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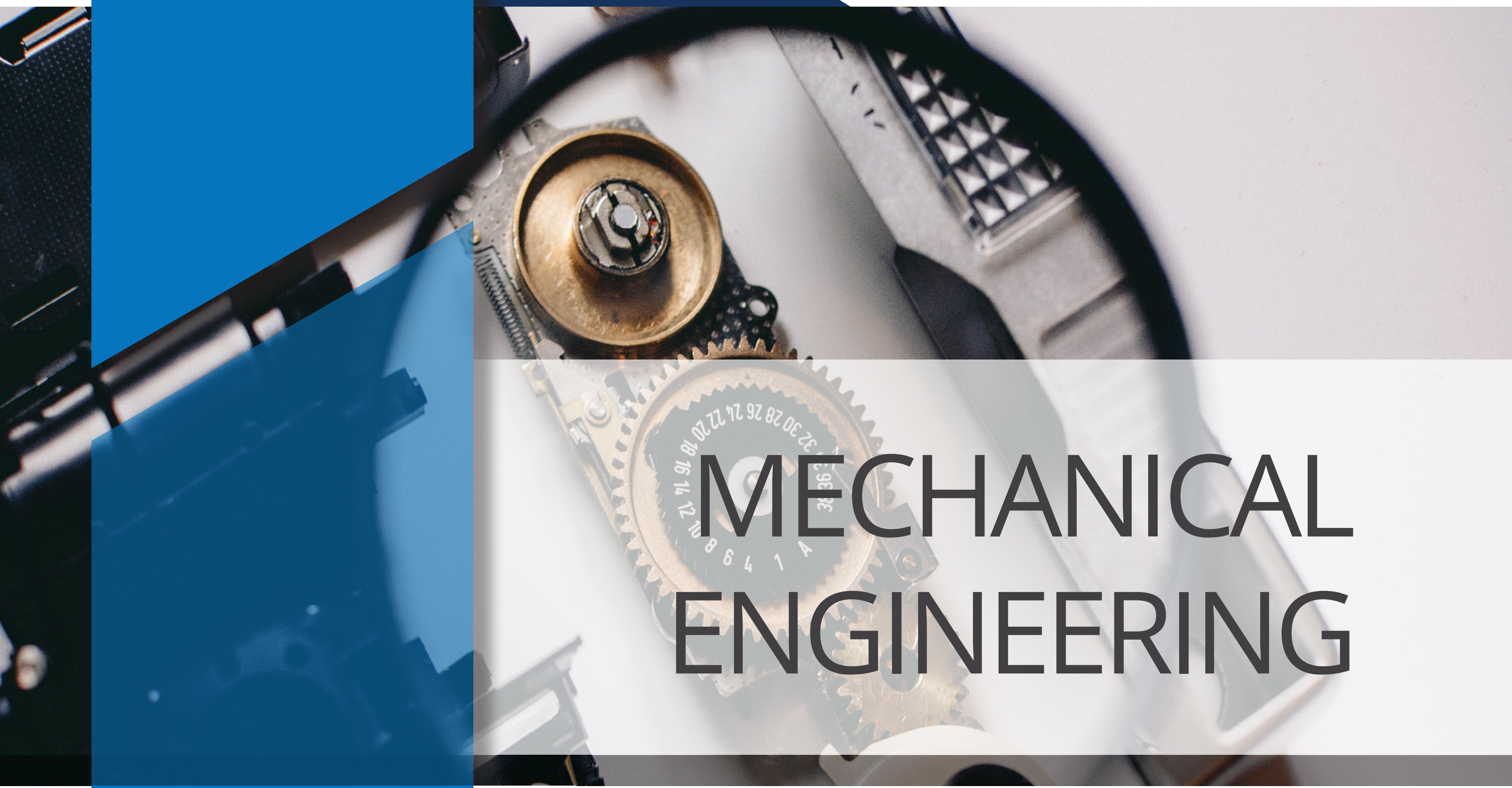


MECHANICAL ENGINEERING

Sheet metal forming

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

VŠTE

EUROPEAN UNION

CONTENTS

1. THERMAL TREATMENT

1.1. Purpose and basic classification of thermal treatment methods

By proper use of metal and alloys properties, it is possible e.g. to reduce a machine or machinery weight, or to use cheaper materials. Both results in increasing the economy of production.

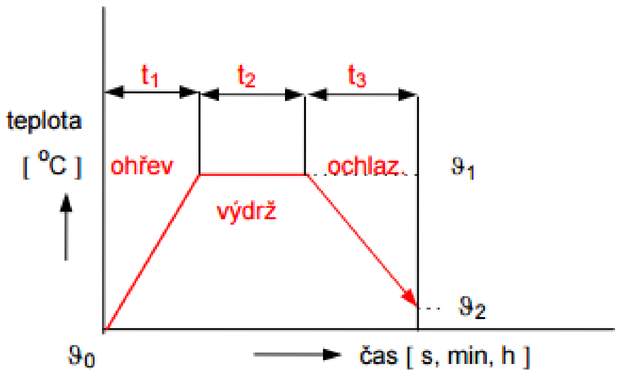
Thermal treatment includes all processes in which an object or material in its solid state is heated and cooled in a certain way in order to achieve desired properties.

It always includes the following processes:

- heating to a certain temperature
- maintaining this temperature
- cooling to a given temperature at certain speed

In some cases, these processes can be repeated several times under different conditions.

The cooling or heating speed is given at high speed in °C/s, at low speed in °C/min, or °C/h.



Legend: teplota – temperature, ohřev – heating, výdrž – maintaining the temperature, ochlaz. – cooling, čas - time

Although both speeds are not uniform (they depend on instantaneous temperature gradient), we mostly consider average speed, which is calculated as follows:

a) při ohřevu

$$c = \frac{\vartheta_1 - \vartheta_0}{t_1}$$

b) při ochlazování

$$c = \frac{\vartheta_1 - \vartheta_2}{t_3}$$

kde: ϑ_0 je výchozí teplota před ohřevem

ϑ_1 je teplota ohřevu

ϑ_2 je požadovaná teplota na konci ochlazování

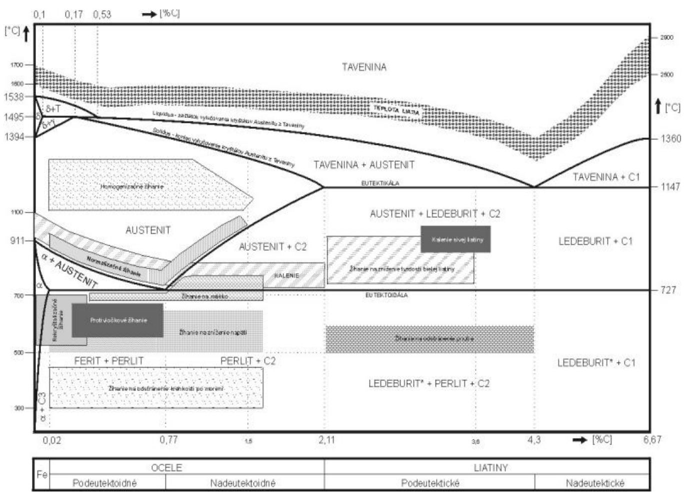
Legend: při ohřevu – in heating, při ochlazování – in cooling, kde – where, výchozí teplota před ohřevem – starting temperature before heating, teplota ohřevu – heating temperature, požadovaná teplota na konci ochlazování – required temperature after cooling

Thermal treatment influences mechanical properties, such as strength, hardness, ductility, notch toughness, wear resistance, etc. In many cases, changes in structure occur; therefore knowledge of equilibrium diagrams and phase changes is required.

Since the equilibrium in phase changes in the solid state is completely determined by diffusion, for the result of thermal treatment it will be important what effect the diffusion will have. The course of diffusion is influenced both by temperature and the duration (period of time) at which the temperature is maintained. By the way of influencing diffusion, thermal treatment is divided into two basic groups:

- Thermal treatment methods enhancing the diffusion on hindering it just slightly. These methods are generally called annealing.

- Thermal treatment methods hindering significantly or stopping the diffusion completely. The non-equilibrium state of the alloy is generally the greater the higher the cooling speed is. The main method is quenching.



1.2. Annealing

The objective of annealing is mostly:

- To reduce residual stress,
- To eliminate the consequences of preceding mechanical processing,
- To improve technological properties (cold-forming, machining),
- To lower chemical and structural heterogeneity.

The decisive technological parameter of annealing is the temperature and the time at the temperature when cooling is very slow. The annealing temperatures of the individual procedures result from the equilibrium diagram of Fe-Fe3C.

All types of annealing can be divided by the annealing temperature:

Annealing to reduce residual stress. The purpose is to reduce internal stress in the material during the casting solidification, cooling after cold and hot-forming, and in surface layers after chip machining. At the annealing temperature of 450 - 650 °C the yield strength is so low that the residual stress can be reduced by local plastic deformation. Depending on the size, shape and material, 2 – 10h remaining at the temperature with slow cooling is necessary to prevent new residual stress.

Recrystallization annealing

It mostly refers to intermediate annealing in cold-forming of low-carbon steel, which removes the hardening and regenerates malleability and ductility. This is done by means of its heating to the temperature of recrystallization (550 – 700 °C), with a duration of 1 – 5 hours. Using this method, it is possible to change significantly the shape and size of grain. The purpose of annealing is usually to refine the grain.

Soft annealing

The surface tension causes spheroidization of eutectoid carbide particles. By changing lamellar perlite to grain perlite, it is possible to improve cold-forming possibility in low-carbon steel and machining possibility in steel with the C content over 0.4 %. Also, annealing enables to prepare a suitable initial structure for subsequent quenching, especially in the case of eutectoid and over-eutectoid steel. The uniform distribution of granular carbides in basic ferritic mass facilitates the subsequent austenitization and improves the general properties after quenching, which is successfully used especially in the case of bearing steels. The annealing temperature is close t eutectoid temperature.
Increasing the temperature above Ac1 or its fluctuation around this temperature facilitates and accelerates balling of carbide particles. The annealing time differs based on the type of the steel and on the previous heat treatment, ranging from 4 h for carbon steel to 16 h for high alloy steels. Annealing is finished by slow cooling in the furnace.

Anti-flake annealing

It is applied at supercritical hydrogen content in steel, when steel is susceptible to creation of internal cracks – flakes. Creation of flakes can be prevented by long-term heating (up to tens of hours) at the temperatures of 650 – 750 °C, where as the result of a significant increase of hydrogen diffusivity in ferrite, its content decreases under the critical value. Annealing must be performed immediately after casting or hot forming (before its cooling to the temperature of the ambient temperature), when the hydrogen present does not create molecules which are not capable of diffusion and thus of removing from steel. After remaining at the annealing temperature for a long time, it is advisable to cool to at least 500 °C very slowly.

Annealing to remove brittleness after pickling

When removing skimming by means of pickling, in steel components, there is diffusion of hydrogen in the metal and subsequently hydrogen fragility. Since during the pickling, hydrogen penetration into steel is limited, hydrogen can be easily removed by annealing at temperature between 300 °C and 500 °C for 1 - 4 h

Normalization

It is one of the most widely used methods of steel heat treatment, as it ensures fine-grained and even structure after casting, forming, or long-term annealing at high temperatures. The classical procedure is used only for sub-eutectoid steels, when at a temperature of 30 – 50 °C and duration of 1 – 4 hours, a fine uniform austenitic structure is formed that after cooling transforms into fine-grained ferritic-perlitic structure with favorable mechanical properties. Exceptionally, it is applied in the case of over-eutectoid steels in order to achieve a better re-distribution of secondary cementite particles that was removed at grain boundaries in the form of grids as a result of slow cooling. By heating to the temperature above Acm, carbide meshes are dissolved in austenite and by its rapid cooling its repeated removing is prevented at grain boundaries.

Homogenizing annealing

It lowers non-homogeneity of the chemical composition of thick-walled castings in which significant dendritic segregation occurred. Long-term annealing at temperatures ranging from 1 100 to 1 200 °C (usually about 200 °C below solidus) causes sufficient diffusion speed of carbon and other elements to reduce segregation and unwanted heterogeneity. Remaining at the temperature depends on the size and thickness of the casting, usually resulting in a significant grain roughness, which requires subsequent normalization annealing.

Solution annealing

This type of annealing is used to dissolve carbides, nitrides and other inter-metallic phases, which increases the homogeneity of austenite and its saturation with alloying elements. It is most often used at high alloy austenite steels, where a pure austenite structure is obtained by annealing at temperatures of 1 050 - 1 150 °C with subsequent fast cooling that prevents repeated elimination of phases.

Isothermal annealing

By combining three types of annealing (normalization, soft, reducing internal stress) in one operation, it is possible to achieve more homogeneous fine-grained structure with improved machining. The process starts with normalization, after which the steel is cooled by a stream of air to the temperature of 700 - 650 °C, at which in isothermal delay the splitting of metastable austenite into fine spheroidized perlite occurs. Remaining at the temperature results from the knowledge of the IRA diagram for the relevant steel class. Finally, it is cooled by the air. The process is suitable for some kinds of medium-alloy steel that are difficult to soft anneal.

1.3. Quenching

The objective of quenching is to improve the hardness, strength and wear-resistance of steel. These properties are typical for partly or entirely non-equilibrium structures which can be obtained by cooling austenite at overcritical speed. Depending on the phase prevailing in the resulting structures, there is martensitic or bainitic quenching.

An important process parameter is the quenching temperature, at which steel is austenitised before cooling. The proper quenching temperature for sub-eutectoid steels is about 30 - 50 °C overAC3, where it ensures the homogeneous structure of austenite before decomposition. For super-eutectoid steels, the adequate temperature is only about 20 °C above AC1, where the initial structure consists of a heterogeneous structure of austenite and undissolved carbides that increase the wear-resistance after quenching. Improper quenching temperature results in increasing unwanted phases in the final structure (ferrite) or to thickening of grain, which may result in quenching cracks.

Quenchability is steel ability to achieve unbalanced state by austenitizing temperature lowering.

Quenching ability is determined by its maximum hardness after quenching; it depends on the carbon content in austenite. The resulting hardness is also affected by the quenching temperature, especially in the case of super-eutectoid steels.

Types of quenching

- **Basic quenching** is the simplest process. The temperature decreases steadily under *MS, when the austenite transformation into martensite starts. High residual stress and maximum deformations arise, therefore this type is not suitable for quenching products of complex shape.*

- **Discontinuous quenching** starts with supercritical speed in order to support perlitic transformation (e.g. in water) and continuous with cooling in moderate ambient (e.g. oil). This way the difference between the temperature on the surface and inside the product as well as thermal stress is reduced.

- **Isothermal quenching** is similar to thermal quenching, with the dwelling time in the bainitic transformation lasts until isothermal austenite decomposition is finished. Thermal and structural stress is minimal, there is no risk of deformation and cracks. The oldest isothermal quenching method is patenting used for production of high-strength wires.

- **Thermal quenching** enables to balance temperatures in the whole volume of the product quenched. It reduces the stress and deformation due to dwelling over the MS temperature. Cooling in the interval of martensitic transformation usually takes place in the air. The process is suitable for thin-walled steel products of complex shapes, whose bainitic area is shifted on the left.

- **Grain quenching by freezing** requires additional cooling in liquid nitrogen freezing baths that should prevent the stabilization of RA (residual austenite) for steels with low MS and Mf temperatures. It is applied to the products working at temperatures below zero, measurement tools, and bearing steel, where the shape stability is required.

- **Continuous bainitic quenching** is used for steels with bainitic area on the left. The resulting composition consists of bainite, martensite and residual austenite.

1.4. Tempering

Tempering is a steel heat treatment method usually following quenching. By heating quenched steel to temperatures not exceeding AC1, martensite decomposition and transformation of residual austenite occurs. The changes of structure and resulting changes of mechanical properties depend mainly on the tempering temperature. From technology point of view, we distinguish between:

- **Tempering at low temperatures (to 300 - 350 °C), which lowers the residual stress after quenching, reduces the RA content and stabilizes dimensions.**

- **Tempering at higher temperatures (above 450 °C), at which a complete decomposition of martensite occurs, which is shown by marked decrease of hardness and strength, but also by increase in plasticity and toughness.**

2.

3. SHEET METAL SHEARING TECHNOLOGIES

3.1. Sheet Metal Forming Technology – Shearing

Hearing is the most widely used forming operations.

It is used for:

- Preparation of semi-finished products (shearing sheets or coils, profiles shearing, flat shapes, etc.)

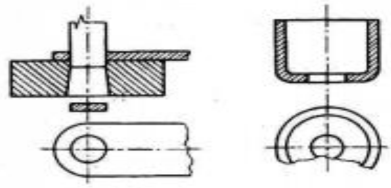
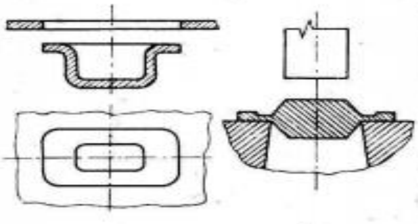
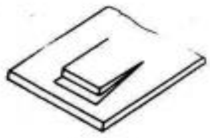
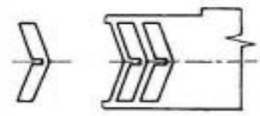
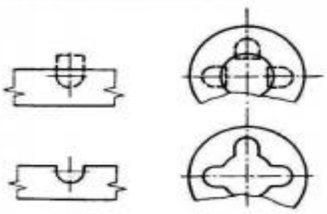
- Shearing sheet metal components either for the purposes of end use or for other technology products (bending, extrusion, drawing, etc.)

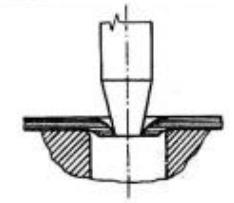
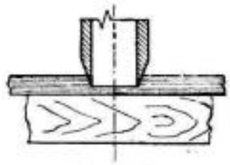
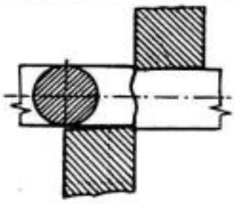
- Finishing or ancillary operations, including:

    - punching,
    - blanking,
    - trimming,
    - roll slitting, etc.

By the process temperature, we distinguish two types of shearing:

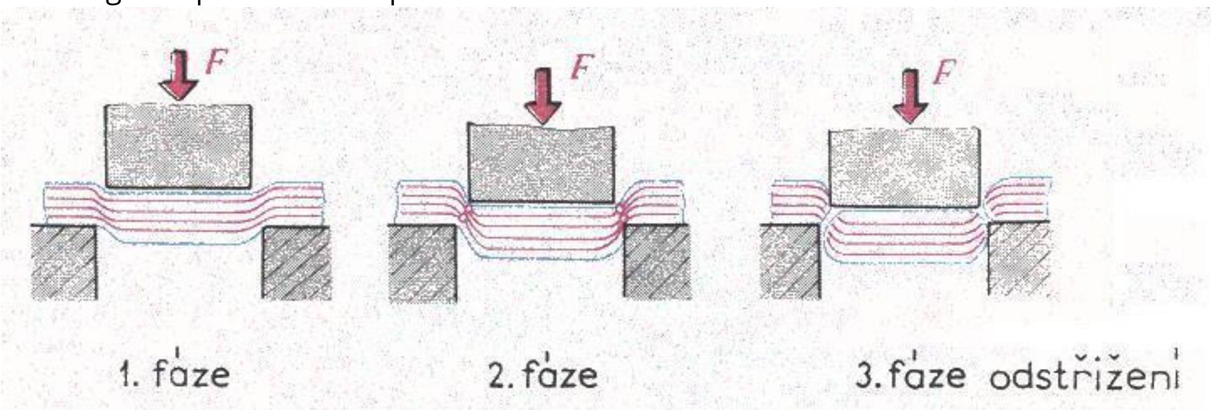
- cold shearing – for soft steels (maximum strength 400 MPa) or for sheets,
- hot shearing – for harder and thicker materials, heating to 700 °C

	Operace	Schéma	Definice
Stříhání plošné	děrování	 a b Obr. 1.	Vytváření otvorů různých tvarů. Vystřižená část tvoří odpad.
	ostřihování	 a b Obr. 2.	Oddělování přebytečného materiálu po obvodu součásti.
	prostřiho-vání	 Obr. 3.	Částečné oddělení materiálu v libovolném tvaru uvnitř dílce.
	vystřihování	 Obr. 4.	Zhotovení výstřižku oddělením od materiálu po uzavřeném obrysu. Vystřižená část tvoří výrobek.
	vystřihování zářezu	 a b Obr. 5.	Oddělování části v okraji i uvnitř materiálu. Vystřižená část tvoří odpad.

	protrhávání	 Obr. 9.	Vytvoření hrotů, otvorů, výstupků v plochém materiálu, přičemž se materiál vyhne z původní roviny.
	vysekávání	 Obr. 10.	Oddělování nekovového materiálu nástrojem na podložce.
Stříhání objemové	stříhání profilů, tyčí, trubek apod.	 Obr. 11.	Dělení profilů, tyčí a trubek podle neuzavřeného obrysu noži, které se míjejí při proměnné tloušťce stříhaného průřezu.

3.2. Shearing Principle

Shearing is separating a part of material by acting of opposing shearing edges causing sliding shearing stress in shearing plane. Shearing principle is shown in the picture. Shearing take place in three phases:



Tři fáze stříhání

Legend: 1. fáze - first phase, 2. fáze - 2nd phase, 3. fáze odstřižení - 3rd phase cut-off, 3 fáze stříhání - three phases of shearing

The first phase is a phase of elastic deformations, when the material is compressed, bent and pressed into the die hole.

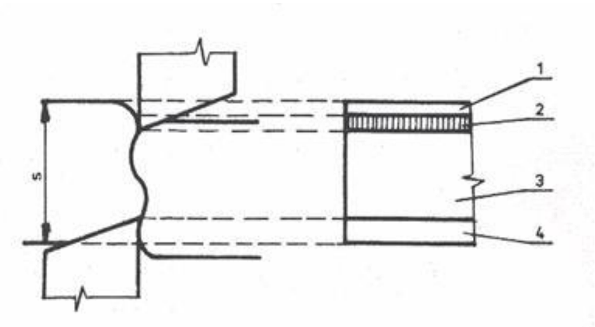
The second phase is the phase of plastic deformations. The punch is pressed into the sheet, this is pressed in the die hole and the stress exceeds the yield strength and approaches the ultimate strength on the edge of punch and die.

In the third phase, cracks appear at the edges, they spread until the material is ripped.

The shearing is separated before the punch passes through the thickness of the material shear and the shearing is subsequently extruded. Due to this, the edges of the shear surfaces are not completely planar and the shear has certain roughness which is not evenly distributed in the area.

The places where the first cracks appeared are rougher than the other shear areas. However, the material is not separated exactly in the required plane since the material is elastic, and the stress causes the pressure across the entire area. This is how we distinguish between the individual zones on the shear area.

Shearing is thus the only forming operation that results in desired material disruption. When calculating the forming forces, this is reflected by using strength limits instead of yield strength.



Deformation zones in shearing
1 – curvature (elastic deformation), 2 – tearing zone, 3 – shear zone (plastic deformation), 4 – pushing zone

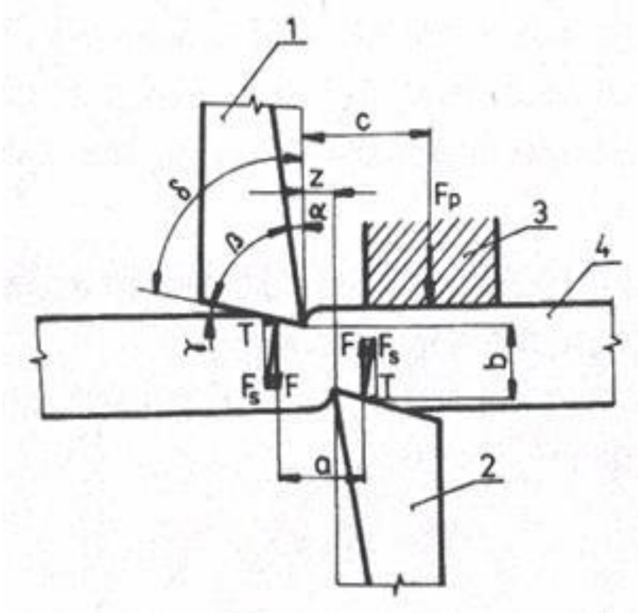
3.3. Calculation of Force and Labour for Parallel Blades

Due to the gap between the punch and die, in the actual process, shearing forces do not act ideally in a single plane, where the shearing force F_s decomposes into friction (***T***) and normal (***F***), which causes bending moments as well as individual zones in the final product or semi-finished.

The moment $M_p = F \,.\, a$ acts to rotate the material, which can be prevented by using retainer, while the heeling moment $M_T = T \,.\, b$ can be reduced by increasing the rake angle γ.

The retainer force can be calculated as $F \cdot a = F_p \cdot c$, where a is 1.5 - 2 times the shear gap size (denoted as z).

The force component T acts to move the blades apart and they are bent (risk of their breaking)



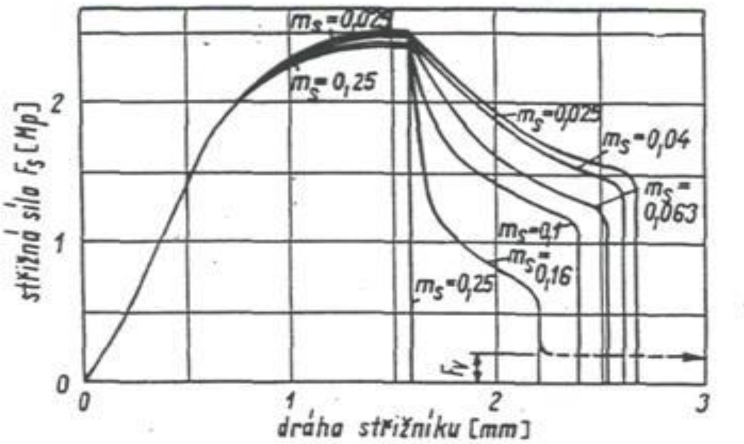
Principle and force acting in the case of shearing with parallel blades 1 – upper movable blade, 2 – lower immovable blade, 3 – retainer, 4 – material sheared

The magnitude of shear forces in shearing with parallel blades is calculated as follows:

$$F_s = (1{,}1 \div 1{,}3) \cdot O \cdot s \cdot \tau_s$$

Where

s ... thickness of sheet [mm],
O... shearing circumference [mm],
τs ... shear stress, shear strength - τs = 0,8 . R_m [MPa],
S ... cross-section area in shearing plane
- S = O . s [mm²].



Course of shearing force in shearing with parallel blades; example of shear gap influence on the course of shearing force F and magnitude of labor A
Legend: dráha stižníku - movement of punch, střižná síla - shearing force

Since shear stress, shear strength are the values depending on the degree of the average pressure of the blade into the material, the formula will not be valid for the whole shearing process, but the shear force will vary from the zero value to certain maximum and back to zero, which depends mainly on the material thickness, and partly also on the shear gap.

Actual shearing process does not produce pure shear but combined stress making the blades blunt; therefore, the actual shearing force is increased by 10 - 30 %. Shearing will be equal to the plane below the curve and will depend on the shear gap.

A = Fs . k . z

Where

K … is the coefficient of the space underneath the curve
z … stroke [mm].

3.4. Calculation of strength and labor for skewed blades

For calculation of shearing force and labor, analogous formula is applied related to a triangle area:

$F_s = (1,1 ¸ 1,3) . s . b . \tau_s = (1,1 ¸ 1,3) . s^2 . \tau_s / tg\ \varphi$

Where

s ... sheet thickness [mm],
b ... shear length – b = a / tg j [mm],
φ *... shearing angle, blade bevel angle (2 - 6° for guillotine shears, 7 - 20° for lever shears)*
τ_s *... shear stress -* $t_s = 0,8 . R_m$ *[MPa].*

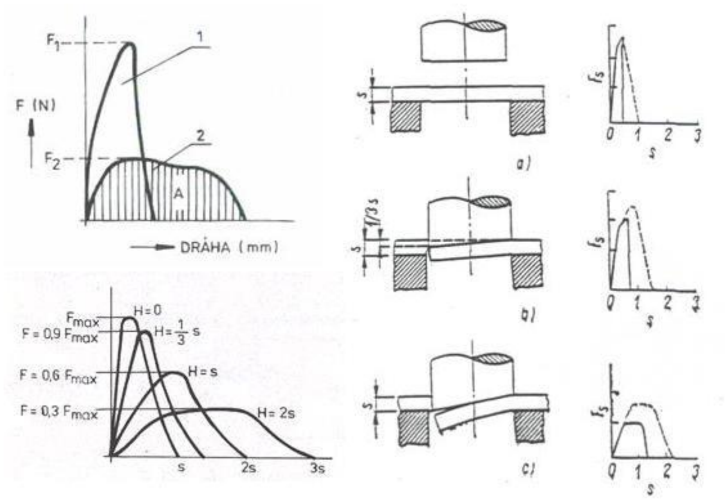
$A = F_s . k . z = F_s . k . b . tg\ \varphi$

Where

K ... coefficient of the space underneath the curve
z ... stroke [m].

The calculated force remains constant if the blade stroke reaches the full material thickness. The magnitude of shear force decreases when the blades are finishing the stroke until reaching zero. The necessary labor magnitude is calculated and equals to the area below the curve.

When comparing the magnitude of shear force and labor for shearing using parallel and skew blades it is obvious that shearing with skew blades is more advantageous, since for the same sheet thickness and shear length, much lower force is necessary than when using parallel blades; however, the length of the shear is much longer. Lowering shear force significantly reduces blade strokes.



Comparing the shear force and labor magnitude force when using parallel and skew blades (upper left) and influence of bevel angle on the force and labor magnitude course (bottom left) showing the course for bevel 0, 1/3 H a H = s (on the right – solid line is for normal shear, hatched line for precise shearing)

3.5. Classification of Shearing

By blades design, we distinguish between several types of shearing:

- shearing with parallel blades,
- shearing with skew blades
- shearing with disc blades,
- blades for shearing profiles and bars.

Shearing with parallel blades

The tool used for shearing with parallel blades consists of a pinch and a die, between which a clearance or shear gap is m_s (1/2 of shear clearance), as it is not possible to construct a tool without a gap due to an accident risk. To achieve a quality chip, an optimal clearance between a punch and a die is necessary. Clearance on one side is usually between 3 and 10 % of the sheet thickness depending on the thickness and strength of the material (clearance increases with the strength).

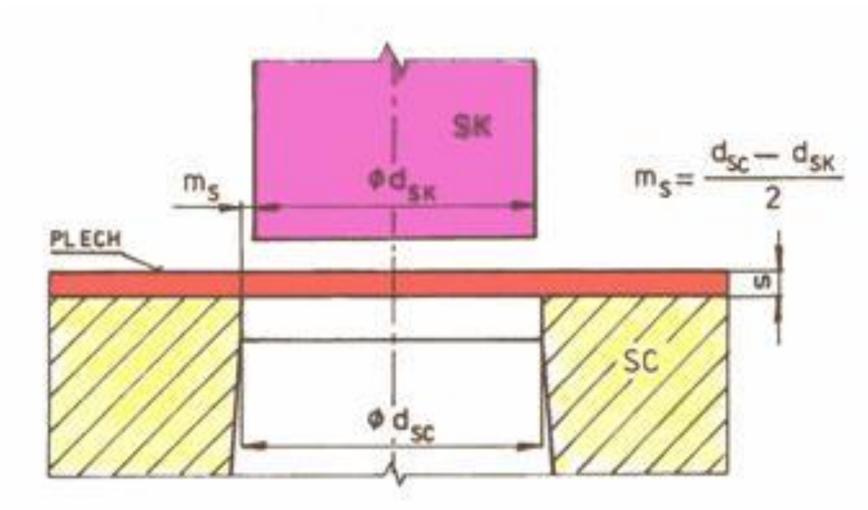
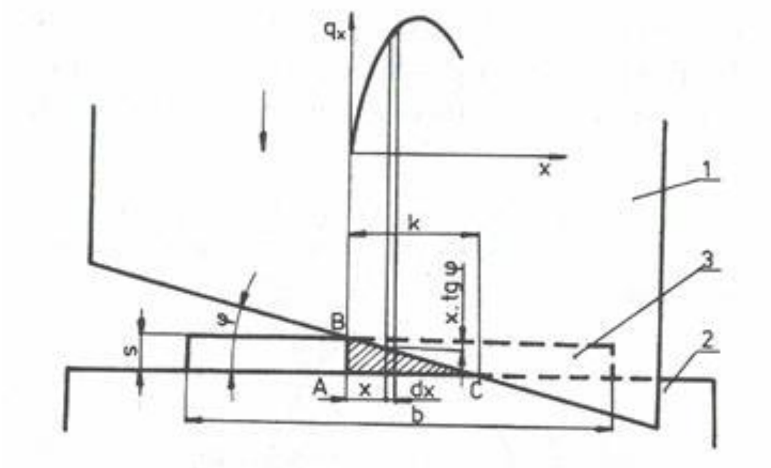


Diagram of shearing using shearing tool (SK – punch, SC – die)

Shearing with skew blades

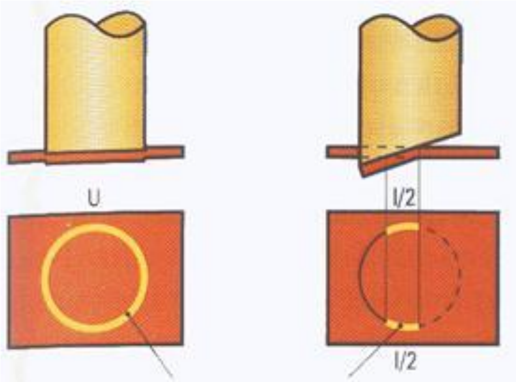
Shearing with skew blades which make a certain angle is suitable as it reduces the overall necessary shear force compared to shearing with parallel blades.

The material is sheared gradually. For the magnitude of the shear force the most important factor is the size of the shear edge and thickness – triangle area.

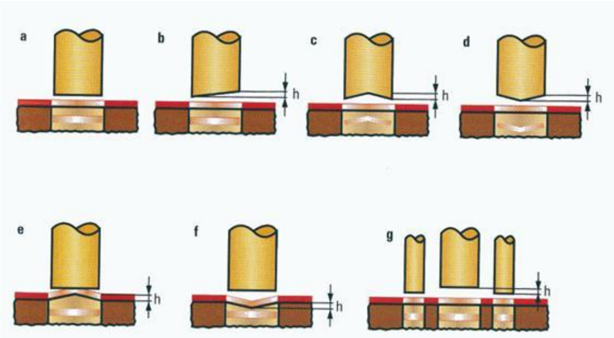


Shearing with skew blades
(1 – upper movable blade, 2 – lower immovable blade, 3 – sheared material)

As in the case of a simple straight shearing, the course of the immediate force can be controlled, even though the total labor exerted to shearing does not decrease. In the case of instruments, shearing tools consisting of die and shear pin used for two most widely used shearing methods, that is, punching and blanking, this could be done in two ways:



Comparison of shear length for shearing with parallel or skewed blades

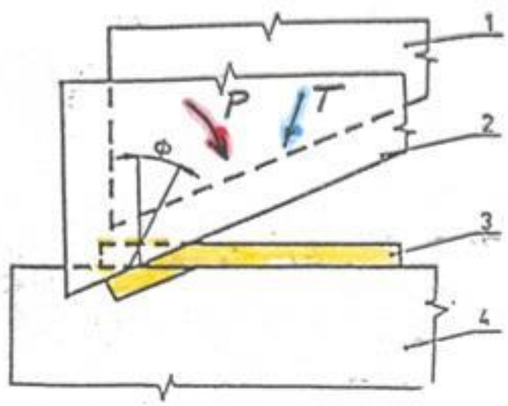


Shear pin and die modifications (a – straight shear, b – unilateral shear pin bevel, c, d – bilateral shear pin bevel, e, f – die bevel, f – stepped arrangement of shear pin)

Shear blades with beveled edges are used when we want to reduce the shear force that is greater than the press force. In the case of blanking, bevel is bilateral on the die – the product is straight, while the waste is bent. Bilateral bevel balances the forces on the shear pin and does not deviate from the axis. Unilateral bevel is used only for notching. For punching, the die is straight and shear pin is beveled, product is straight and waste is bent. When shearing complex shapes, edge bevel is not recommended.

Oblique shear includes lever shears whose blades are moved by angular tilting. Since the angle $\boldsymbol{\lambda}$ changes with tilting the blades, lever shears are usually designed with one or both oblique blades, so the angle $\boldsymbol{\lambda}$ remains constant along the shear line.

A specific method of shearing with skewed blades is a TAHANÝ STŘIH, when the SHEAR (DRAW TAŽENÍ) angle φ is 2 - 10° . This shearing method is used for shearing fibrous materials, where the shearing force is reduced by up to 20 % with the angle φ = 70°.



Material shearing – TAHANÝ STŘIH
(1 – initial position of movable blade, 2 – position of movable blade in shearing, 3 – lower immovable blade, 4 – sheared material)

Shearing with disc blades

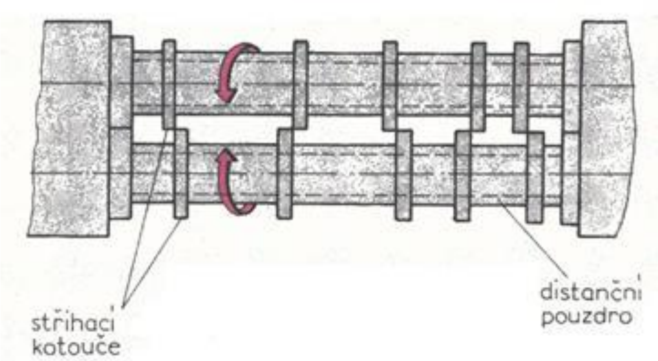
For longitudinal shearing of long strips, disc shears are used. It is a shearing tool with rolling blades.

The use of disc blades extends the shearing time but at the same time reduces the strokes. The angle of the edge changes from the highest values at the point of the stroke to zero.

The combination of a two-cone and cylindrical blade is used for shearing curved shapes, using the advantage of tilted tool axes.

For curve shearing the blades diameter shall be as small as possible. This enables to design shears with long disc carrying arms, thus enabling handling with sheared material.

A special type of shearing instrument is oscillating shears. They are used for trimming and making grooves and holes. The maximum material thickness is about 10 mm.

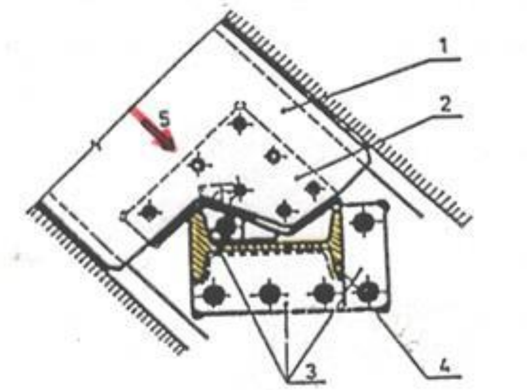


Circular shears – stripes shearing

Legend: střihací kotouče – shearing blades, distanční pouzdro – case

Shearing profiles, bars and tubes

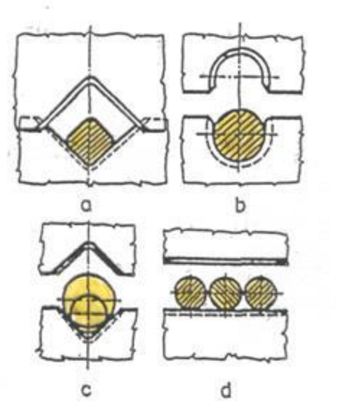
What is often sheared is profile material, circular, round, profiles, etc. While the cross-section of the functional parts of the tools remains roughly the same, the longitudinal shape changes according to the shear purpose.



Profile shearing blades
(1 – punch, 2 – movable blade, 3 – immovable blade, 4 – sheared profile, 5 – direction of blade movement)

When shearing any profile material, the principle is that the thickness shall be always almost the same. The shape of the movable blade adapts to this principle. The figure shows the blade shape for shearing profiles and blades shape designed for shearing square profiles as well as for shearing circular shapes. In the case of oblique movement of the movable part of the tool, a more uniform course of shear force is achieved in dependence on the stroke than if the movement of the blade depended on some of the cross-section axis.

When shearing tubes, with as little deformation as possible, the movable part of the tool has a shape of a pointed arc. The pointed part first pierces the tube; the sides then cut so that the resultant force on the edge is perpendicular to the direction of the highest toughness. The shear gap is not the same along the entire length; it increases from the sides to the center.

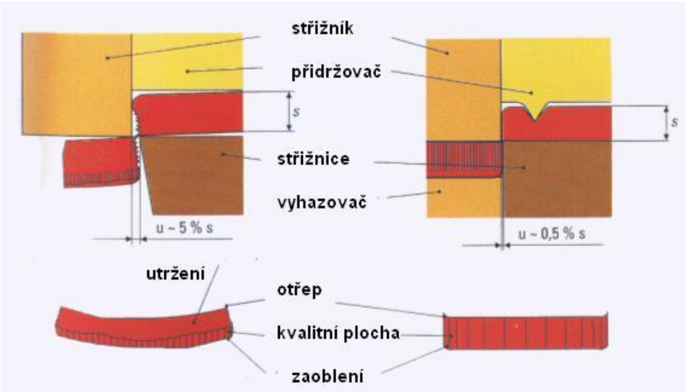


Blades for shearing square and circular material (a – square cross section, b – circular cross-section, c – cross-section with different diameter, d – circular cross-section with allowed deformation of profile)

4. PRECISION BLANKING AND SPECIAL SHEARING METHODS

4.1. Precision Blanking

Using the shearing methods described above, the shear surface and the sheared product have certain standard quality. This refers to the roughness of the sheared area surface and the precision of the dimensions. The following figure shows the shear quality for normal and precision blanking.



Shear quality for normal and precision shearing

Legend: střižník – shear pin, přidržovač - retainer, střižnice - die, vyhazovač - ejector, utržení - tear, otřep - burr, kvalitní plocha – quality surface, zaoblení – curvature

To enable using the sheared parts directly for assembly without any further modifications, technologists strived for improvement of the shearing process. All methods improving the quality of the shearing surface and dimensions of the sheared component are jointly referred to as precision blanking.

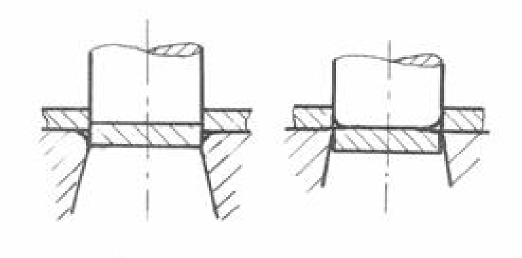
For the final product quality, clearance (gap) between shear pin and die is very important, since increasing the gap eliminates the tensile components caused by bending stress and the stress is close to pure shear stress.

Basically, precision shearing methods can be divided into producing the products:

- Within one operation – shearing without clearance, shearing with retainer, shearing with pressure edge, shearing with pressure edge and back pressure, reverse shearing, shearing with negative clearance, shearing using ESSA press,
- In two operations – trimming, vibrating shear pin.

Shearing without clearance

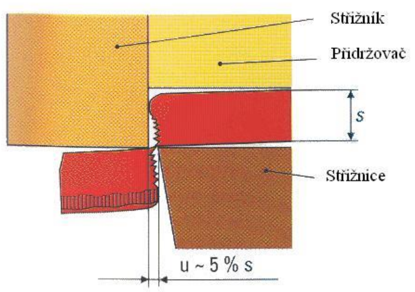
Shearing without clearance is shown in the figure. One functional part of the tool (either shear pin or die) is designed without an edge, with rounded shearing edge. The second part is sharpened. Left-sided arrangement improves the quality of the hole, right-sided arrangement improves the quality of the product surface.



Shearing without clearance

Shearing with retainer

Using retainer prevents bending the product edges and improves the quality of the surface. The tensile stress acts together with compressive stress, thus improving the stress at the shear point.

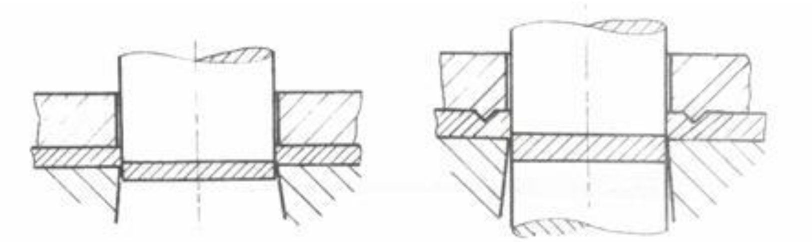


Použití přidržovače

Legend: střižník – shear pin, přidržovač – retainer, střižnice – die, použití přidržovače – using retainer

Shearing with pressure edge

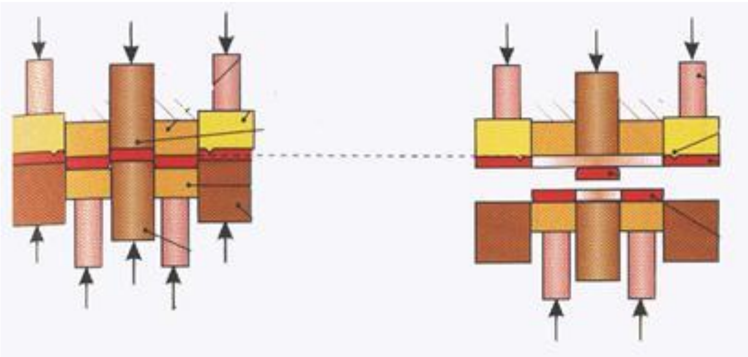
The best results so far in terms of precision blanking have been reported by using shearing with pressure edge. Pressure edge is pressed in the area of shear circumference, where it changes the stress in the shear area into a tri-axial one. The pressure edge also causes compression that facilitates moving closer to clean shear. Back press is ensured by elastic lower punch. This arrangement enables shearing of even relatively thick materials. For thicker materials (thickness of more than 5 mm) either two circumference can be used or one on the shear pin and one on the die.



Shearing with retainer (on the left) and shearing with pressure edge and back pressure (on the right)

Reverse shearing

Reverse shearing consists in gripping semi-finished product so the tension does not act.

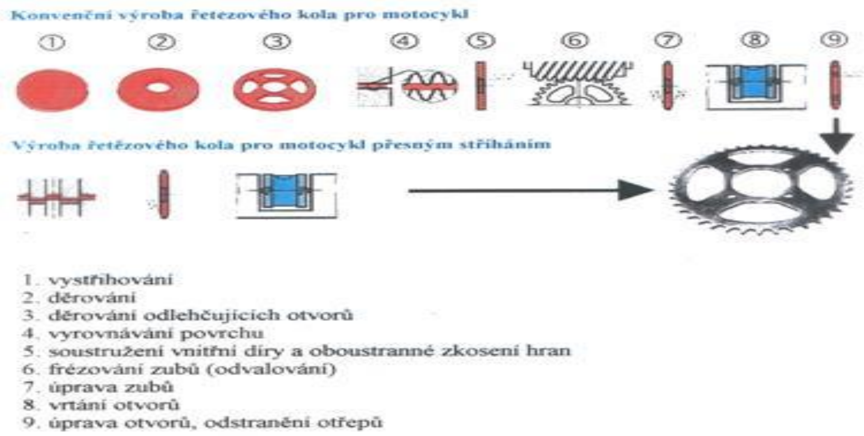


Reverse shearing

Shearing with negative clearance and using ESSA press

Shearing with negative clearance is a process when the shear pin does not penetrate into the die hole. The shear pin diameter is roughly by 0.1 – 0.2 % of the sheet thickness higher than the die diameter. Shear pin must be 0.2 – 0.5 mm over the die plane, thus causing compression in the material and therefore also higher shearing force.

Shearing using ESSA press is the process when shear pin shears and oscillates simultaneously, thus polishing the shear surface.



Legend: konvenční výroba řetězového kola pro motocykl – conventional production of motorcycles sprocket, výroba řetězového kola pro motocykl přesným stříháním – production of motorcycle sprocket by means of fine blanking, 1 – shearing, 2 – punching, 3 – making relief holes, 4 – surface treatment, 5 – making inner hole, bilateral edge bevel, 6 – cog milling, 7 – modification of cogs, 8 – drilling holes, 9 – modification of holes, removing burrs

4.2. Shearing Plans

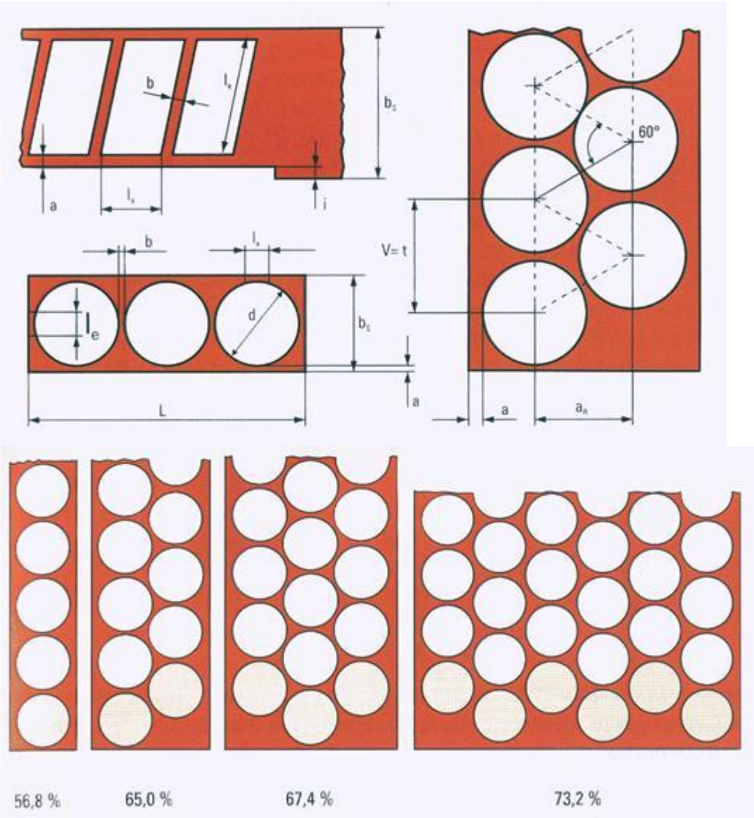
During shearing it is very important to place the pieces on the sheet so that there is as little waste as possible. Placement on the pieces on the sheet is then referred to as shearing plan. Waste (both technological and construction) is an inseparable part of the shearing technology, which is one of the mass production processes; therefore, placing the pieces must be paid great attention to, as material represents roughly 60 – 70 % of the overall costs. The selection of the shearing plan depends on the shape and structure of the product, adherence to construction principles, minimum distances between the products and the distance from the edge of the sheet.

Shearing plans can be either a piece plan, when the most suitable shearing method is chosen, or a large-scale shearing plan, when various shapes and components of one product are to be sheared.
Shearing efficiency is characterized by the coefficient of the material use, expressed as:

$$\eta = S_o / S_p$$

where

S_o … *overall area of the products [mm²],*
S_p … *area of the sheet strip [mm²].*



4.3. Shearing Tools

Shearing tools are the tools where the function of upper movable blade is performed by shear pin and function of lower immovable blade is performed by die.

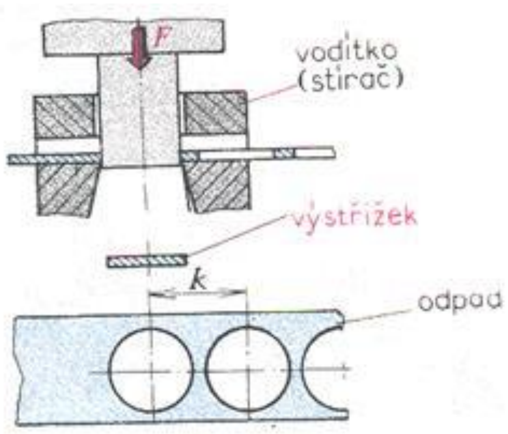
Classification:

- by number of operations
    - Single-operation,
    - progressive,
    - combined,
    - compound,
    - compound progressive,
- by type of operation
    - shearing,
    - bending,
    - pulling, etc.

- by number of products
    - single-product
    - multiple.

Single-operation shearing tools

The first type is a single-operation shearing tool. The position of the belt is ensured by stop, the movement is by one step (size of the product plus addition)



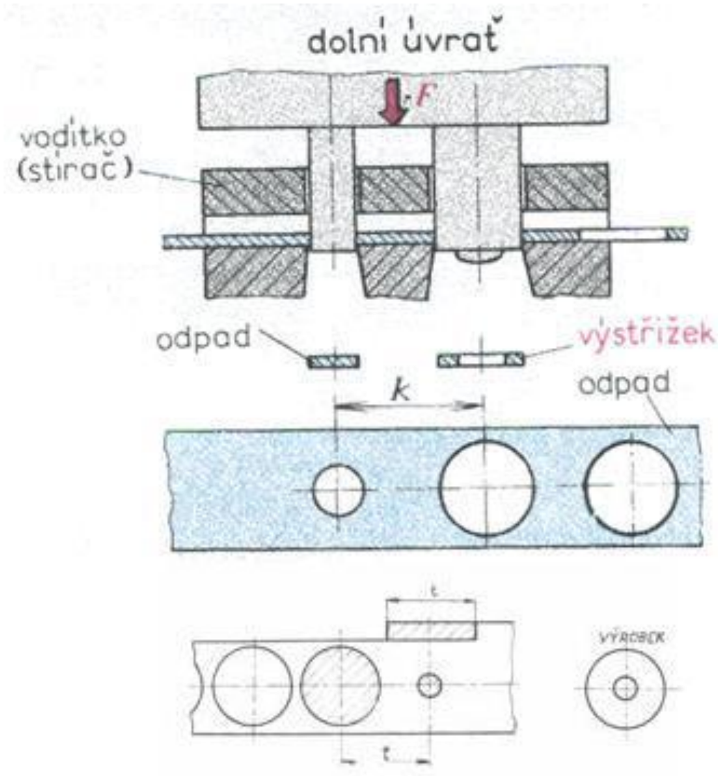
Single-operation shearing tool

Legend: vodítko, stírač – striper, výstřižek – product, odpad - waste

Progressive shearing tools

Progressive shearing tool makes the product progressively, using several steps and several operations. A load stop is used when a new belt is inserted. The position of the belt is ensured by fixed end stop.

The function of the tool can be seen in the figure. There are 3 hatched areas that are sheared in one stroke. The rectangular area is cut off by a side shear pin, ensuring so-called step, that is, the movement of the belt by distance ***t***. Circular areas of different diameters represent different products. The movement of the belt is from right to left. The right (small) circular product goes into waste, on the left side, the finished products (washers) can be seen.

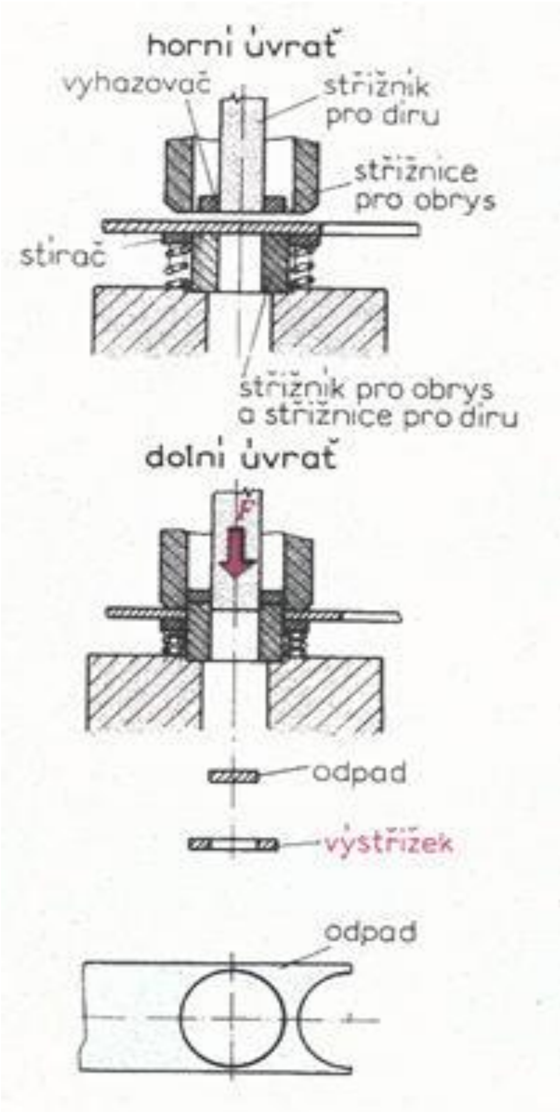


Progressive shearing tool
Legend: dolní úvrať – lower dead centre

Combined and compound shearing tools

A combined shearing tool is designed for several operations per one step. This way e.g. punching and blanking is performed while shearing.

Unlike this, a compound shearing tool is designed for combining various tasks per one step (e.g. shearing, bending, pulling, etc.) or per more steps. This is referred to as compound progressive tool. The individual operations are ensured by the design of the



shear pin or the tool as such.
Combined shearing tool

Legend: horní úvrať – upper dead centre, vyhazovač – ejector, střižník pro díru – shear pin for making hole, střižnice pro obrys – die for making outline, střižník pro obrys – shear pin for making outline, střižnice pro díru – die for making hole, dolní úvrať – lower dead centre

4.4. Special Shearing Methods

Shearing by means of rubber

Shearing by means of rubber is used for shearing the product from thin tin sheet. The shearing tool here consist of a steel plate, its thickness is 6 – 10 mm, with the same contour as the product contour is, and rubber either fixed in a frame or loosely placed on a semi-finished product.

Using this tool, trimming, punching, or combination of trimming and punching can be performed. The rubber plate thickness is about 150 mm and it consists of several components.

The steel frame is very stressed, as well as the steel shearing plate which must be of a smooth surface so that it does not leave traces on the final product.

The advantage is the tool simplicity and low price, the possibility to shear various parts at the same time, or a possible combination with pulling. Disadvantages include the volume of waste, thickness limitations, and low rubber durability.

Shearing at increased speed

Shearing at increased speed is based on minimizing the volume with depleted plasticity. The cracks are very close to each other, resulting in perpendicular and planar shear surfaces.
This is only possible at critical speeds, the values for carbon steel being between 3 - 5 $m.s^{-1}$.

5. BULK-FORMING TECHNOLOGIES – EXTRUSION

5.1. Extrusion

Extrusion is a technology that can be done at various temperatures – there is hot extrusion, warm extrusion, and cold extrusion. Stress in the deformed part of material is three-axial, under pressure from all sides. The material being formed is moved in the direction determined by the design of the forming machine – extruder. The product is then called extrudate.

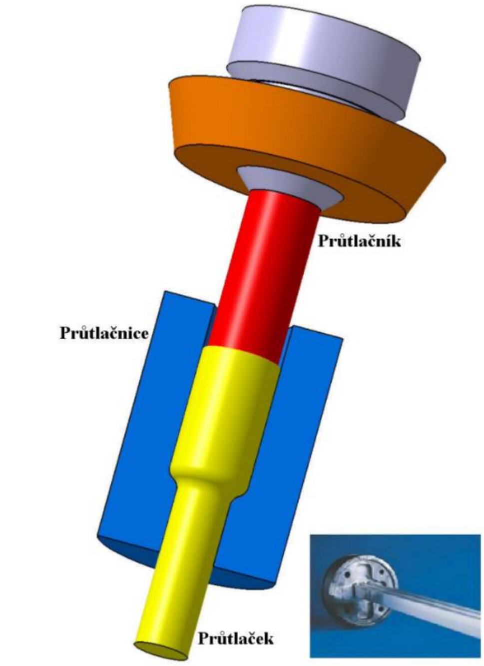
There are two types of this technology. The first type deals with final product manufacturing, the second type deals with semi-finished products (tubes, bars, profiles, etc.). Cold extrusion has been used for deforming light and non-ferrous metals for more than 100 years. This technology has been used e.g. for producing tubes, cartridges, etc.

Hot extrusion

- This technology is used for bars and tubes with a complicated cross-section that cannot be manufactured by rolling.

Cold extrusion

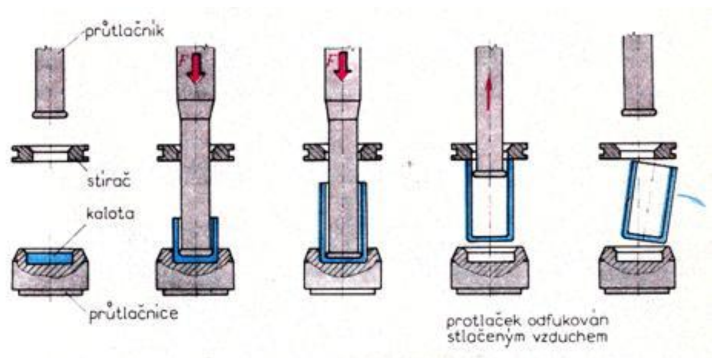
- This technology is used for producing thin-wall bodies: cartridges, tubes, spray cans.



Legend: průtlačník - pusher, průtlaček - extrudate, průtlačnice - die, protlačovací nástroj – extruder

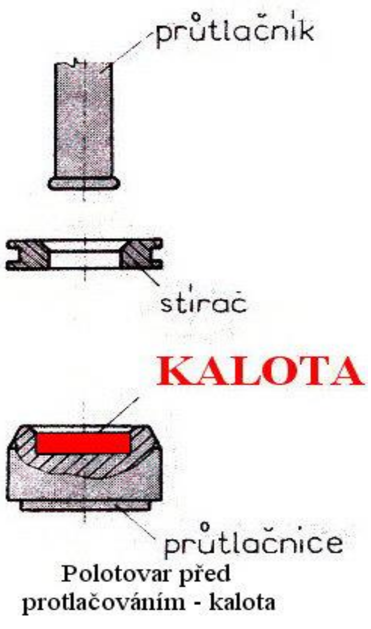
5.2. Extrusion Principle and Influence of Material

Extrusion principle consists in material deformation due to the forces acting in a pre-determined direction resulting in production of a final product with desired mechanical properties and dimensions. Extrusion is one the processes that contributed most to the significant reduction of the costs in production and therefore to the rationalization of production. The precision of extrudates is usually very high (± 0.05 mm), so it is not necessary to size them prior to mounting. Also the utilization of material is very high (90 - 100 %).



Legend: průtlačník - pusher, stírač - striper, kalota - calotte, průtlačnice - die, protlaček odfukován stlačeným vzduchem – extrudate blown off by compressed air

- The quality and initial state of the material significantly influences extrusion technology and process.
- Due to the magnitude of resistance, for extrusion, materials with more than 10% ductility and 50% contraction (steels with a C content up to 0.2 %) are suitable.
- Unsuitable materials are those that require forming pressure higher than 2500 MPa or if it is not possible to make at least a 25% deformation during one operation due to their chemical composition.
- Materials with low forming strength (aluminium and its alloys) can be extruded in one operation.
- Steels and other metals are extruded in more than one operation. In some cases, intermediate annealing is necessary (first recrystallization and then soft annealing).
- The maximum reduction per one extrusion is limited by the permissible stress of the device. Reduction e.g. for steel with a 0.1% C content is up to 60 %.
- Before extrusion, the material must be modified by straightening and dividing into calottes, including heat treatment and followed by surface treatment.



Legend: polotovar před protlačováním (kalota) – semi-finished product before extrusion (calotte)

5.3. Labour and Foce Calculation

For cold extrusion, high deformation forces are necessary, depending on the chemical composition of the material, preparation and heat treatment, lubrication, tool geometry (the bigger, the higher force), size of reduction (the bigger, the higher force), wall thickness (the thinner, the higher force), type of the machine. The necessary forces and labour are difficult to calculate and will not be mentioned here. The cold extrusion resistance grows with the degree of the material reinforcement, and the calculation is as follows:

kostř = (ko1 + ko2) / 2,

It is the same even if it is not a line but a curve. In the case of hot extrusion the resistance is constant.

5.4. Influence of Friction

One of the decisive factors in extrusion process is *friction* that significantly influences the process, the quality of the product and economy of production, especially in the case of steels – appropriate surface treatment is necessary, otherwise dry friction occurs and the tool blows. Surface treatment consists of:

- Removing surface defects (blasting, grinding, pickling in the case of Al, ...),
- Chemical and mechanical cleaning (washing, drying, ...),
- Phosphatising (phosphate surface has high adhesion to initial material, which is mostly a disc or a disc with a hole, so-called calotte. This allows the material surface to be lubricated due to the porosity of the phosphate layer at high pressure, which was first used in the 1930s.),
- Application of a lubricant layer (e.g. by solution of organic oil and soap).
- Magnitude of friction forces also depends on the roughness of pusher and die surface and their wear at critical points. In some cases, glass of a suitable chemical composition is used as a lubricant for hot extrusion. The glass melts when extruded (and it is necessary to remove the glass-like film). In the case of non-ferrous metals, so called *chemise* is used /gap between the pusher and die, about 2 – 4 mm, where the material leaks and acts as a lubricant.

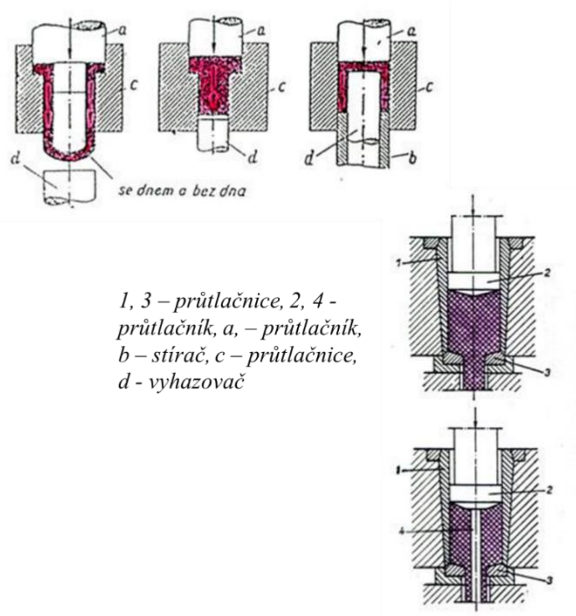
5.5. Classification of Technologic Methods of Extrusion

Extrusion is divided into several types by the direction of movement and tool:

- Forward (direct),
- backward,
- combined,
- side extrusion,
- radial.

Direct extrusion

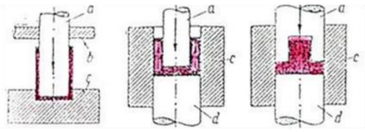
In forward (direct) extrusion, the material moves in the same direction as the pusher. The initial semi-finished product is a calotte obtained by e.g. sheet metal pressing or bars parting. It is used in forming pins, bolts, bushings, etc., that is, products with not constant cross-section.

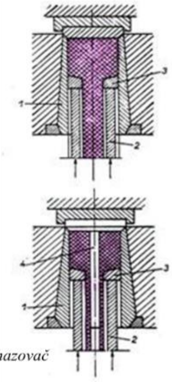


Legend: 1,3 – die, 2,4 – pusher, b – striper, d – ejector, se dnem a bez dna – with and without bottom

Backward extrusion

In backward extrusion, the material moves in the opposite direction. It is used for manufacturing hollow extrudates with ribs, where the wall thickness is very small or very high compared to an average.

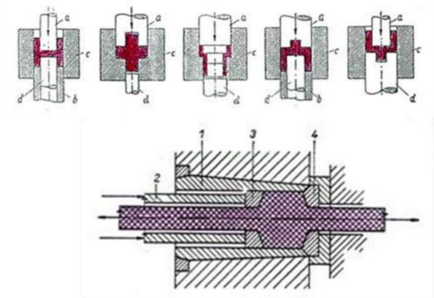




1, 3 – průtlačnice, 2, 4 - průtlačník, a, – průtlačník, b – stírač, c – průtlačnice, d - vyhazovač

Combined extrusion

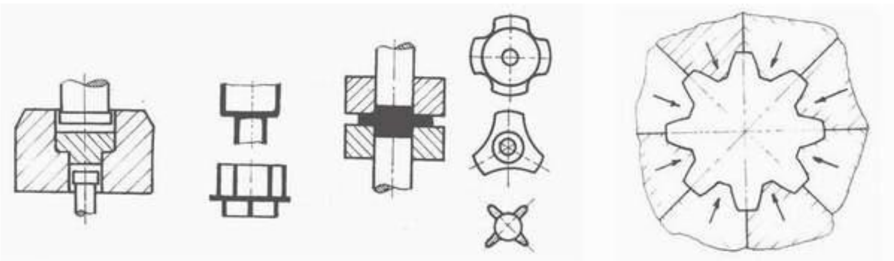
It is used for manufacturing profiles that are much stressed and that do not have to be of a cylindrical shape. In combined extrusion, material moves in both directions, if the degree of deformation in the lower part of the extrudates at the bottom of a die must be lower than in the upper part formed by a pusher; otherwise the material does not get into the bottom.



1, 3 – průtlačnice, 2, 4 - průtlačník, a, – průtlačník, b – stírač, c – průtlačnice, d – vyhazovač

Side and radial extrusion

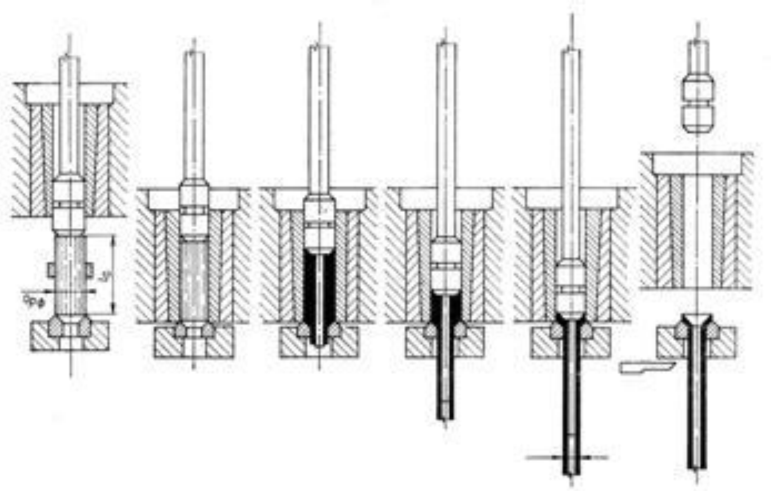
In side extrusion, the material formed moves perpendicular to the direction of the pusher movement. It is used for manufacturing extrudates with external and internal bilateral mounting. Radial extrusion consists in forming in which the material and machine parts move in the radial direction to the material axis.



5.6. Special Extrusion Methods

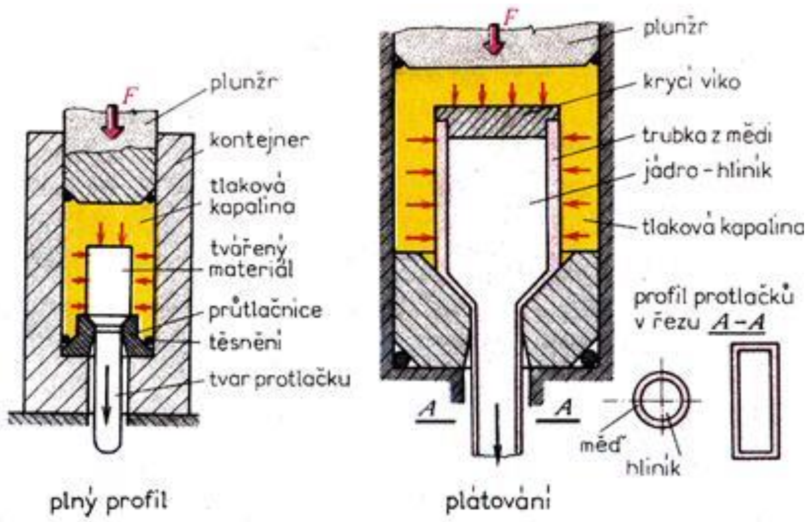
Pipes extrusion

For the technology of ***pipes extrusion*** the initial semi-finished products are rolled blocks of required length. This is followed by heating and **punching** and **forward extrusion**. When the process is finished, in the die there is remaining material, technological waste that has to be removed. The degree of deformation is high, the coefficient of lengthening is 8 – 25 (from the semi-finished product of a 700-mm length and 200-mm diameter, a pipe of a 6-18-mm length can be made).



Hydrostatic extrusion

Another special technology is **hydrostatic extrusion**, where the semi-finished product is surrounded by a fluid of a high pressure. This creates a tension on all sides and the malleability of the material increases. Technological possibilities of hydrostatic extrusion are so advanced that extrusion can be done without a phosphate layer, or it can be used for the copper clad products. Hydrostatic pressure is up to 3000 MPa. Forming in one operation can be up to 80%.



Legend: plunžr - plunger, kontejner – container, tlaková kapalina – pressure fluid, tvářený material – material formed, průtlačnice – die, těsnění, tvar protlačku – extrudates shape, plný profil – full profile, krycí víko - lid, trubka z mědi – copper pipe, jádro – core, hliník – aluminium, profil protlačků v řezu A-A – profile of extrudates in A-A section, měď – copper, hliník –aluminium, plátování – cladding

5.7. Extrusion Machines and Tools

An important factor is also the *construction* of the tool and *geometry* of the die and pusher. It is not possible to choose any bevels, radii, curvatures (zaoblení), etc. of the forming parts of the tool. A tool, whose main parts are pusher and die, is subjected to a specific pressure, so its material, heat treatment, and surface roughness are important. The lifespan of the forming parts of the tool is between 3000 and 50000 pieces. The cold extrusion process of steels is limited by the strength of the die material; in the case of backward extrusion, also by the pusher material strength.

For cold extrusion, mostly mechanical crank and toggle vertical presses and hydraulic presses are used. The pressing force is 300 - 120000 kN. In hot extrusion, the materials processes are the materials whose cold formability is limited and would be expensive (e.g. rolling). After extrusion, the extrudates are ejected by the ejector or blown by compressed air. In combined extrusion, the extrudates are ejected by the ejector or striper (depending on whether they stick to the pusher or remain in the die). The inner walls of the extrudates are slightly conical with a bevel of 1 - 2°. The tool must have holes for air and lubricant leakage.

6.BENDING

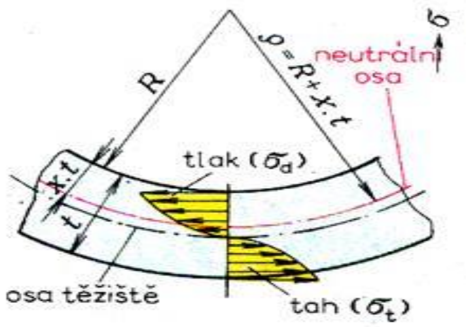
6.1. Technology of Sheet Metal Forming – Bending

- Bending is a forming process in which the material is deformed in various bending angles with higher or smaller edge rounding.

- For bending, a **bending tool** is used, consisting of a **bending punch** and **bending die**.

- The product is a **stamping (bend)**.

- Bending (the resulting shapes can be returned to their original shape) into the desired shape works on the same principles of plasticity as other forming methods. Exceeding the yield strength, plastic deformation is achieved. Plastic deformation is accompanies by elastic deformation. It´s an elastic plastic deformation



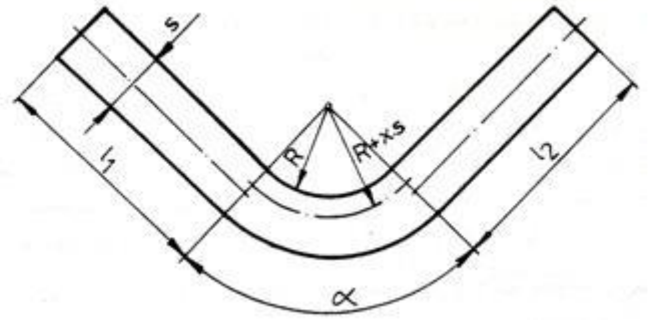
with a different course from the material surface to the neutral axis.

Distribution and size of stress in material
Legend: neutrální osa – neutral axis, osa těžiště – center of gravity axis, tlak – pressure, tah – drawing

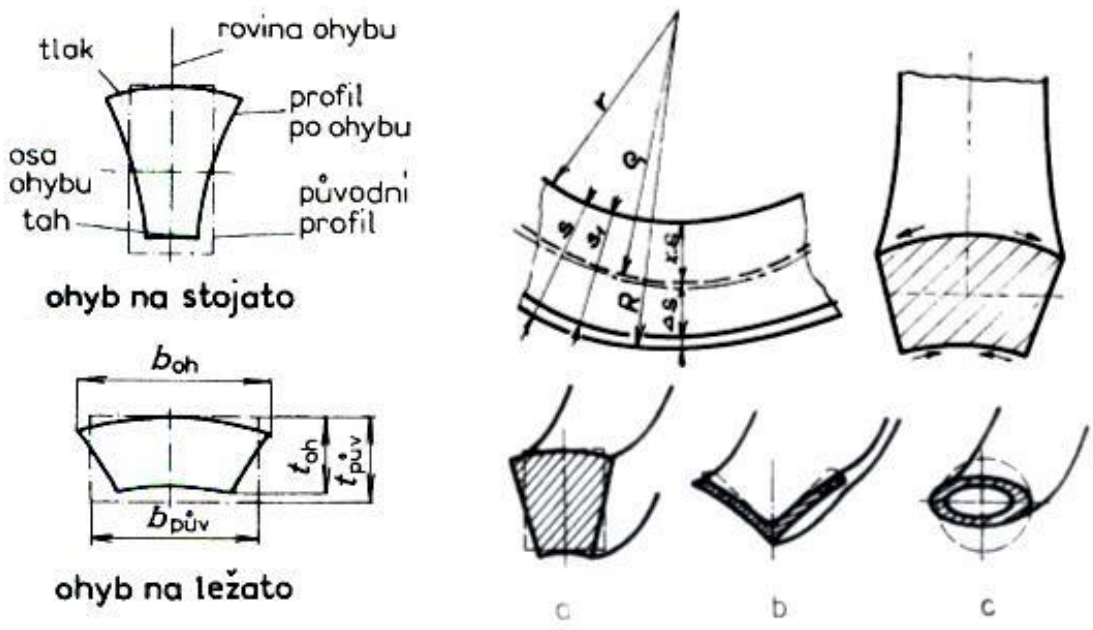
6.2. Deformation of Cross Section, Neutral Axis

Bending deforms cross-section. In the case of higher cross-section, the deformation is higher than in the case of smaller cross-section. In the case of wide bands (b ≥ 3s) the material is not deformed because the resistance of the material of large width (due to its small thickness) acts against the deformation in transverse direction. Metal layers on the outside of the bend expand and extend in the longitudinal direction and compress in the transverse direction.

Around the central part of the section of the bent material, tensile stress achieve lower values than the yield strength of the material is. Between the two bands the fibres are stress free and there is no deformation. Their links make a so-called neutral axis in which there is no stress and which neither shortens or extends in bending. The neutral axis is at the beginning in the centre of the section, during bending it moves towards the inner side of the bend. It is thus not identical to the centre of gravity axis of the bent material.



Movement of neutral axis at the point of bend



Cross-section deformation during bending for different heights and profiles

Legend: tlak – pressure, osa ohybu – bending axis, tah – draw, původní profil – initial profile, profil po ohybu – profile after bending, rovina ohybu - bending plane, ohyb naležato - horizontal bending, ohyb nastojato - vertical bending

The length of the semi-finished product before bending is determined from the length of the neural axis in bent parts and from the length of the straight sections. In the case of thin tin sheets, the difference is not significant, however, it has to be taken into account in the case of thick tin sheet. The distance ***x*** characterizing the position of the neutral axis depends on the ***R/t*** – see the table. The bending radius of the neutral axis is

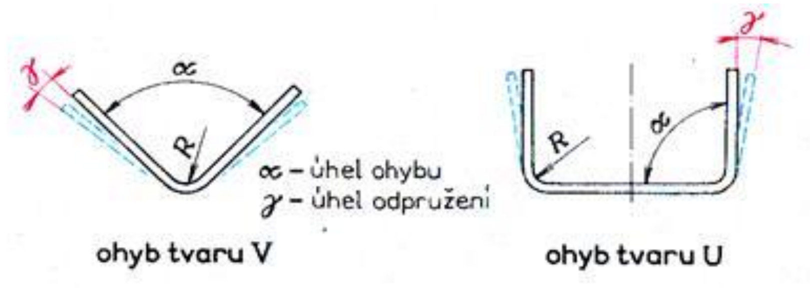
ρ= *R* + *x* . *T*

where

R … inner bending radius [mm],
x … coefficient of neutral axis movement,
t … thickness of material [mm].

6.3. Cushioning

If the external forces do not act on the body being deformed any more, the dimensions of the body partially return to the initial state, that is, the body will cushion. While in the case of the technologies discussed above the cushioning was negligible, it is important in the case of bending. Cushioning at bending shows as an angular deviationy, whose importance increases with the length of the arms. Reverse cushioning of the bent parts is caused by the elastic deformation of the material around the neutral axis. The size of the angles depends on the material ductility, bending radius and bending method. It usually ranges from 3 to 15°.

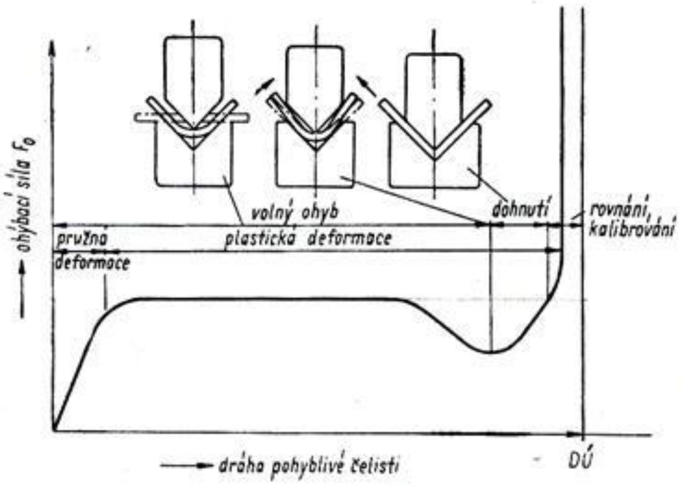


Legend: úhel ohybu – bending angle, úhel odpružení – cushioning angle, ohyb tvaru V/U – V/U-shape bend

Cushioning is mostly limited as follows:

- The material is bent by the value of the cushioning angle γ, which is determined either by the empirical formulas or from the tables. The tool must be designed with the angle correction γ, otherwise the product won´t have the desired shape.

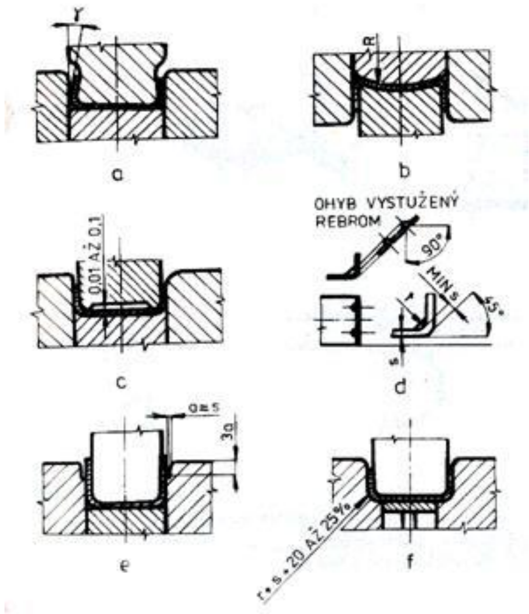
- *Calibration* is used, i.e. the pressing force at the end of the pressing cycle is increased, local plastic deformation occurs at the point of the bend and the value



of cushioning decreases until it eventually disappears.

Course of bending force including calibration
Legend: ohýbací síla – bending force, pružná deformace – elastic deformation, plastická deformace – plastic deformation, volný ohyb – loose bend, kalibrování - calibration

- **Depressions** on the **stamping** will be used, when the cushioning is almost completely removed. Bending cushioning can be removed as follows: lightening (podbroušení) of the movable jaw by angle γ, rounding of the lower side of movable jaw and retainer by radius R, strengthening of the material in the corners by impact, pressing of the rib at the point of bending, gradual bending with the lightening of fixed jaw by the material thickness and strengthen-

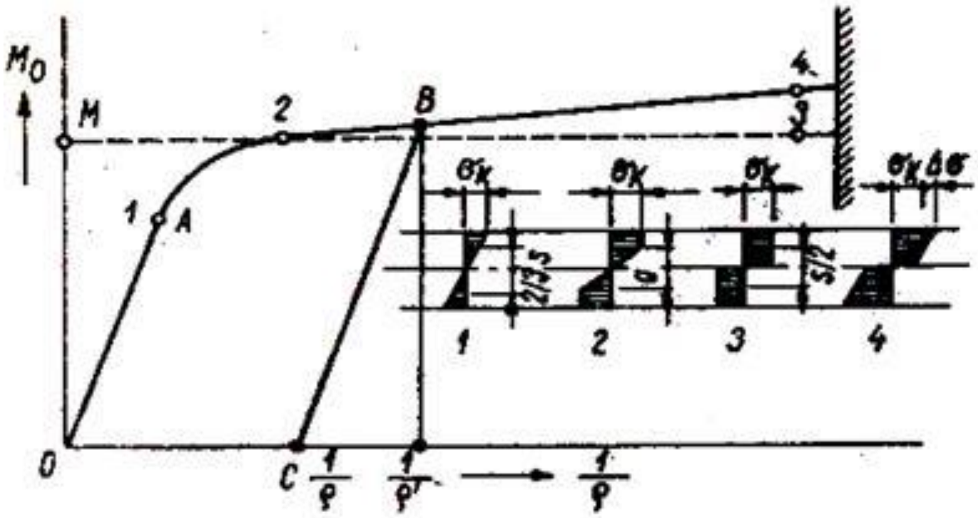


ing the material by a deformation radius in the fixed jaws.

Structural adjustments of bending jaws as a protection against the material cushioning

6.4. Distribution of Stress

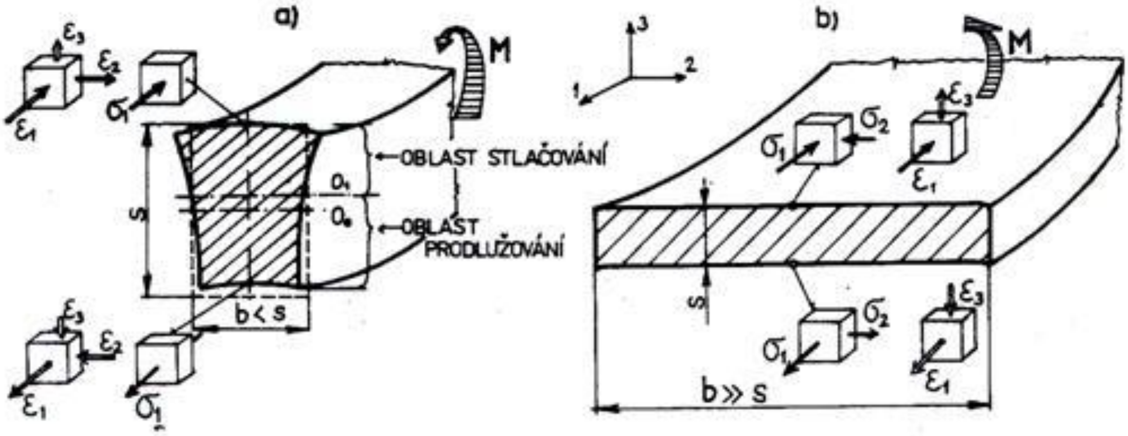
- When bending, the stress in the outer fibers of the materials is opposite (draw, pressure).
- The figure (**1**) shows the distribution of the stress in the material cross-section subjected to bending below the yield point.
- If the stress rises above the yield point, plastic deformation increases as well (in the centre). In this case, the stress in the zones of plastic deformation does not rise above the yield point value (**2**).
- If the bending moment increases, the elastic core disappears and the size of stress remains constant (**3**).
- If we consider strengthening of the material in cold forming, the ratios are according to (4) and the figure on the right.
- Around the neutral axis, there is a zone of elastic deformation, which causes cushioning after lightening.



Stress distribution in cross-section when bending material

At the point of bending, the material bent shows three zones (the stress in the bent material in the case of thin tin sheet is shown in the figure):

- Zone of elastic deformation around neutral axis,
- Outer zone of permanent prolongation,
- Inner zone of permanent heading



Stress and deformation in bent material

Legend: oblast stlačování - compression area, oblast prodlužování - lengthening area

6.5. Bending Technological Procedures

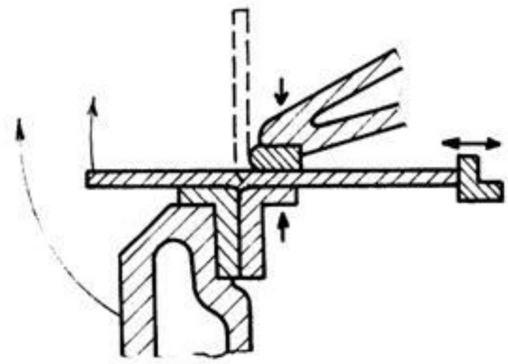
- Bending can be performed freely or using a fixed tool.
- Bending technological procedures can be divided as follows:
    - By the tool used,
    - By the curvature radius,
    - By the technological method.

Classification of technological procedures of bending by the tool used

- **Manual** bending using **manual bending tools,** benders.

- Not all bending operations can be done using press. For some bending operations, special bending tools, also manually operated, are designed, e.g. for bending long strips and tin sheets (these are bent using a machine with a hinged plate – see the scheme in the figure)

- The material to be bent is placed on the machine table and leveled to the stop. Then it is clamped at the bending edge. The edge on the machine consists of replaceable steel hardened bar. After being clamped, the material is bent by tilting the plate by any angle pre-adjusted with a stop. The machine is delivered with a number of auxiliary devices.



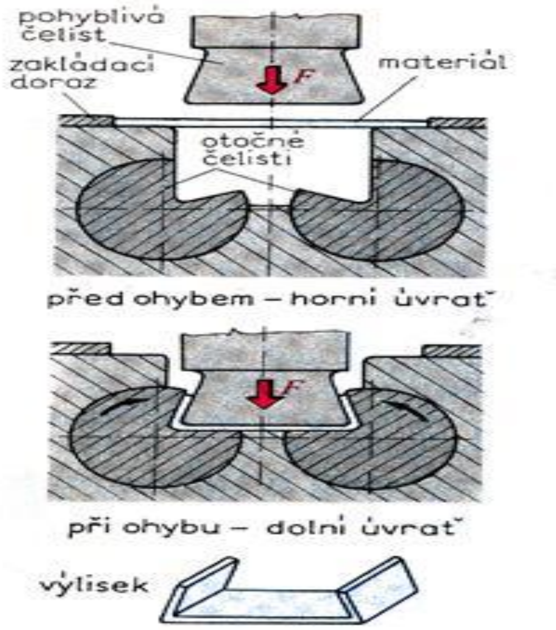
Bending tool with a rotating plate

- Bending using **presses** in a bending tool (bender), whose movable jaw performs rectilinear reciprocating movements.

- This type of bending is done using the following types of presses:

    - mechanical
    - hydraulic,
    - Special machines - depending on the technological process itself

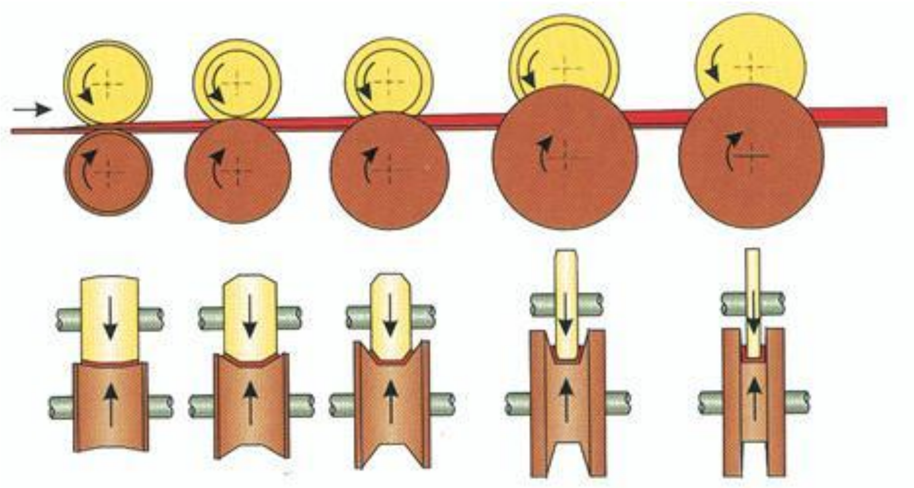
- Bending tools for press application are quite simple compared to other tools. The figure shows a bending tool for bending with a bending angle above 90°. The cylindrical parts of the tool rotate around the cylinders axes and springs return them into the initial position. The product is removed from the tool by sliding from the bend, perpendicular to the bend plane.



Bending tool (bending angle above 90)°

Legend: pohyblivá čelist – movable jaw, material –material, otočné čelisti – rotating jaws, před ohybem – before bending, horní úvrať – upper dead centre, při ohybu – during bending, dolní úvrať – lower dead centre, výlisek - stamping

- Bending using rollers: the bending tool are the rollers performing a rotating movement. The following figure shows an example of bending by rolling.



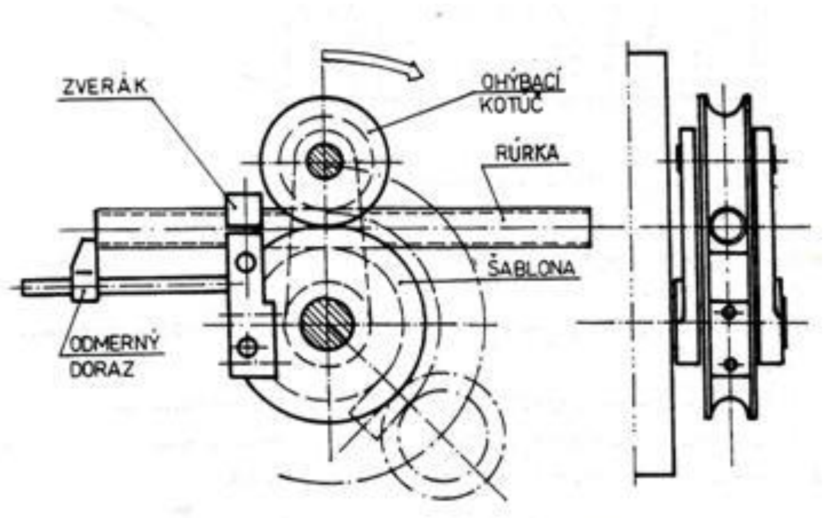
Bending by rolling

Classification of technological procedures by curvature radius

- Bend with a small radius – large plastic deformation,
- Bend with a high radius – low degree of plastic deformation.

Classification by production technology

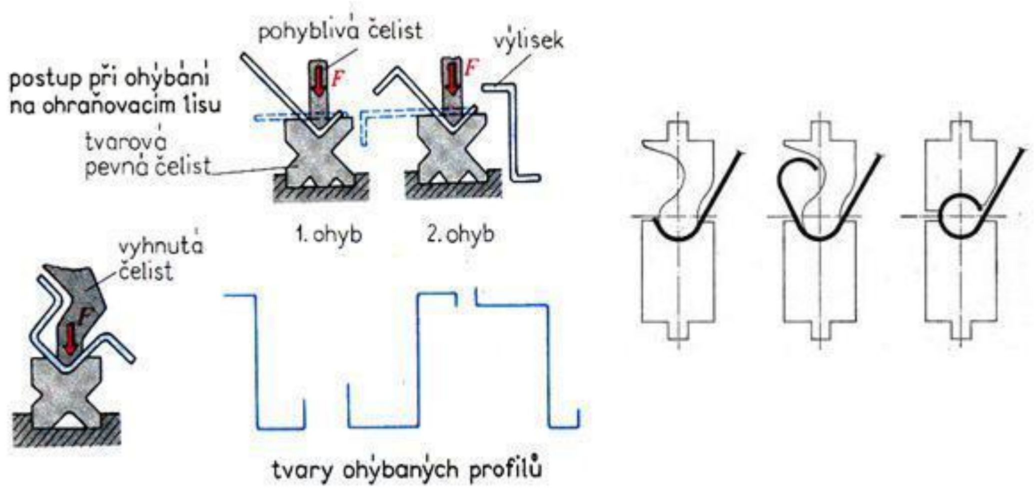
- "classical" bending - examples of bending were shown in the figures and diagrams. The figure below shows bending of tubes. Bending is carried out by rolling the disc over the pipe inserted in the slot of another disc. The disc are replaceable, the slots dimension must correspond to the diameter of the tubes. Deformation of tubes is prevented by inserting the tube into the slot so that it cannot widen.



Bending of tubes

Legend: svěrák – clamp,doraz – impact, ohýbací kotouč – bending disc, rúrka (trubka) – pipe, šablona – mould

- **Brake bending** on presses that serve to produce various thin-walled profiles as well as profiles of thickness of 20 mm, and profiles with a small rounding radius. The principle is not different from bending on common press. The difference is in the length of the machine and the press. The length is limited by the width of the braking press.



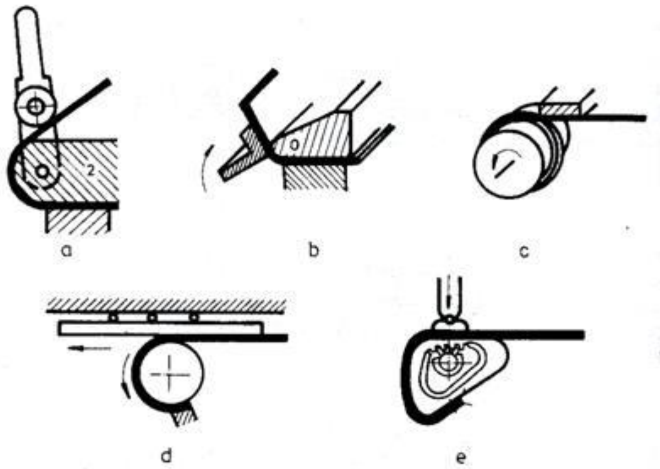
Brake bending examples

Legend: postup při ohýbání na ohraňovacím lisu – brake bending on brake press, tvarová pevná čelist – fixed jaw, pohyblivá čelist – movable jaw, výlisek –stamping, ohyb – bend, vyhnutá cellist – bent jaw, tvary ohýbaných profile – shapes of bent profiles

The starting material is the sheet bands. Each forming operation is performed per one press stroke and for each profile shape a separate tool must be attached to the press. The tool consists of various steel bars that are both delivered with the machine and also specially designed and manufactured. The upper part of the tool can be shaped. Brake press is a mechanical press enabling to use long bar tools. On both machines, the bend is performed in the entire length of the material:

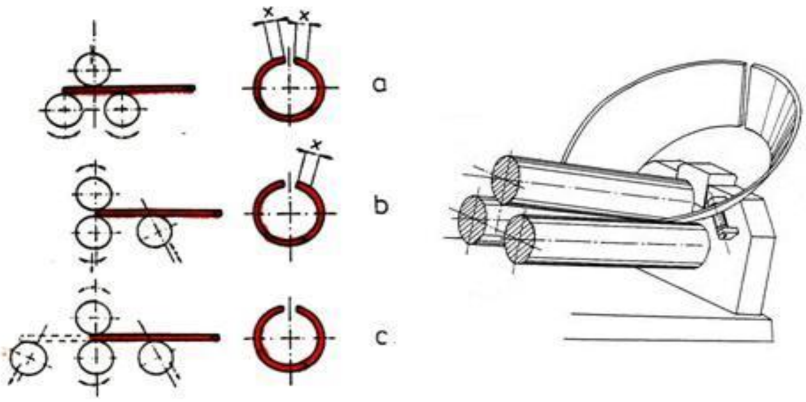
- **Flashing (lemování)** is an operation when we need to reinforce the edge of a stamping or prepare a semi-finished product for an additional forming of joint. It is also used to make grooves in the middle or on the edge to increase the rigidity of the product.

- **Winding (navíjení)** is a process when the formed material is wound up gradually on the roller and produces the desired shape identical to the shape of the tool. Most often, winding is used in coil sheets.



a – manual, b – using bending tool, c- winding springs on mandrel,
d – winding bars, e – winding a belt on mould

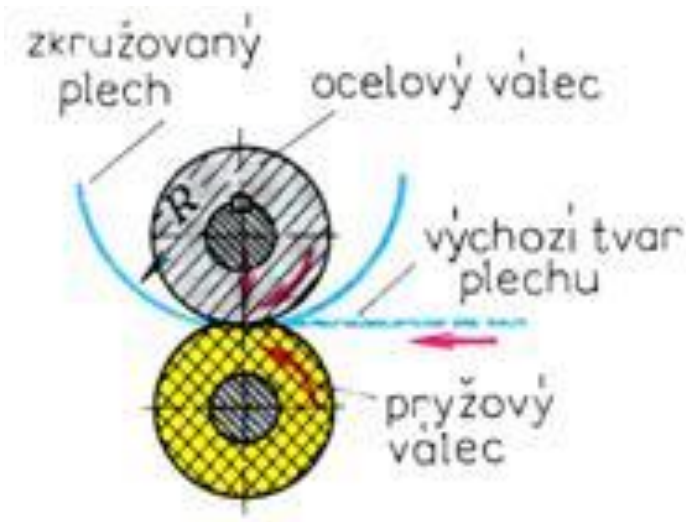
- **Roll bending** is used for manufacturing cylindrical or conical casing of containers, tubes, even for 30-mm thick sheets. Thicker sheets are then hot rolled. Machines used for this purpose are called bending rolls (see the figure below). The tools can be three or multi-roll tools, and their design depends on the sheet thickness and requirements for the rounding of sheet ends.



Arrangement of bending rollers (on the left) and a detailed view to a cone bending (on the right)
a – three-rolled symmetrical tool, b – three-rolled unsymmetrical tool, c – four-rolled

Thin sheets are bent on the machines with a steel and rubber roller – technology of bending using elastic tool. The bending radius changes depending on the rubber compression. The surface quality of the products is significantly better, but more forming labour is necessary, as a part of it is necessary for the deformation of the elastic part of the machine – rubber.

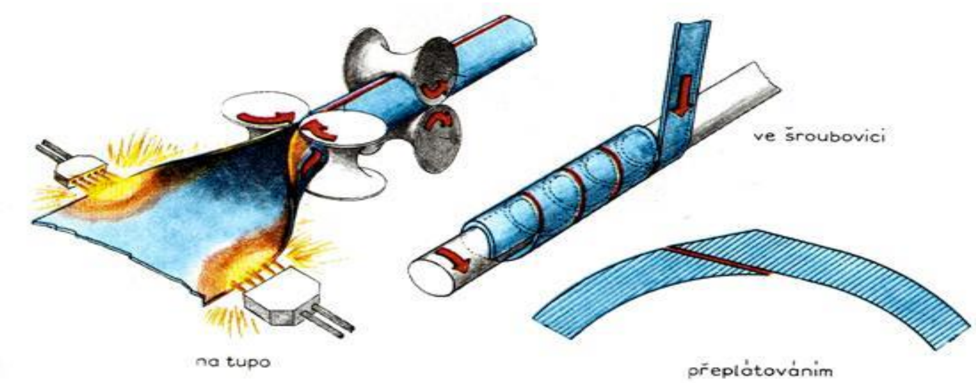
- Rolling, profiling, winding on presses is performed in order to create a circular shape on the sheet edges. It consists in a gradual continuous bending of strips on profiling machines and it is used for manufacturing tubes (welded, thin-walled) and profiles or for winding hinges wings using the vertical movement of press beam. During rolling, a gradual change of shape occurs by bending using rollers that are of different dimensions so that there is a horizontal tension in the sheet and the strip moves on its own, at a high speed (about 25 m.min-1).



Bending tool with rubber roller

Legend: zkružovaný plech bent sheet, ocelový válec – steel roller, výchozí tvar plechu – starting sheet shape, pryžový válec – rubber roller

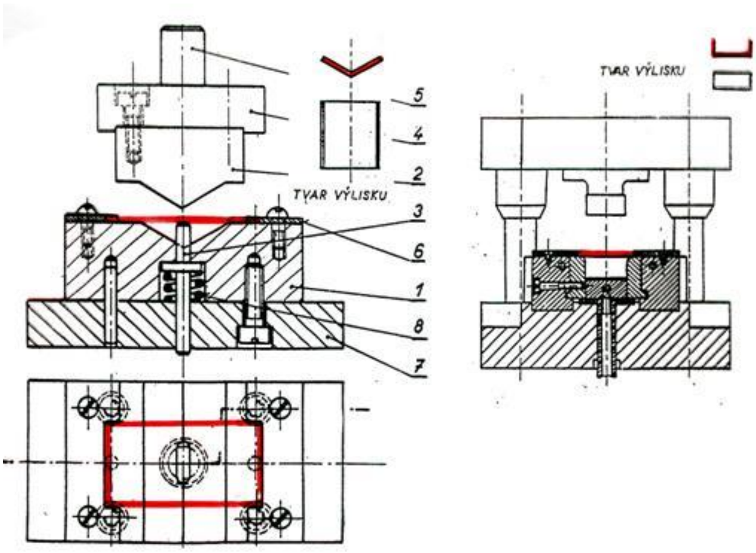
For profiling, simple two-part tools can be used, designed as a pair of profiled discs. The figure on the left shows a tool adapted for lateral bending of a sheet, the figure on the right shows adaption for beading (žlábkování). The lateral bend and the groove can be made on the edge of a planar sheet (strip) as well as on the edge of a sheet rolled into a cylindrical shape. By gradual bending, it is possible to make a profile of any length, including in the case of more complex profiles.



Manufacturing of thin-walled tubes by profiling, winding, overlapping
Legend: na tupo - butt, ve šroubovici - helix, přeplátováním - overlapping

6.6. Bending Tools

- Bending tool consists of *bending punch* and *bending die*, or loading stops. Bending tools can be divided by the method and technology of bending, mostly for a U or V shape. Bending tools are usually not separate and are designed as combined tools.

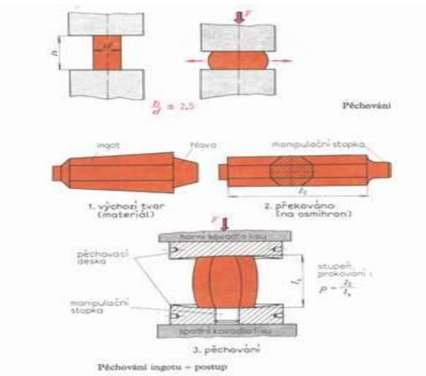


Tools for a V (on the left) and U (on the right) bent

7.SPECIAL FORGING METHODS

7.1. Upsetting

- The basic procedures of open die forging include **upsetting**.
- Upsetting is the simples forging process, in which plastic deformation of the material occurs between two flat or forming jaws.
- On the other hand, upsetting is the most force and energy-intensive forging operation. It can be either direct forging when forging flat forgings or a pre-operation for perfect forging of the material, reducing anisotropy and more suitable arrangement of fibres.
- It reduces the height and extends the cross-section surface.
- For forging, the material shall be heat up evenly and ensure parallel end faces, reduce the thinness of the material (risk of bending), and ensure position perpendicular to the machine axis.



Upsetting of cylindrical semi-finished products

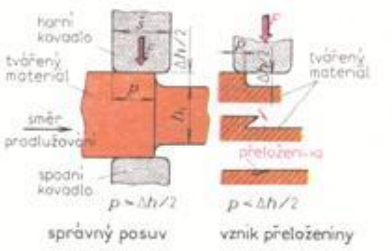
Legend: pěchování – upsetting, ingot - ingot, manipulační stopka – handling shank, výchozí tvar materiálu - starting shape of material, překováno na osmihran – forged into octagon, pěchovací deska – upsetting plate, spodní kovadlo – bottom die, stupeň prokování – forging degree

7.2. Fullering

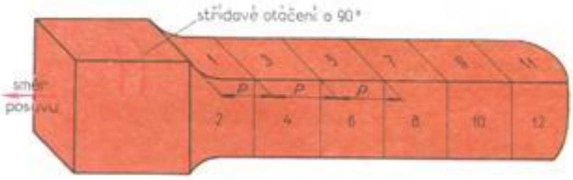
- Another technology of open die forging is **fullering** (drawing out).

- It is the most widely-used forging operation, consisting in carrying out more up-setting operations side by side, thus extending and at the same time reduction of the cross-section.

- Semi-finished product is mostly turned by 90° and moved by distance p, thus compensating the expansion. The stroke p is always smaller than the width of the die s is.



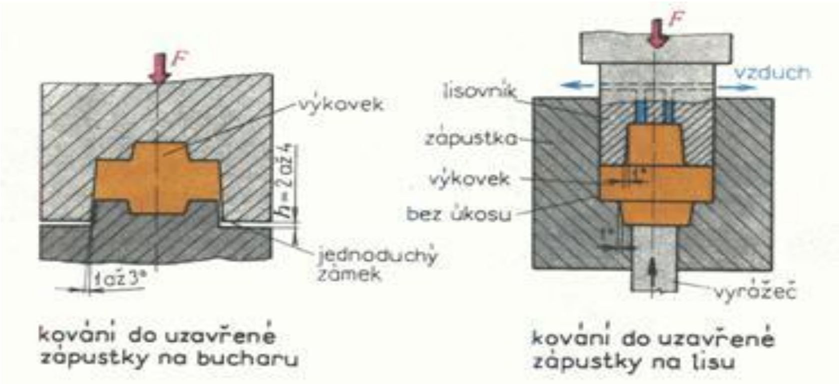
Prodlužování



7.3. Precision forging

- Forgings with minimal machining allowances and bevels are made in closed dies by means of so-called **precision forging**.

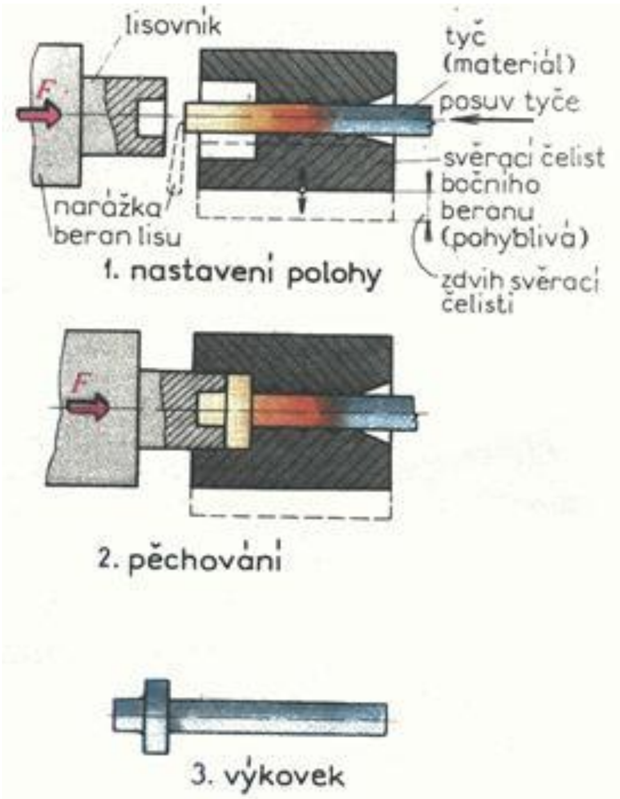
- In the case of precision forging, the volume and centring of the material inserted into die must be strictly observed. Rotary shapes are most preferred.



Legend: výkovek – forging, jednoduchý zámek – simple lock, kování do uzavřené zápustky na bucharu - forging in closed die on hammer, lisovník - punch, zápustka - die, bez úkosu – without bevel, vyrážeč - ejector, vzduch - air, kování do uzavřené zápustky na lisu – forging in closed die on press

7.4. Forging using horizontal forging press

- **Forging using horizontal forging press** enables a partial or complete automation of the process.
- It consists in using horizontal crank press suitable mainly for upsetting from bar material and working with closed dies.
- The principle is shown in the figure.
- It uses a closed three-piece die, forging is without flash. The cavity of the die is two-piece, divided by a vertical or horizontal plane, with a roughened passage for bar material. It acts as a chuck for the bar material when the two halves approach to each other. The third part (upsetting part) is inserted into the cavity in the axial direction.
- Principle: the bar is moved into the forging position, to the stop. This way the volume of the forged material is determined. Then the two-part block clamps the bar and moves the stop. In this phase, the protruding part of the bar is heated (nowadays it is most often inductively).
- After upsetting the heated end of the bar, the sliding blade separates the forging from the bar and the cycle is repeated.

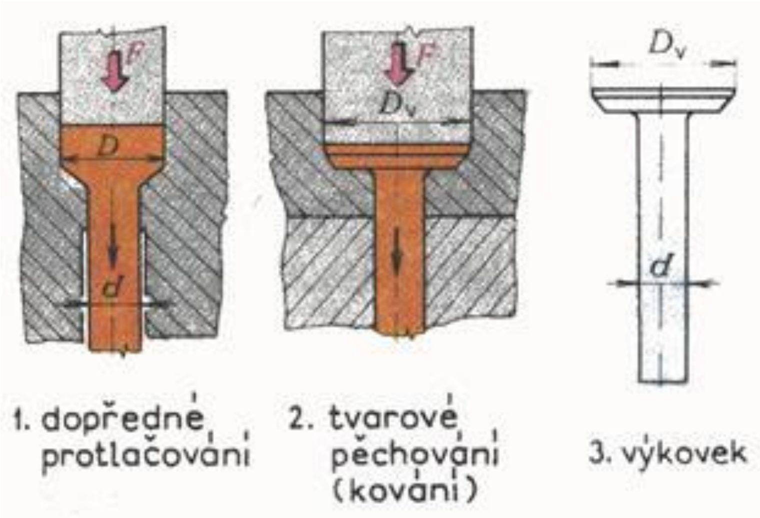


Forging using parallel forging press

Legend: lisovník - punch, narážka - stop, beran lisu – press beam, tyč (material) – bar (material), posuv tyče – movement of bar, svěrací čelist bočního beranu (pohyblivá) – clamping jaw of side beam (movable), zdvih svěrací čelisti – stroke of , nastavení polohy - positioning, pěchování - upsetting, výkovek - forging

7.5. Extrusion forging

- Another technological process is forging – hot **extruding**, when the formed material is pressed by extruder in a closed die.
- It is a combination of extruding and forging. This method is used for aluminium and copper alloys as well as for steel.
- It increases the ductility of metal, as the material is subjected to spatial pressure stress.
- It can be performed as forward extrusion, backward extrusion or combined extrusion. It is necessary to take into account also friction and high strength and heat resistance of the tools.

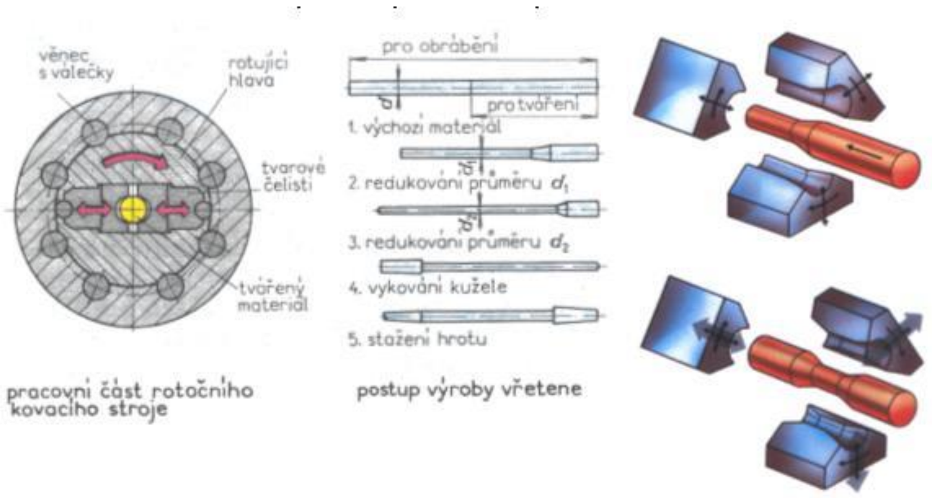


Legend: dopředné protlačování – forward extrusion, tvarové pěchování – shape upsetting, výkovek – forging

7.6. Rotating forging

- A special forging procedure is so-called **rotating forging**.
- It is used for reduction of cross-section to a smaller diameter or forging of a cylindrical shape from a square profile. Unlike other forming processes, rotating forging is cold, only for manufacturing components of bigger diameters, hot forging is used.
- It is included among forging methods because deformation is done by repeated thrusts.
- Principle: two radially movable dies are rotated. They are drifted towards the edge by means of centrifugal force. Here they impinge on hardened cylinders which give them a return impulse. This creates a repetition.
- The semi-finished product is rotated slowly and axially moved into the forming process.

Examples of rotating forging and methods of rotating are shown in the figures below

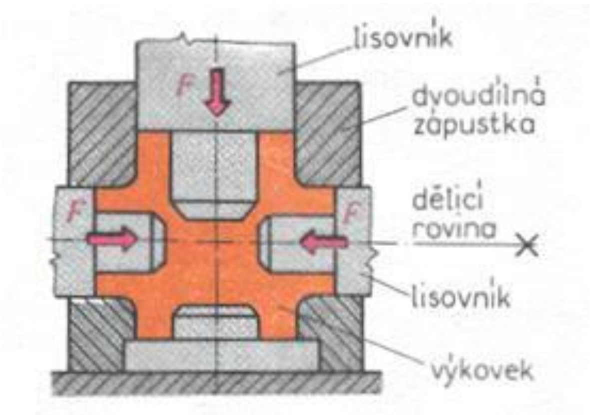


Rotating forging principle

Legend: věnec s válečky – rim with rollers, rotující hlava – rotating head, tvarové čelisti – forming jaws, tvářený material – formed material, pracovní část rotačního stroje – working part of rotary machine, pro obrábění – for machining, pro tváření – for forming, výchozí material – starting material, redukování průměru – reduction of diameter, vykování kužele – forging a cone, stažení hrotu – tip reduction, postup výroby vřetene – spindle manufacturing

7.7. Multidirectional forging

- The last special forging method is **multidirectional forging**.
- The material in the closed die is subjected to the pressure of the punch from several directions.
- Forging are precise, with minimum machining allowances.



Legend: lisovník – punch, dvoudílná zápustka – two-part die, dělicí rovina – separating plane, výkovek - forging