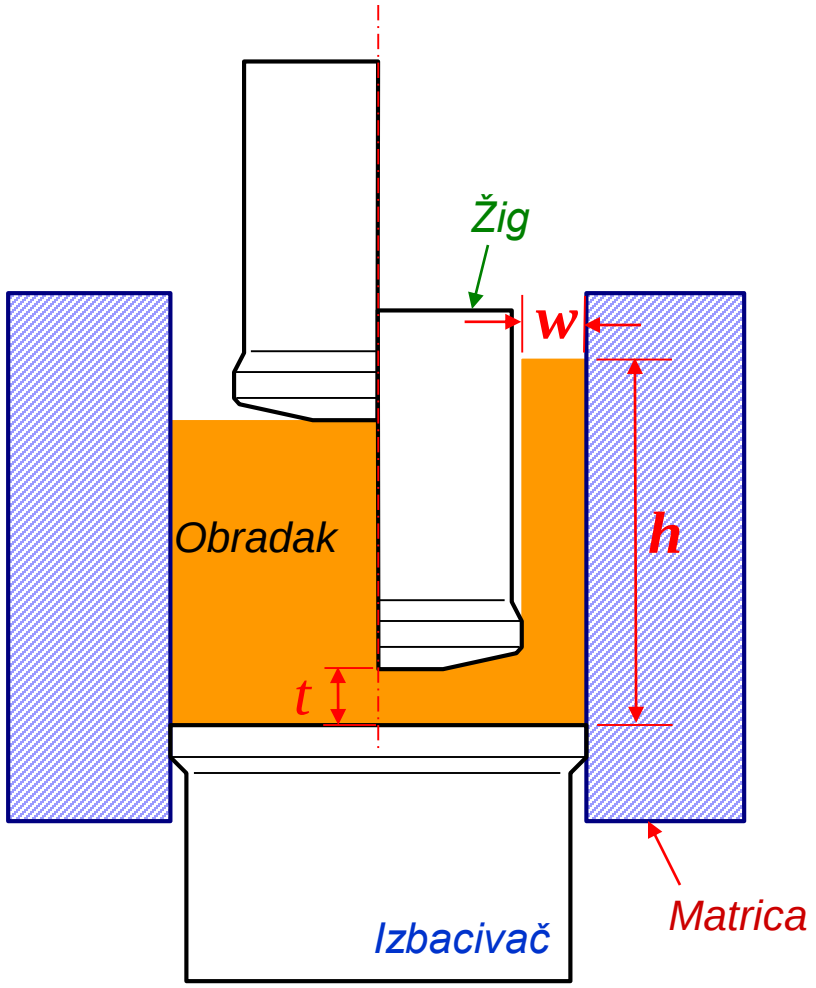
$$\%\boldsymbol{R.P.} = \frac{\boldsymbol{d}_{\check{z}}^{2}}{\boldsymbol{D}^{2}} \times 100$$

- *Max dubina utiskivanja:*

$$\boldsymbol{h} = 2 \sim 3 \times \boldsymbol{d}_{\check{z}}$$

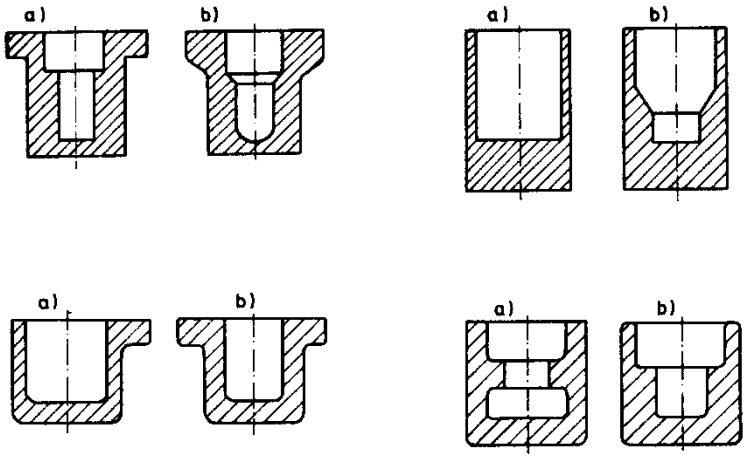
- *Min debljina dna:*

$$\boldsymbol{t} = \boldsymbol{1} \sim \boldsymbol{1.5} \times \boldsymbol{w}$$



Projektovanje tehnologije hladnog istiskivanja

1. Analiza tehnologičnosti konstrukcije dela



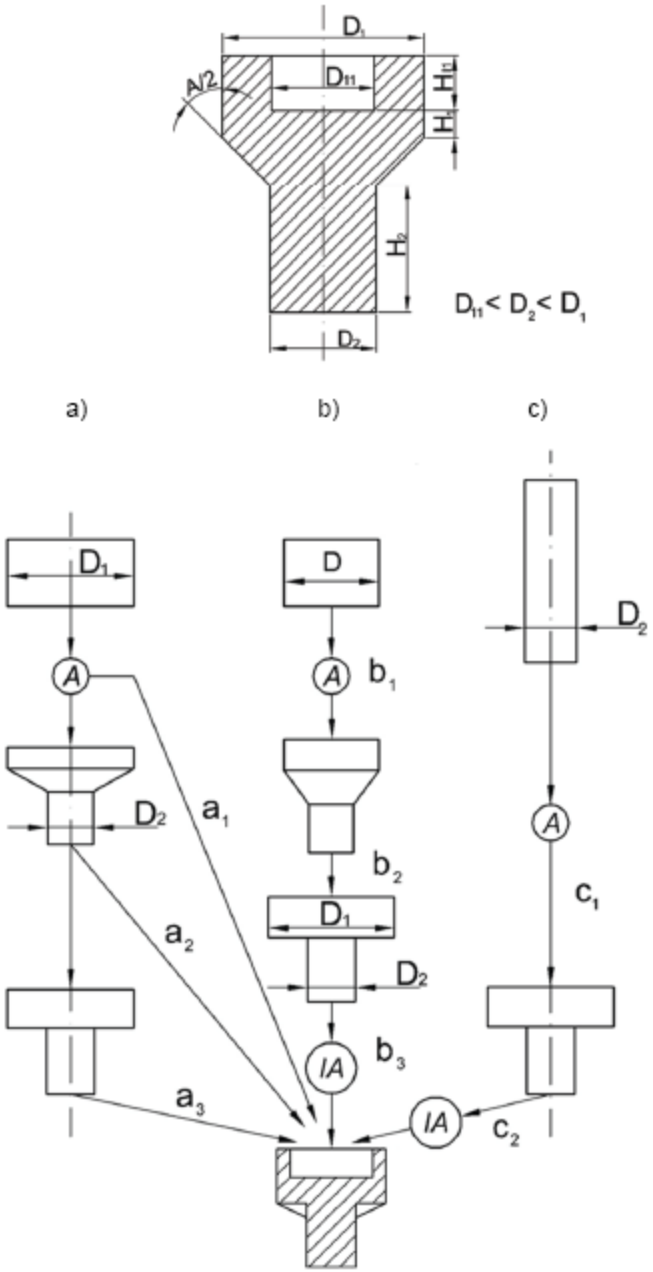
2. Određivanje oblika i dimenzija pripremka i način njegove izrade

$$V_p = V_o = \text{const.}$$

- ❑ Pripremci oblika šipke (okrugli, kvadratni šestougaoni i pravougaoni presek)
- ❑ Pločasti pripremci

a) strugovima (automati)
b) testerama
c) makazama

→ d) presama (razdvajanje)

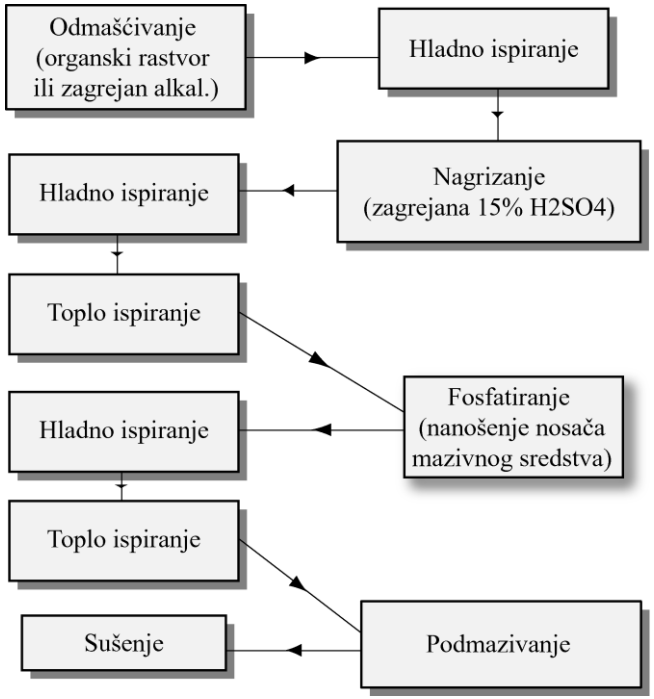


a) spoljašnji prečnik pripremka jednak je najvećem prečniku obratka (D1)

b) prečnik pripremka je između najvećeg i najmanjeg prečnika obrade D2<D<D1

c) prečnik pripremka jednak je najmanjem prečniku obratka (D2).

3. Podmazivanje u procesu hladnog istiskivanja



Debljina sloja
- 1–15 μm (fosfatni sloj)
- 5–8 μm (oksalat).

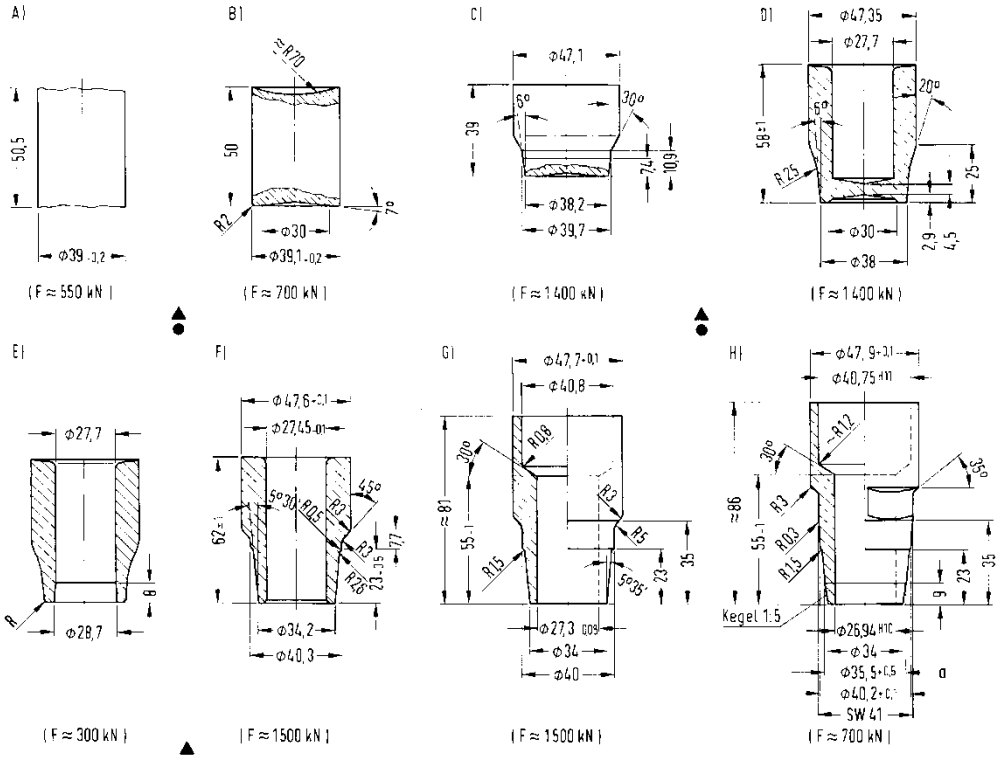
Proces		Mazivno sredstvo			
		Čelik	Nerđajući čelik	Aluminijum i njegove legure	Bakar i njegove legure
Sabijanje	lako	Mi + EP	Mi + EP	mast, ulje	nije potrebno
	teško	Ph + sapun Ph + MoS_2	Ox + sapun	Lanolin	Lanolin + sapun
Hladno istiskivanje	lako	Ph + Mi + EP	Mi + hlorparafin	Lanolin sapun	nije potrebno
	teško	Ph + sapun Ph + MoS_2 Ph + sapun + MoS_2	Ox + sapun MoS + lak Cu + Mi	Ph + sapun	Sapun + masti + ulje + grafit

sapun → metalni sapuni ("tehnička sapunica")
Mi – mineralno ulje; EP – aditiv za visoke pritiske; Ph – fosfatni sloj
Ox – oksalatni sloj; Cu – bakarni sloj

4. Definisanje operacija istiskivanja

Kriterijumi za određivanje broja operacija:

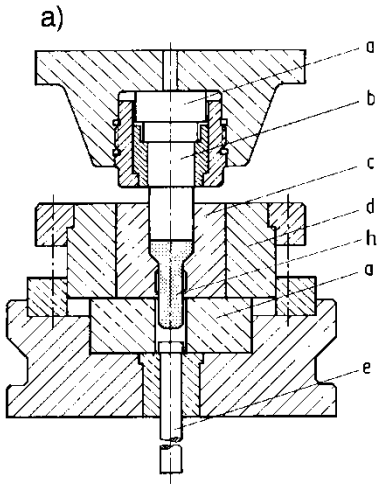
- dozvoljena veličina deformacije u jednoj operaciji
- formiranje parcijalnih zapremina obrade
- opterećenje alata

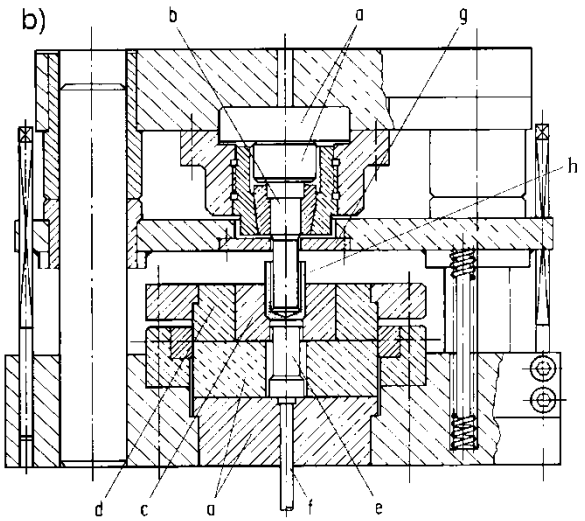


▲ meko žarenje
● fosfatiranje

A – odsecanje iz šipke
B – kalibrisanje
C – sabijanje
D – suprotnosmerno istiskivanje
E – probijanje dna
F – istosmerno istiskivanje šipljih obradaka
G – kombinovano istiskivanje
H – završno istiskivanje

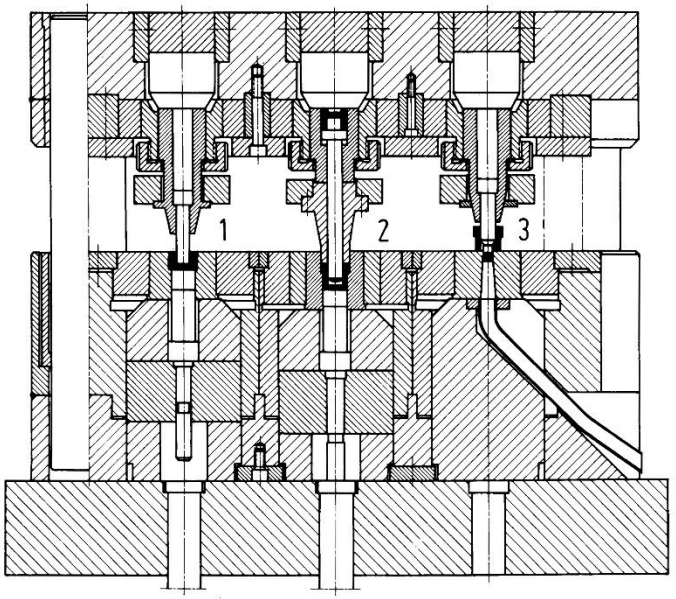
Alati za hladno istiskivanje

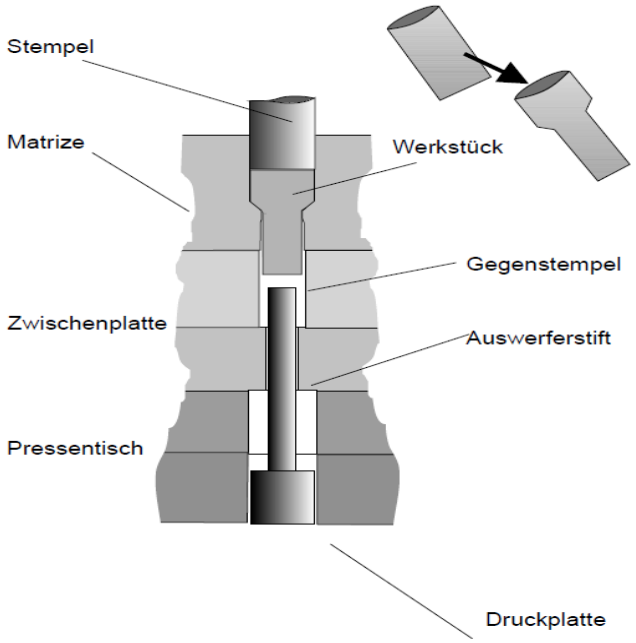




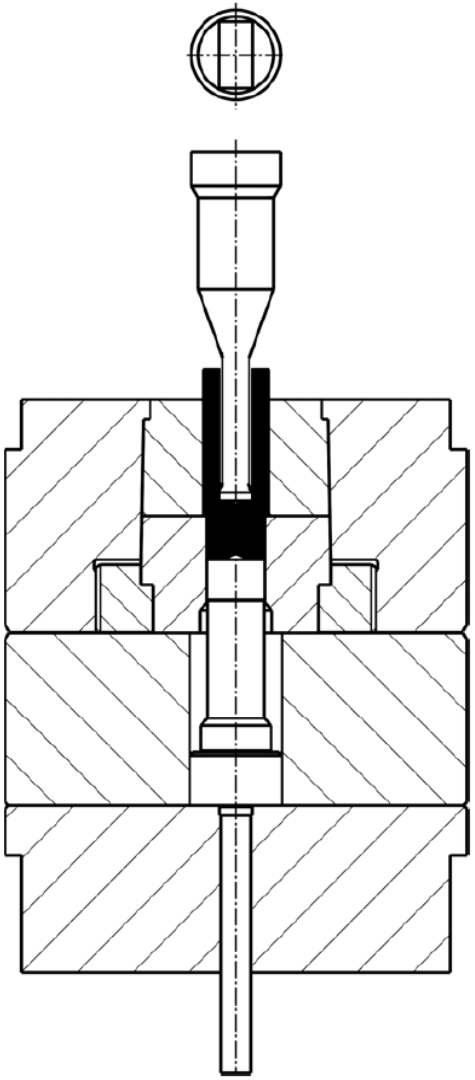
Alat za a) istosmerno, b) suprotnosmerno istiskivanje

Višepozicioni alat





Primeri alata za hladno istiskivanje



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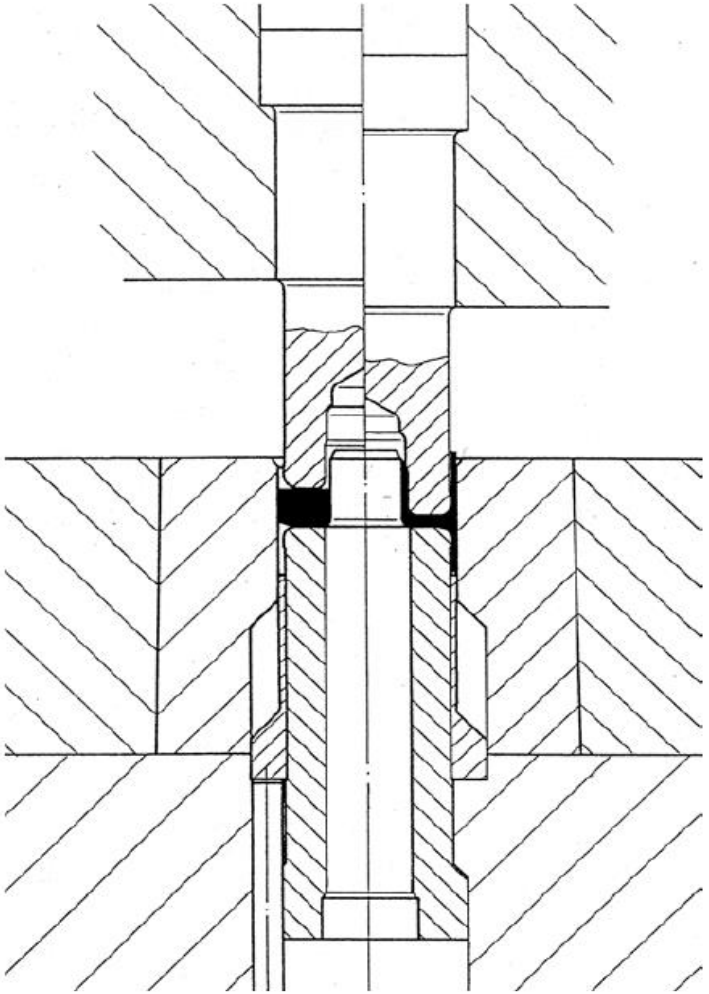

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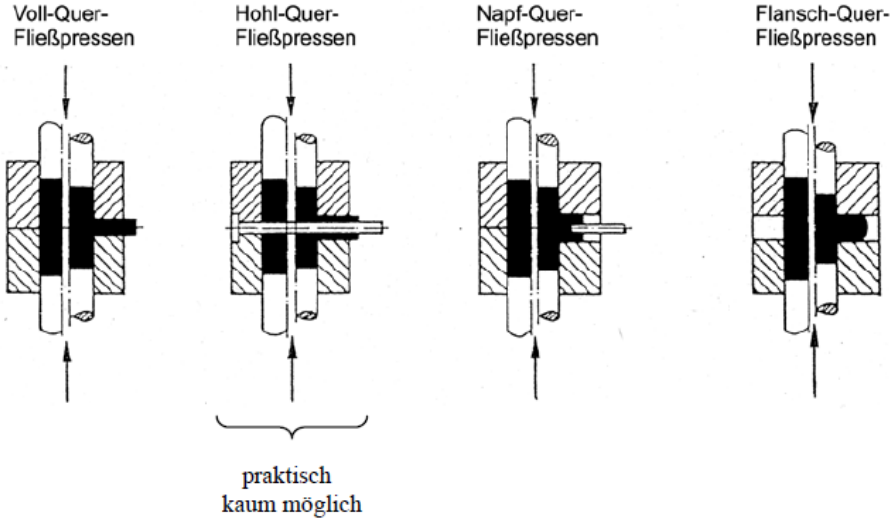
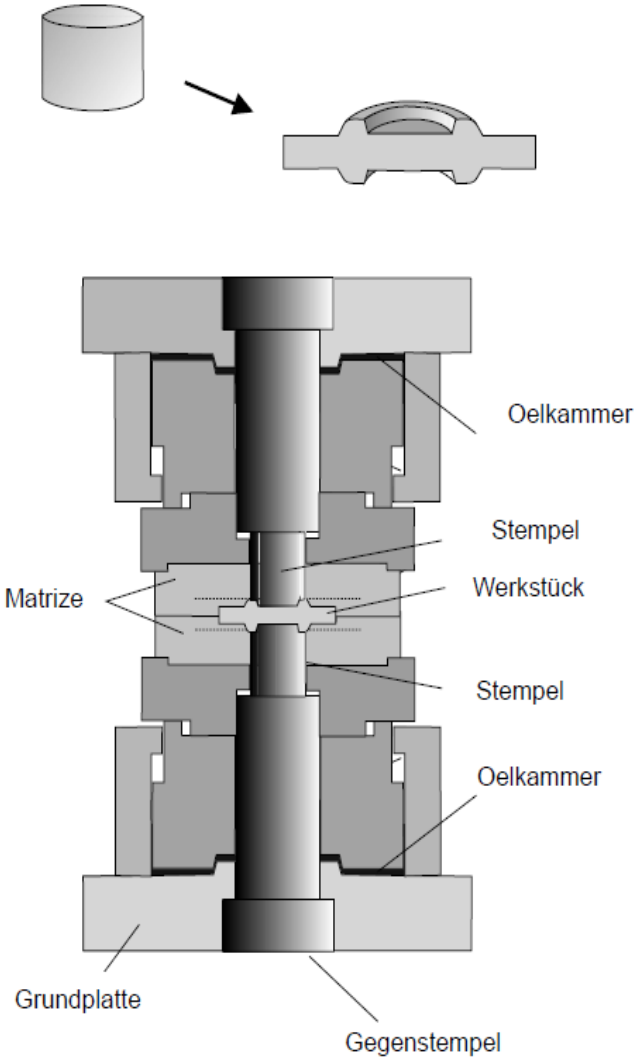
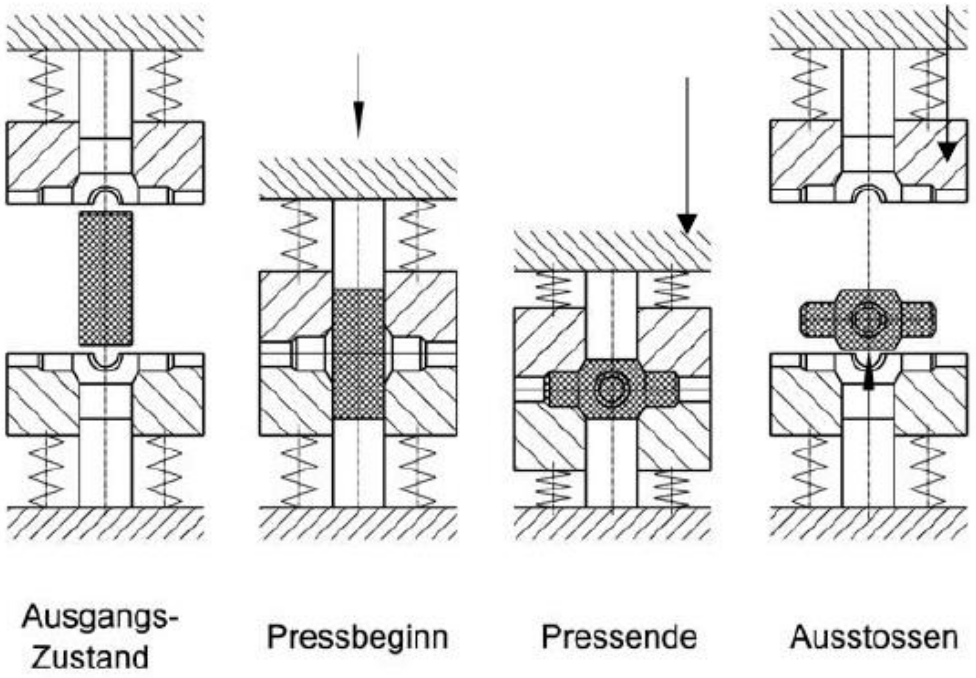
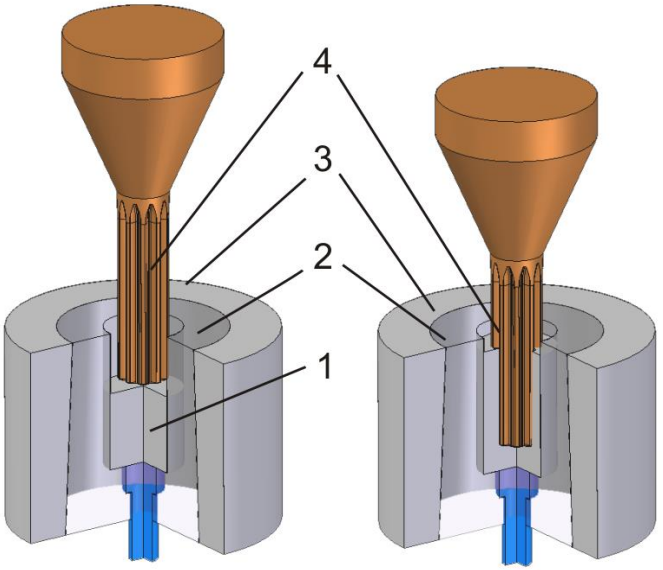


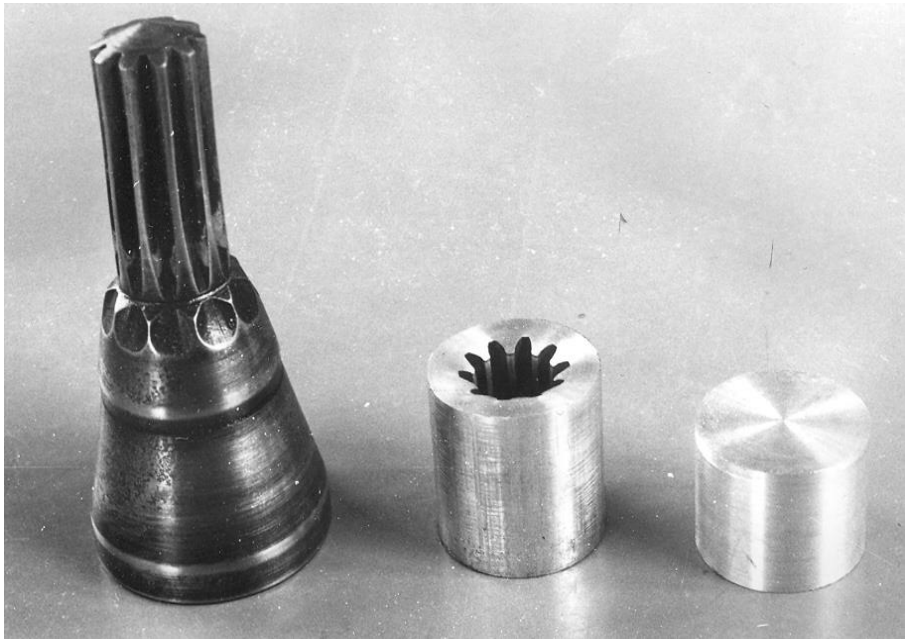


Primeri alata za hladno istiskivanje

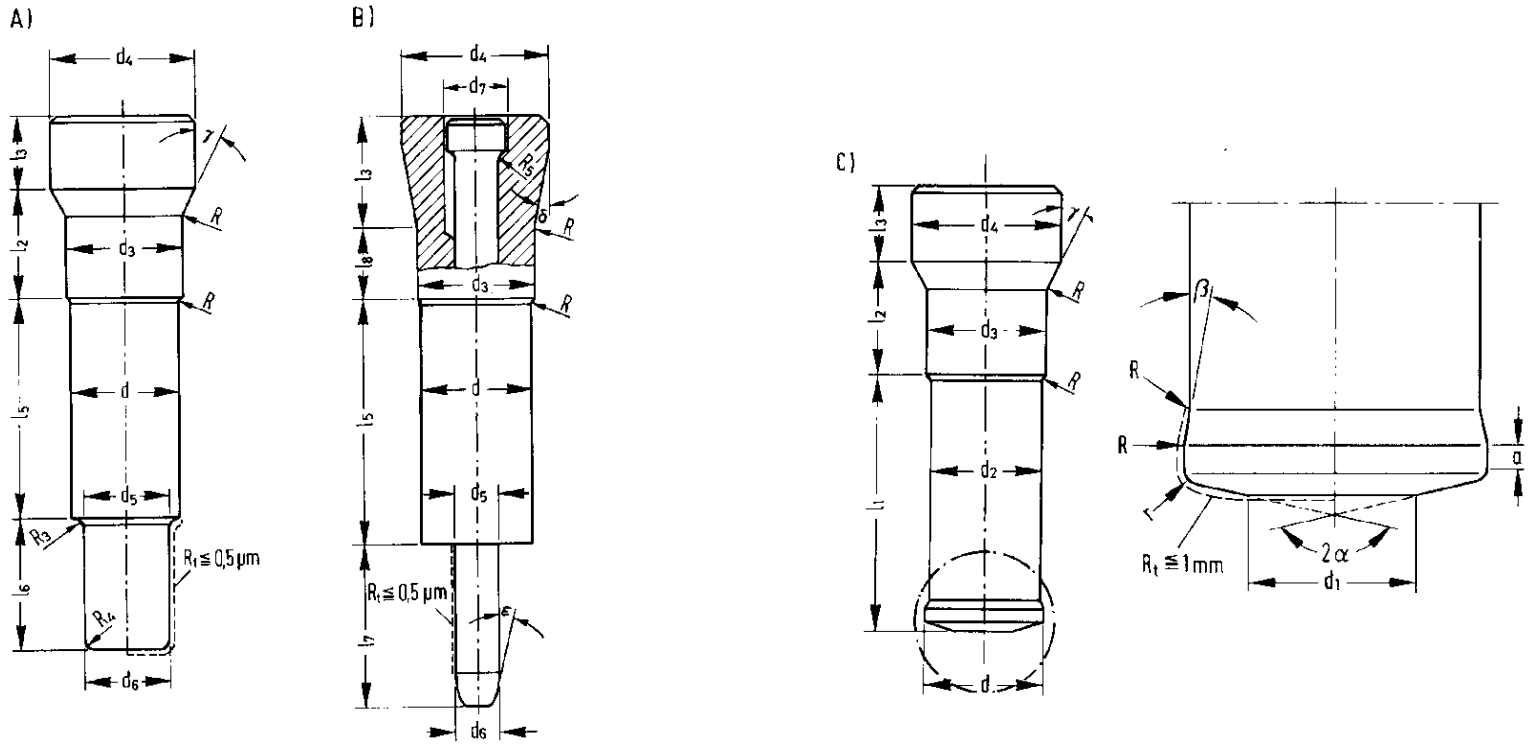


SUPROTNOSMERNO ISTISKIVANJE PROFILISANIM ŽIGOM





Žigovi za hladno istiskivanje

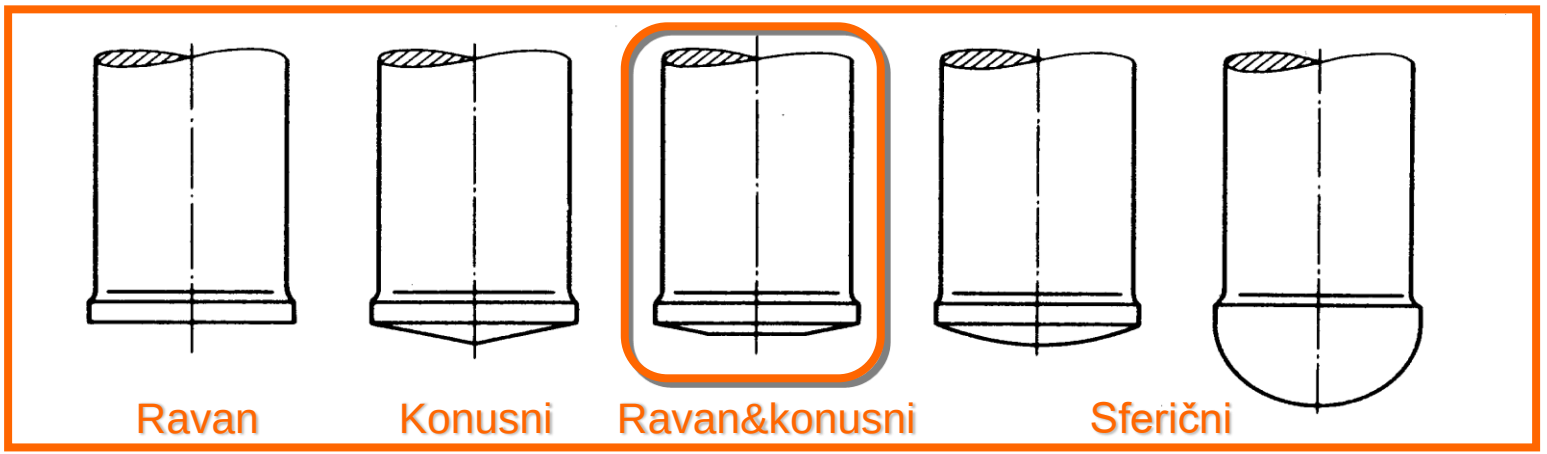


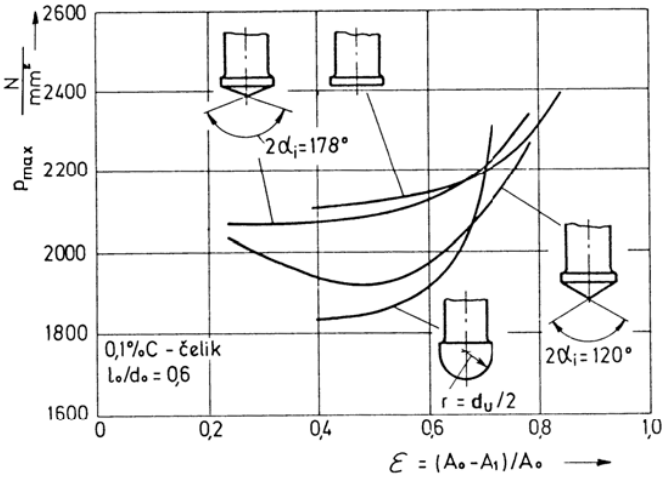
Najveći pritisak

Niski pritisci

Kombinacija

Najniži pritisak ali limitirana primena





Geometrija žiga za hladno istiskivanje

- *Prečnik ravnog dela čela,*

$$d_f = d_{\check{z}} - [2R + (0.2 \sim 0.3)d_{\check{z}}]$$

- *Ugao čela žiga,*

$$2\alpha = 160^o \sim 170^o$$

- *Dužina glave žiga,*

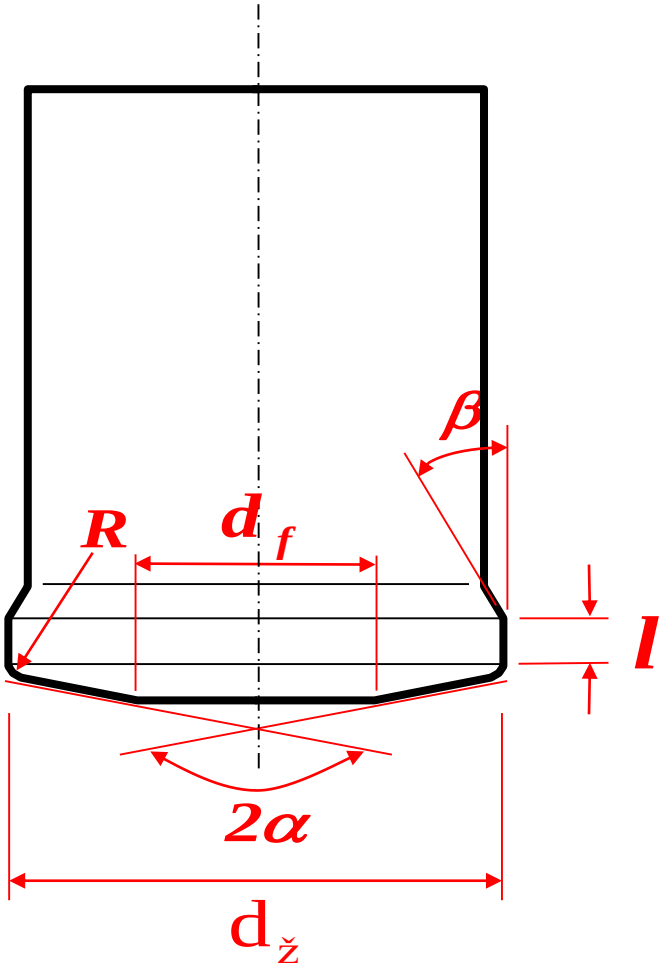
$$l = 0.3 \sim 0.7 \times \sqrt{d_{\check{z}}}$$

- *Radijus zaobljenja žiga,*

$$R = 0.05 \sim 0.1 \times d_{\check{z}}$$

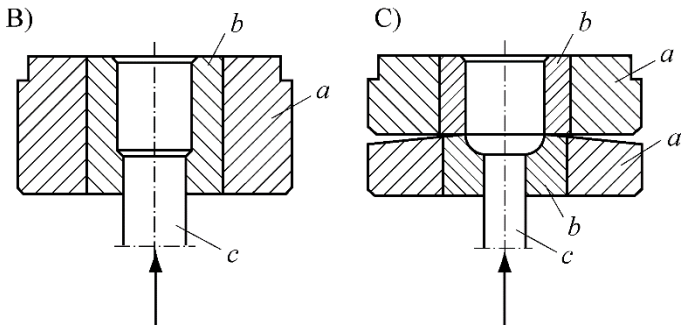
- *Izlazni ugao ,*

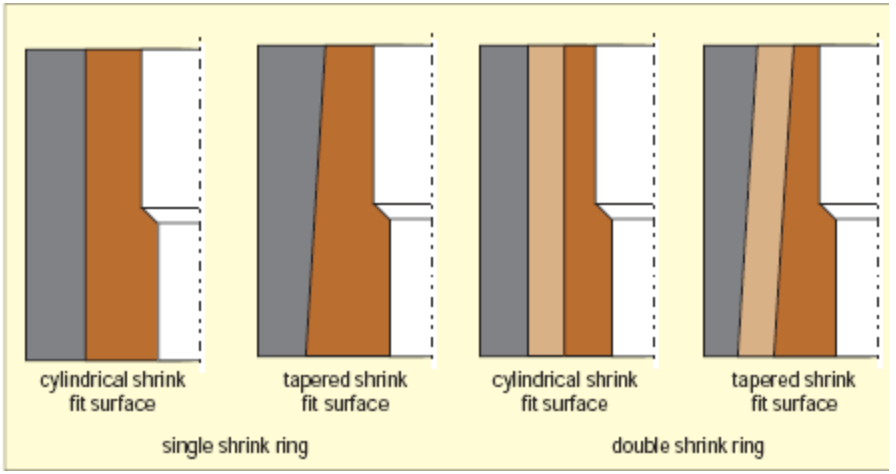
$$\beta = 4^o \sim 5^o$$

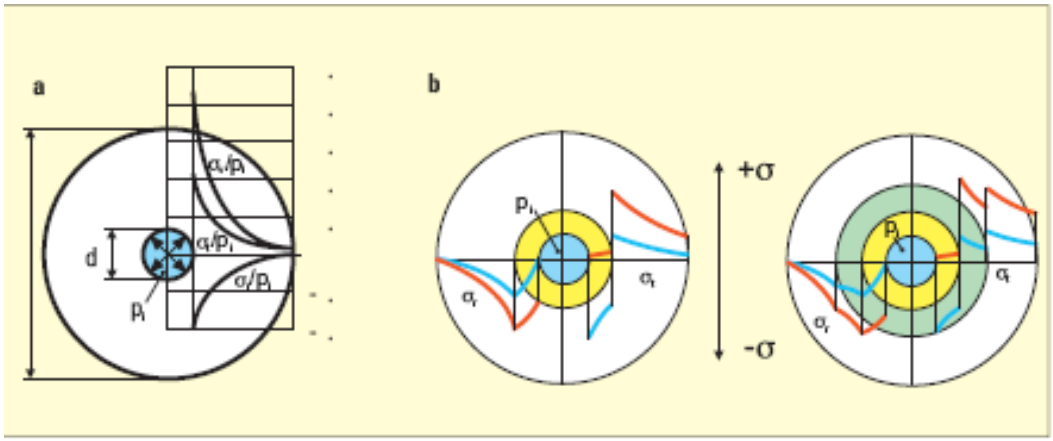


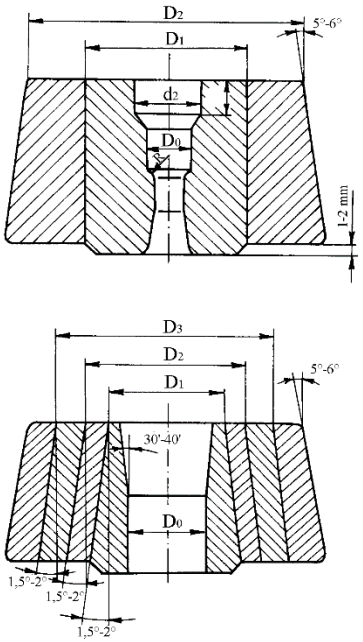
Geometrija žiga prema preporukama ICFG

Matrica za hladno istiskivanje





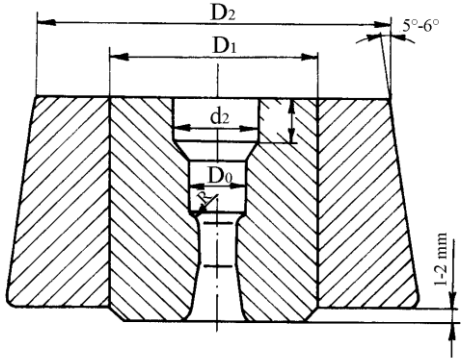




- p ≤1000 MPa – nije potrebno ojačavanje matrice
- p ≤1600 MPa – potreban jedan ojačavajući prsten
- p ≤ 2200MPa– potrebna dva ojačavajuća prstena
- p ≥ 2200MPa– potrebna tri ojačavajuća prstena

- *Prečnik matrice*

$$D_0 = d_{prip.} + (0.05 \sim 0.1)mm$$



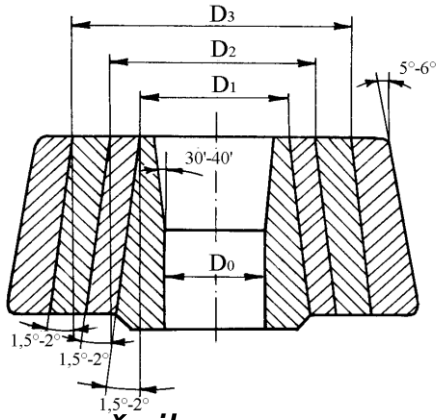
- *Matrice bez ojačavajućih prstenova* $p_{doz} \leq 1100[MPa]$

$$D_1 = (3 \sim 4)D_0$$

- *Matrice sa 1 ojačavajućim prstenom* $p_{doz} \leq 1600[MPa]$

$$D_1 = (1,8 \sim 2)D_0$$

$$D_2 = (2 \sim 2,5)D_1$$



- *Matrice sa 2 ojačavajuća prstena* $p_{doz} \leq 2000[MPa]$

$$D_1 = (1,2 \sim 1,8)D_0$$

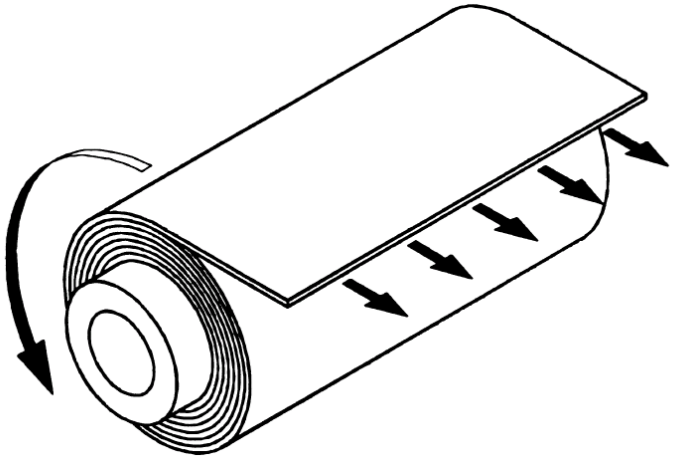
$$D_2 = (2,5 \sim 3,2)D_0$$

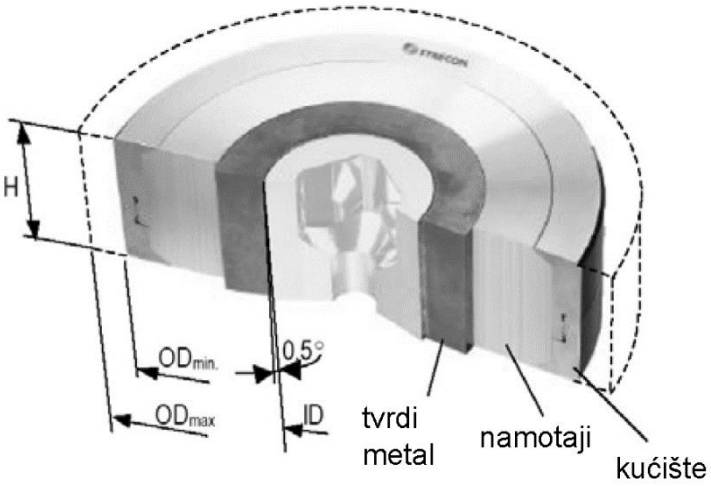
$$D_2 = (4 \sim 6)D_0$$

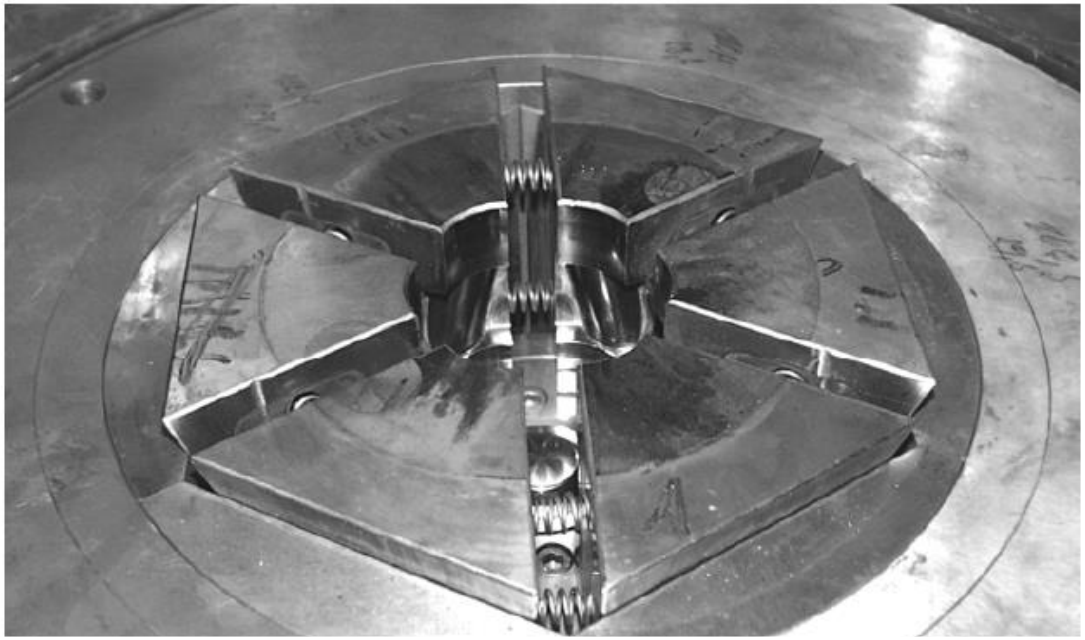
Negativni zazori: 0,1mm/25mm prečnika

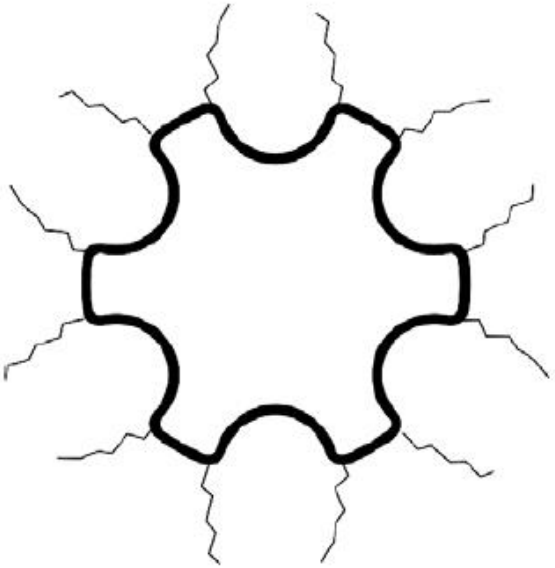
$$\Delta_1 = 0,025D_1 \quad \Delta_2 = 0,008D_2 \quad \Delta_3 = 0,004D_3$$

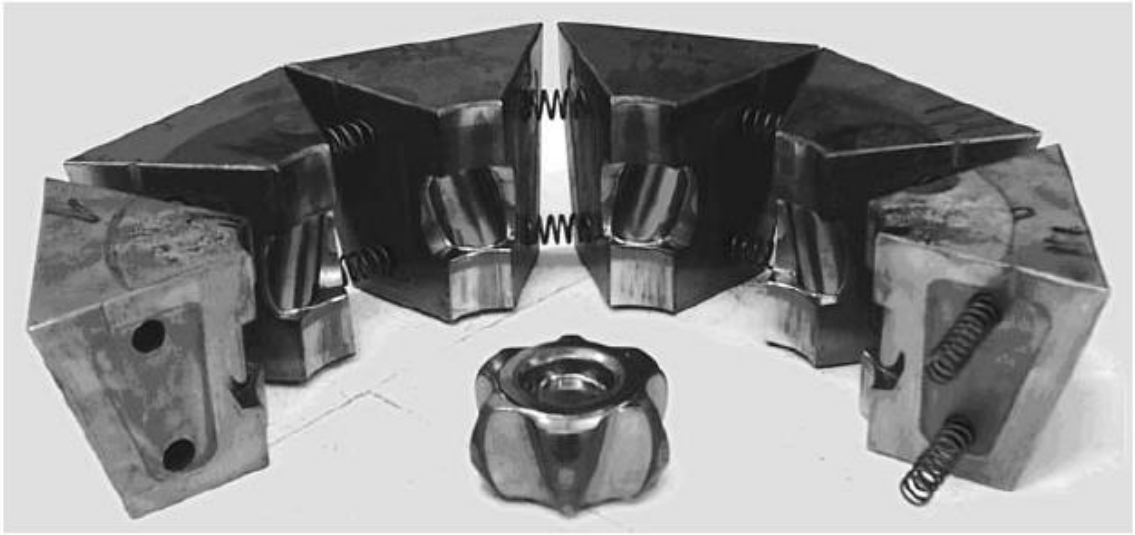
PREDNAPREZANJE MATRICE POMOĆU TRAKA



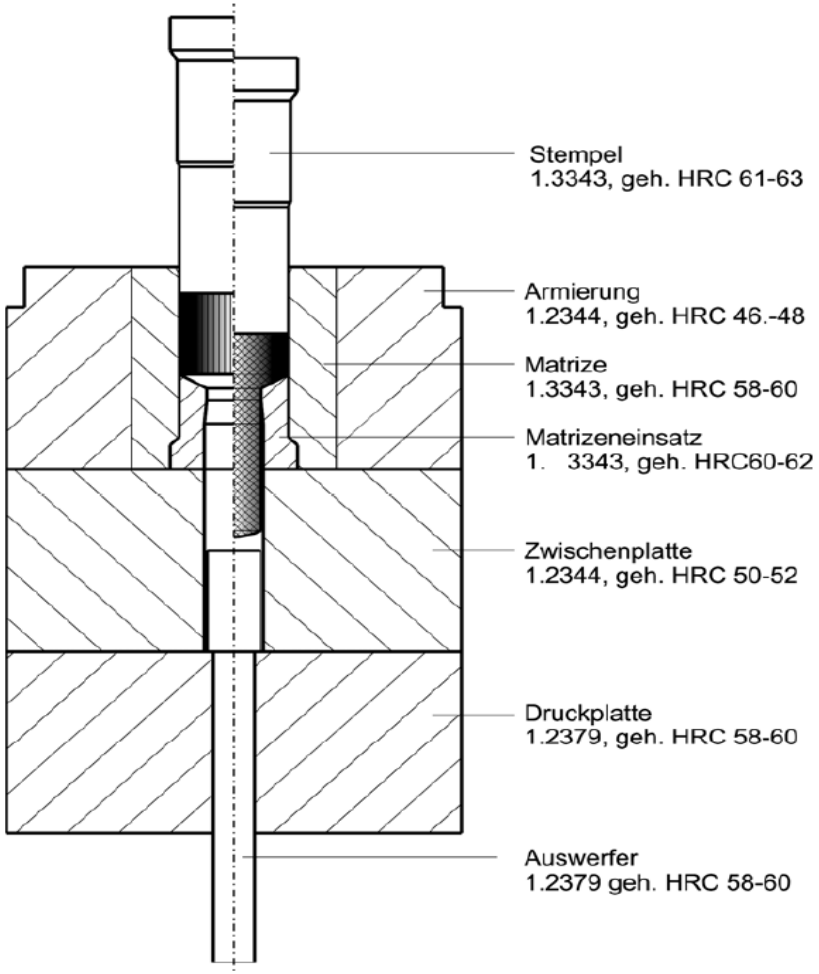








MATERIALI ZA IZRADU RADNIH ELEMENATA ALATA ZA ISTISKIVANJE



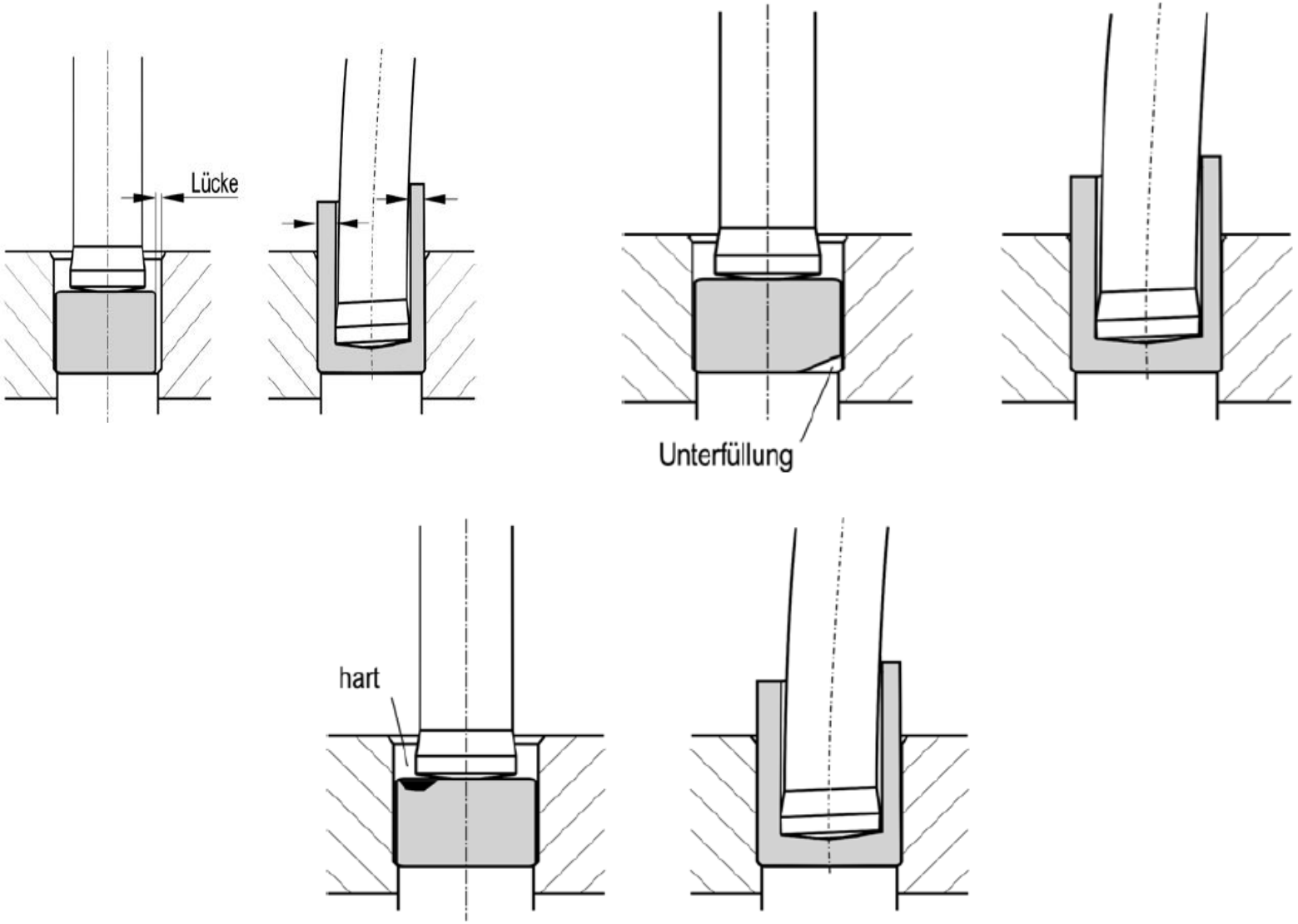
MATERIALI ZA IZRADU RADNIH ELEMENATA ALATA ZA ISTISKIVANJE

R. br.	ELEMENTI ALATA	OZNAKA MATERIJALA			TVRDOĆA UGRADNJE (HRc)
		DIN	JUS	proizvodjač	
1	oslona ploča žiga	100 Cr 6	Č. 4144	OCR-4	58 ÷ 62
2		145 Cr 6	Č. 4840	merilo spec.	60 ÷ 62
3	žig	210 Cr 46	Č. 4150	OCR-12	60 ÷ 63
4		50 Ni Cr	—		57 ÷ 60
5		40 Ni Cr Mo 15	—		51 ÷ 58
6	matrica	100 V 1	Č. 1940		60 ÷ 62
7		210 Cr 46	Č. 4150	OCR-12	58 ÷ 62
8		50 Ni Cr 13	—		58 ÷ 60
9	1. ojačavajući prsten	55 Ni Cr Mo V 6	Č. 5741		56 ÷ 58
10		40 Ni Cr Mo 15	—		51 ÷ 56
11	2. ojačavajući prsten	31 Ni Cr 14	Č. 5438		40 ÷ 45
12	protužig	100 Cr 6	Č. 4840	merilo spec.	56 ÷ 60
13		210 Cr 46	Č. 4150	OCR-12	58 ÷ 62
14	ležiste matrice	100 Cr 6	Č. 4845	merilo spec.	56 ÷ 60
15		210 C 46	Č. 4150	OCR-12	60 ÷ 62
16	podloga matrice	55 N C M V 6	Č. 5741	utop ex. 1	56 ÷ 58
17		45 S C V 6	—		52 ÷ 58
18	izbacivač	120 W V 4	—		60 ÷ 62
19		140 Cr V 1	—		58 ÷ 65

RADNI VEK ALATA ZA HLADNO ISTISKIVANJE

Vrsta procesa i element alata		Količina izradjenih komada		
		Legirani alatni čelik		Tvrdi metal
		Srednji vek	Maksimalni vek	
AMERIČKI PODACI				
Protusmerno istiskivanje	Žig	5000-25000	50000	$(250-1000)\cdot10^3$
	Matrica	10000-50000	100000	$(500-5000)\cdot10^3$
Istosmerno istiskivanje	Žig	25000-100000	250000	$10^6-10\cdot10^6$
	Matrica	5000-50000	100000	$(0,5-5)\cdot10^6$
NEMAČKI PODACI				
Protusmerno istiskivanje	Žig	$(3-30)\cdot10^3$	-	-
	Matirca	$(5-50)\cdot10^3$		
Istosmerno istiskivanje	Glava žiga	$(7-50)\cdot10^3$	-	-
	Vrat žiga	$(15-100)\cdot10^3$	-	-
	Matrica	$(5-50)\cdot10^3$	-	-

GREŠKE PRI HLADNOm ISTISKIVANJU

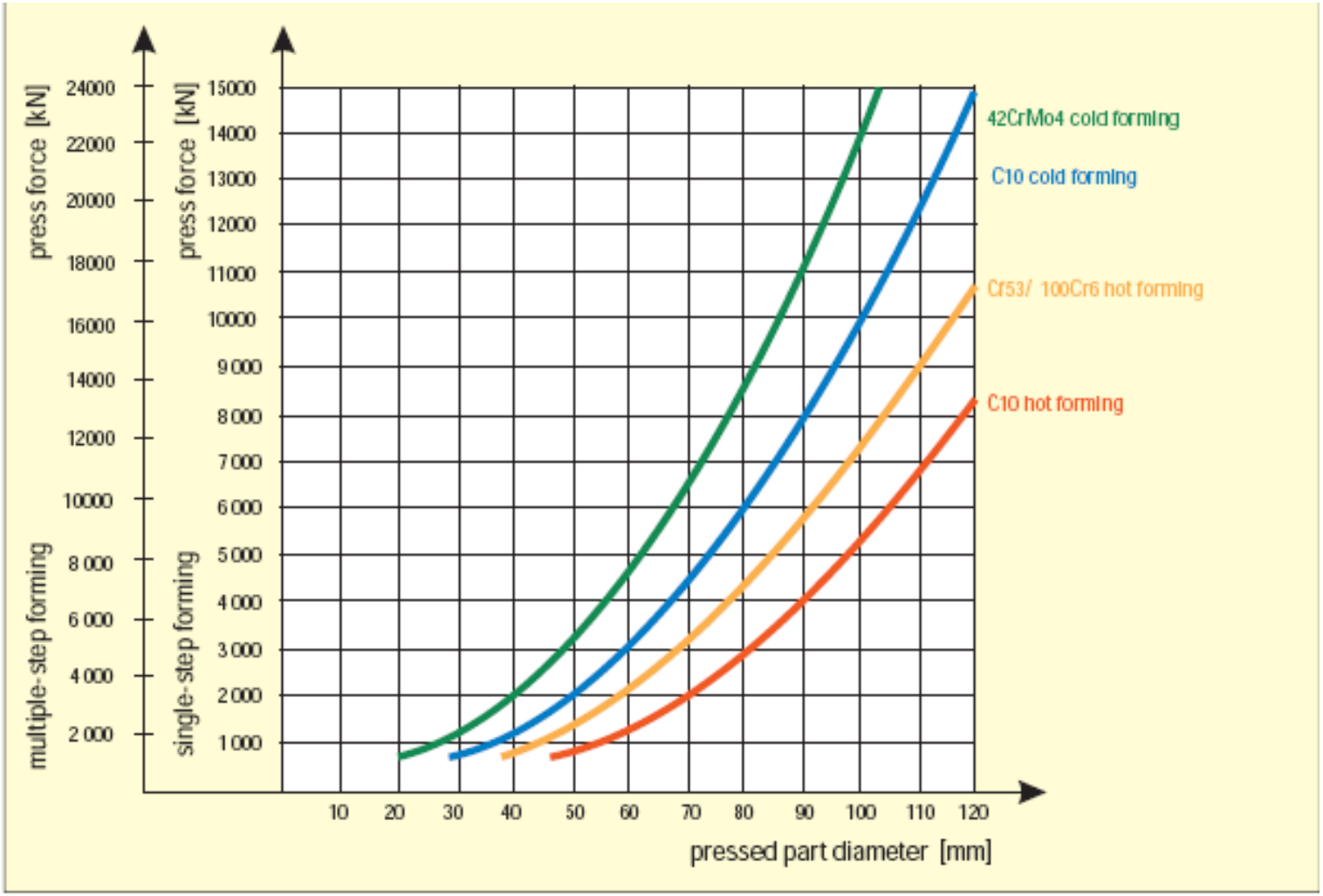


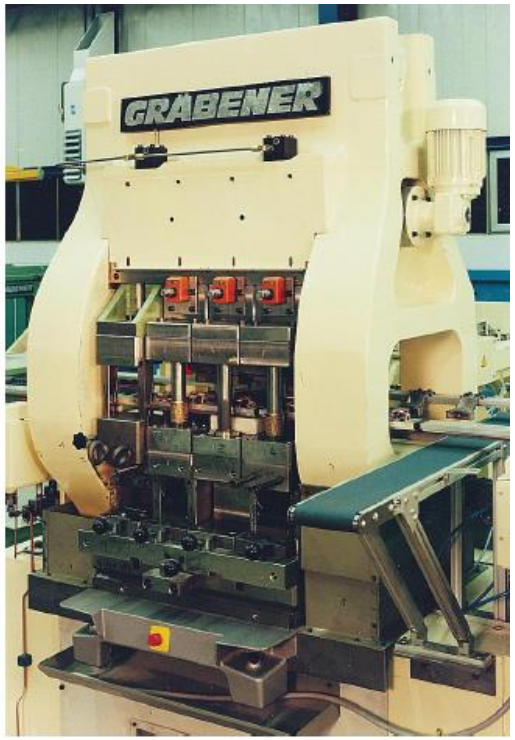
Mašine za hladno istiskivanje

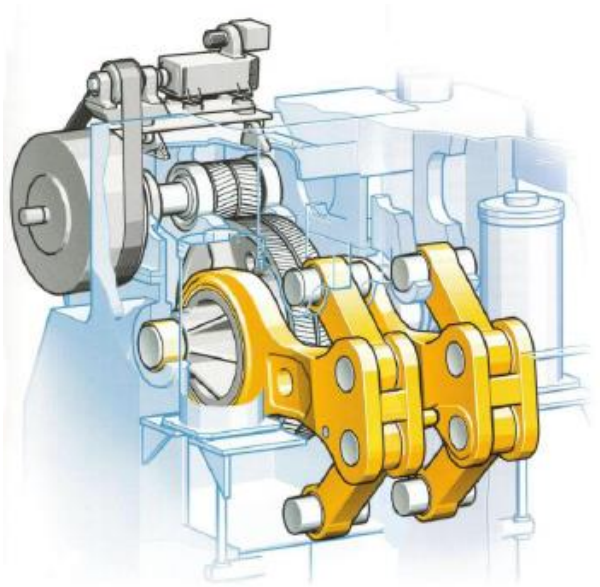
- mehaničke prese i hidraulične prese
- jednopozicione i višepozicione

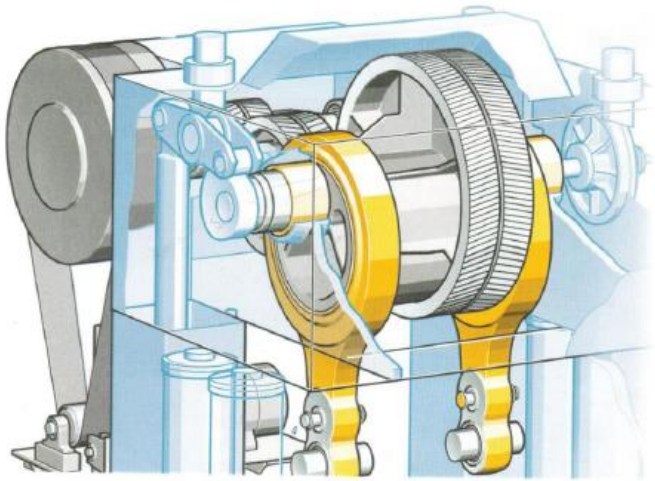
Kriterijumi za izbor mašina za hladno istiskivanje:

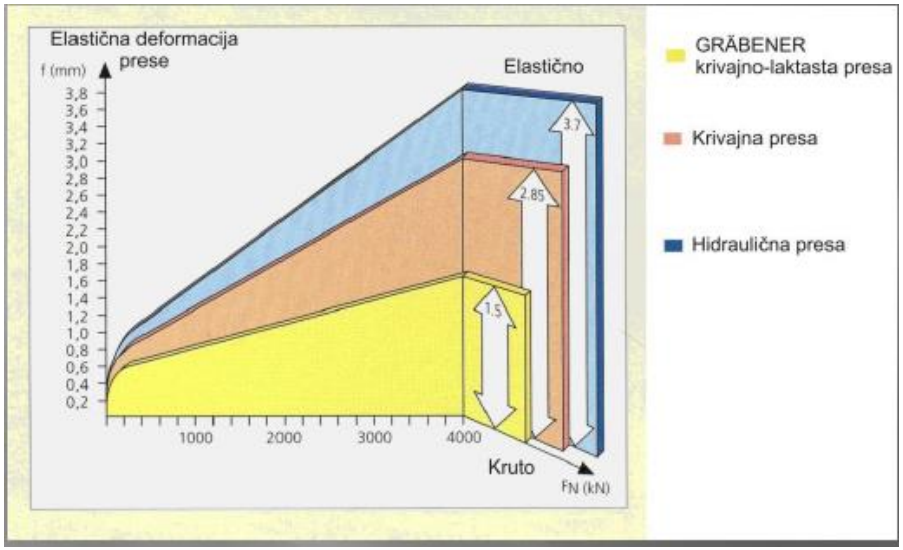
- deformaciona sila
- veličina hoda
- podešavanje hoda (da ne bude komplikovano)
- veličina brzine sudara alata i obratka (treba da je što manja)
- što veća krutost noseće strukture i što tačnije vođenje bata
- osiguranje od preopterećenja
- jednostavno podešavanje položaja hoda
- jednostavno podešavanje uređaja za izbacivanje
- pristupačnost za ulaganje i vađenje obratka i postavljanje i skidanje alata
- mogućnost merenja deformacione sile u toku procesa
- osiguranje od nesrećnog slučaja
- natpis s karakteristikama mašine


press force [kN]
24000
22000
20000
18000
16000
14000
12000
10000
8 000
6 000
4 000
2 000
multiple-step forming
press force [kN]
15000
14000
13000
12000
11000
10000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
single-step forming
10
20
30
40
50
60
70
80
90
100
110
120
pressed part diameter [mm]
42CrMo4 cold forming
C10 cold forming
Cr53/ 100Cr6 hot forming
C10 hot forming


GRÄBENER






Elastična deformacija prese
f (mm)
3,8
3,6
3,4
3,2
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
Elastično
3,7
2,85
1,5
1000
2000
3000
4000
Kruto
FN (kN)
GRÄBENER krivajno-laktasta presa
Krivajna presa
Hidraulična presa

Polutoplo istiskivanje

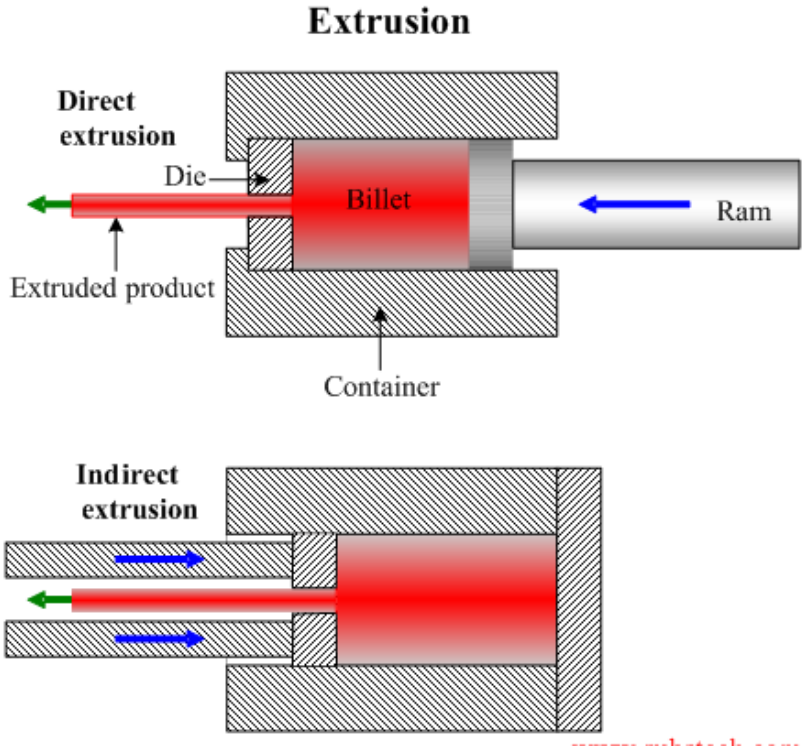
Zagrevanje na temperaturu ispod temperature rekristalizacije (čelik 600 do 720 ° C)

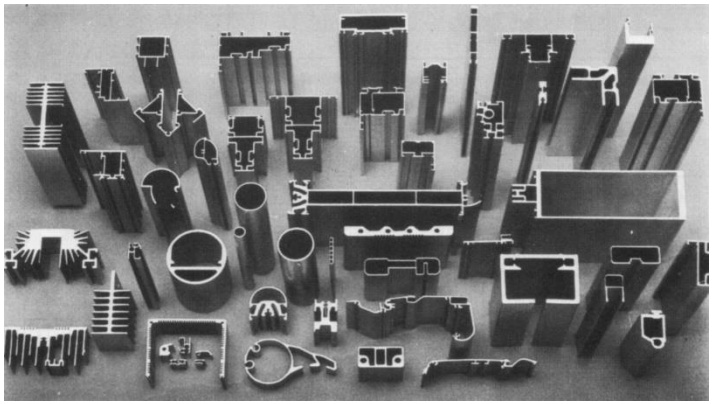
- dobar kvalitet površine, bez značajne oksidacije
- visoka iskorišćenost materijala
- kratko vreme izrade
- veća plastičnost (čelik sa C>0.4%)
- manje sile, pritisci

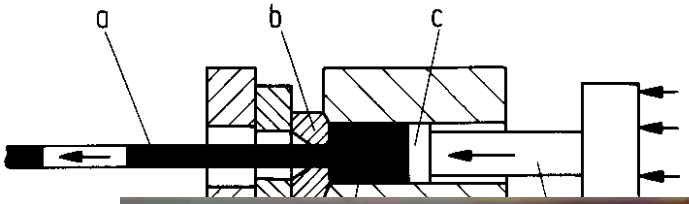
Alati se predgrevaju na 300oC radi sprečavanja pojave temperaturnog šoka na početku procesa

Toplo istiskivanje profila, šipki i cevi

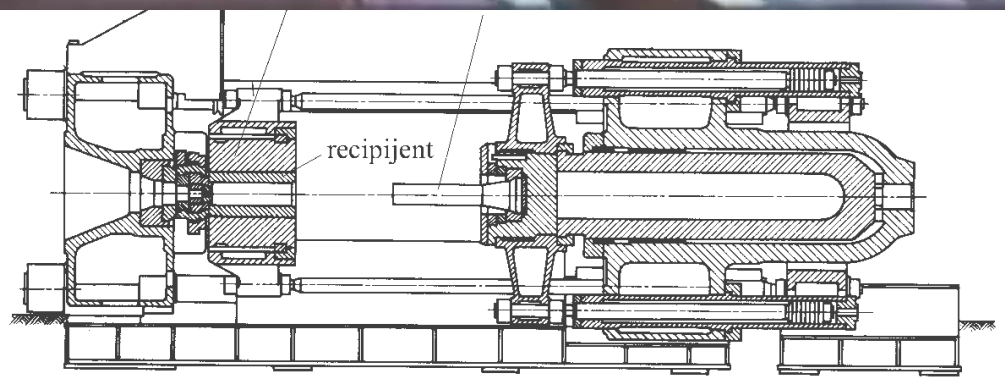
Najčešće se obrađuju obojeni metali (Al, Cu i njihove legure) a u manjoj meri i određeni čelični materijali.
Temperature na koje se materijal pre obrade zagreva su iznad temperature rekristalizacije (za čelik to je 1300^{o}C).

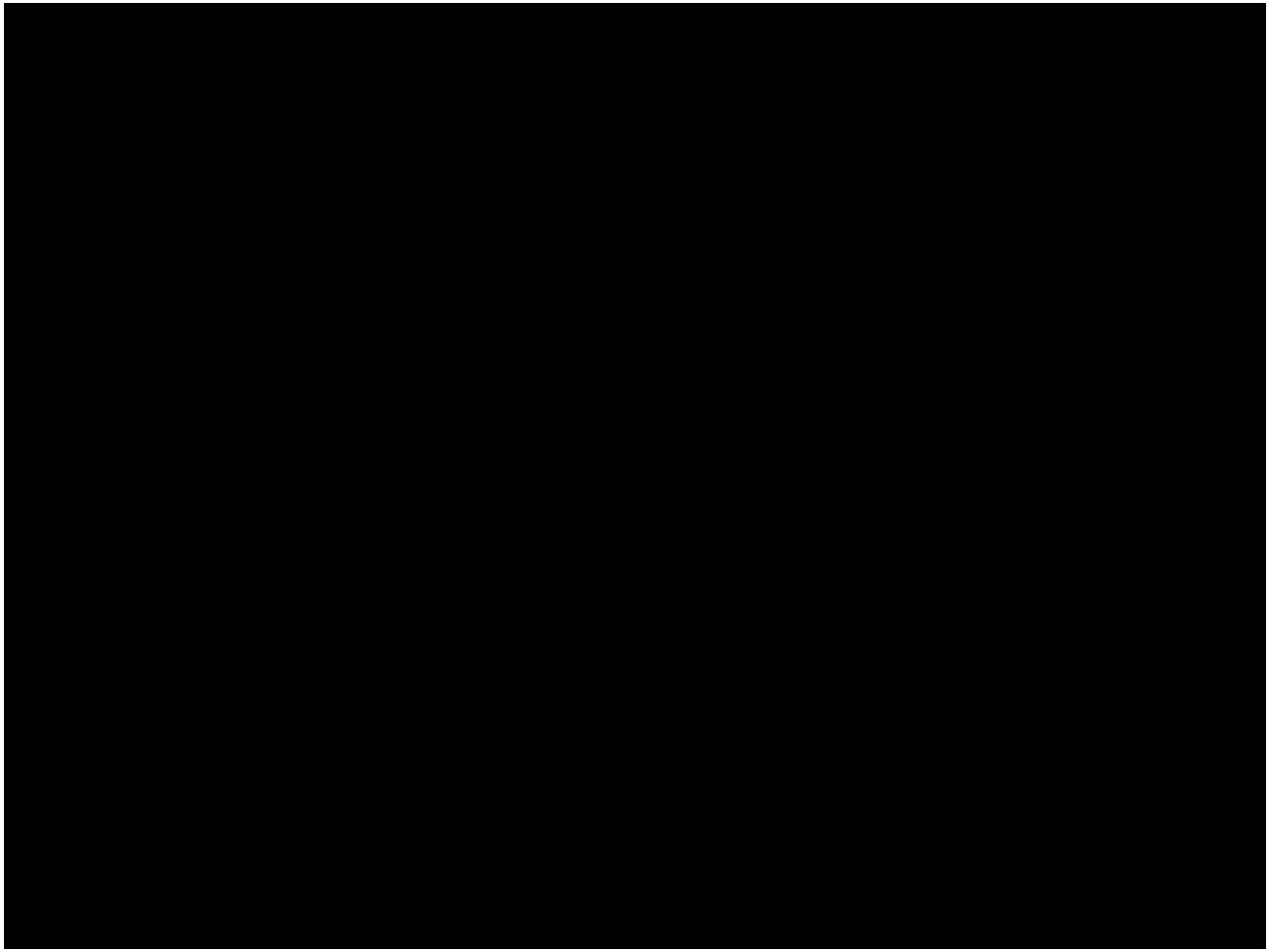




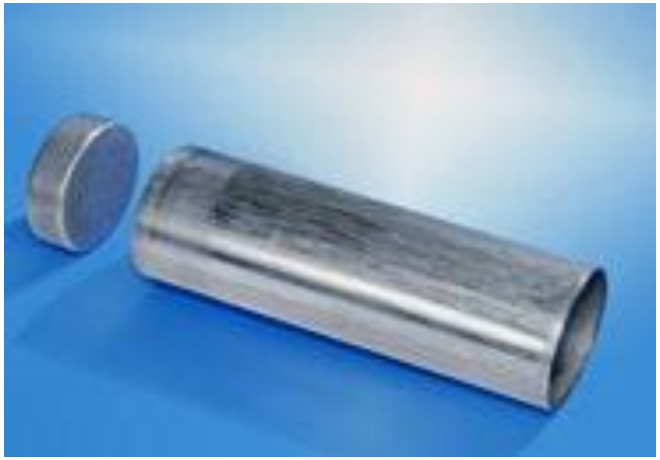


a – istisnuti profil
b – matrica
c – pritisna ploča
d – potpore





Posude od aluminijuma izrađene istiskivanjem

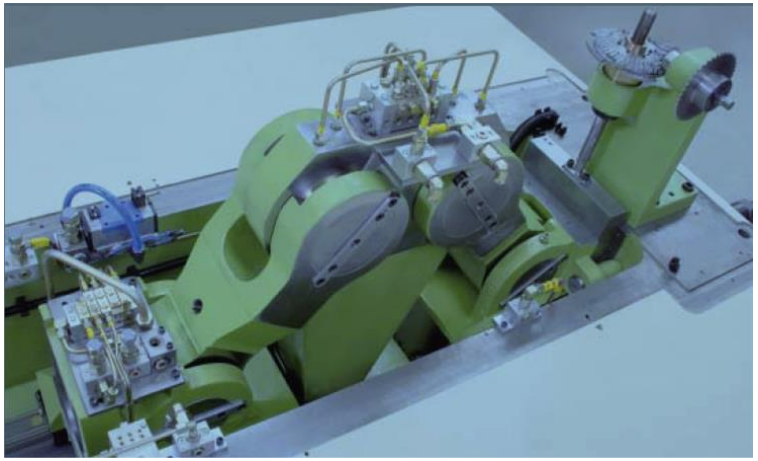


Prese za istiskivanje tankozidih posuda

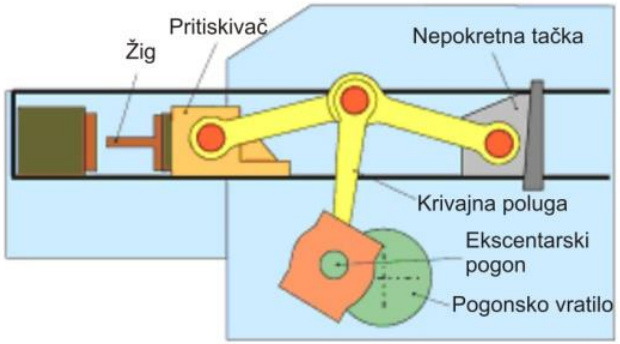
a) *b)*

Presa za istiskivanje posuda od aluminijuma,
a) izgled mašine, b) ploča za dodavanje pripremka i međuoperacioni transport

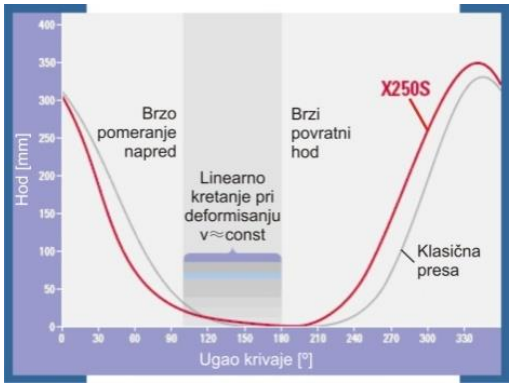
Prese za istiskivanje tankozidih posuda



a)



b)



c)

Pogonski sistem prese

a) izgled, b) konstrukcija pogona, c) dijagram brzine