Heating of the metal before metalworking.

Dynamic recovery (restoration). During heating of metal up to certain temperature the thermal oscillation are increased so the return of the atoms at equilibrium state is facilitated. Due to this fact elastic deformation which occur during metalworking disappear. Such phenomena of decreasing of residual stresses after loads cease to act is called dynamic recovery. For pure metal recovery occur at temperature equal to $(0.25–0.3)T_m$. In the present of alloy components this temperature increases.

Several submicro- and microprocesses may be involved during hotworking that may affect the hardness and strength of the material. First of all, the hardness usually increases due to strainhardening as a result of the increase in the dislocation density. This strainhardening may be counteracted by a softening process due to dynamic recovery as a result of the elimination of dislocations and due to dynamic recrystallization. If dynamic recovery proceeds rapidly enough, the flow stress increases progressively up to a steady state value at which the stress-strain curve levels off. Dynamic recovery causes decreasing of resistance of the material to deformation and increasing of plasticity. Restoration doesn't affect the size and shape of the grain. The rate of the recovery is increased due to temperature rise. Effect of the recovery may be reduced due to high strain rate.

During temperature increasing some carbon steel manifests ageing. This strengthening effect may be explained by the precipitation of intermetallic compounds along the slip planes.

Further heating will cause recrystallization as a result of the continuous nucleation and growth of new grains. When dynamic recrystallization occurs the strain-strain curve may exhibit a maximum, which may be eventually followed by the steady state stress. New grid has right, uniformly oriented unit cell. For pure metal temperature of recrystallization is equal to 0.4 Tm.

Depending on temperature there are four types of deformation:

a) Hot working – dynamic recovery occurs, no strainhardening, deformation temperature range is 0.7Tm < Tm < 0.8 Tm where Tm = incipient melting temperature.

b) Warm working – some strainhardening and/or precipitation hardening may occur, deformation temperature range is 0.3 Tm < T < 0.5 Tm.

c) Cold working – strainhardening occurs, deformation temperature range is <0.3 Tm.

The forgeability does not always raise due to heating. For example, when heated grey iron exhibits low yielding limit and at the same time low percent elongation to fracture.

The temperature interval of forging may be defined as range of temperatures when metal exhibit high plasticity and low resistance to deformation or high forgeability. There two kind of such temperature interval: optimal and technologically appropriate interval. Optimal interval is defined by starting and final temperature of forging which are determined according reference literature concerning certain metal in certain condition. It is maximum interval.

Technologically appropriate interval is defined by the time which is necessary to accomplish certain forging operation. It is less then optimal. It is advisable to use mechanical characteristic dependence on temperature.

The low boundary of temperature interval must be greater than temperature of the phase transformation. The upper boundary of temperature interval is limited by temperature of *burning* and *overheating* of metal.

Burnt metal – permanently damaged metal caused by heating conditions that produce incipient melting or intergranular oxidation. *Overheated metal* is the metal with an undesirable coarse grain structure due to exposure to an excessively high temperature. Unlike a "burnt" structure, the metal is not permanently damaged but can be corrected by heat treatment and/or mechanical working.

When temperature is raised up to 750-800^{0}C plasticity is decreased due to phase transformation. Austenite structure is most plastic. At the temperature equal to 1100-1200oC carbon steel has austenite structure. Austenite is a solution of the carbon in α-iron with great plasticity and toughness. At the same temperature high carbon steel has two-phase structure – austenite+perlite. It must be taken into account mass of the forging, whether or not further heat treatment, cooling procedure. For example, big mass is cooled slowly and small grains have time to increase.

Sometimes the upper boundary of temperature interval have to be reduced because of necessity to reduce scaling and decarbonization of steel. A steel is high oxidized in medium which contains oxygen O_2, water vapour H_2O and sulfurous anhydride SO_2. With temperature raised this process is intensified. This is illustrated by following

Temperature. . .	900°	950°C	1000°C	1100°C	1300°C
Scaling coefficient . . .	1	1,25	2	3,5	7

Due to high temperature carbon in surface layer burn away. Hence mechanical properties of a metal are deteriorated. Processes of oxidation and decarbonization depend on temperature, rate and time of heating.

There are two way to heat a metal – direct or indirect. Indirect heating is the heating when heat is transferred to metal due to contact with some heated medium (gaseous or liquid). Direct heating is the heating when heat is generated right in metal and the temperature of an environment is lower then temperature of a metal.

Indirect heating are the heating in furnace, molten salts, electrolytes.

Direct heating are the follows: contact (energizing the workpiece), inductive.

Heat transferring from surface inside the stock resulting from thermal conductivity, heat capacity (temperature conductivity):

$$a = \frac{\lambda}{c\rho}$$

where a - temperature conductivity

λ - thermal conductivity

c - heat capacity

ρ - density.

The higher thermal conductivity the faster heat transferring occur inside a stock, the less time is required for equalization of the temperature across cross section of a stock. Thermal conductivity is depend on chemical composition of steel. The greater percentage of alloying element and carbon, the less its thermal conductivity. Thermal conductivity of alloyed steels increases when temperature is raised and for carbon steel decreases. Heat capacity of a carbon steel is less then heat capacity of alloyed steels.

Temperature difference across cross section is always occur. Such difference is greater when heating rate and cross section are greater. Additional stresses arise in metal due to temperature difference because of nonuniform volume changing. Such stresses may cause breaking of the workpiece.

Another factor which influences the process of heating is plasticity of the heated metal. All metals become more plastic at temperature greater then 550 so further quick temperature alteration doesn't cause breaking of a metal.

Choosing of a method of the heating and of equipment for heating influenced by sizes of heated stocks. Ingots for open die forging and for extrusion are heated in combustion furnace of different design in which different types of fuel are used (solid, gaseus and liquid). There is wide variety of used heating equipment in aircraft manufacturing industry for closed die forging.

HEATING EQUIPMENT CLASSIFICATION

The main methods for heating equipment classification are follows:

1) energy source classification: combustion and electrical furnace;
2) principle of operation: continuous and batch-type furnace;
3) purpose of function: for forging, for rolling.

In batch-type furnace stocks are unmovable. Loading and unloading are fulfilled through the same charging opening. In continuous furnace stocks are moved from loading opening.

Combustion furnaces may be classified according used fuel: solid, gaseous and liquid. Such type of furnace are used for heating of steel stock. Electric furnaces are used for heating of non-ferrous metals.

In electroinduction equipment temperature arises due to eddy currents which occur in surface layer of a stock. Electrolitic method is based of effect of heating of cathode when current flow in saline solution.

The advantageous of electrical heating are follows.

1. Quick heating of a metal, no need to supply working place with air so oxidation is minimized.
2. Increase of die durability due to lack of the scale which cause abrasive wear of a die.
3. Enhansement conditions of work
4. Rise of quality of products

Disadvantages of electric heating are follows high initial costs of equipment end electrical energy, difficulties of the heating of shaped blank.

Continuous furnaces are used for alloyed steel.

The main parameters for heating are time of heating and heating rate. Heating rate depends on design of furnace and its thermal power, properties of a metal. The most dangerous heating concerning stress is heating up to 500°C. Cracking occurs in big ingot made from low-plastic steel of complicated composition. Cracking occur during cooling too. The alteration of the thermal properties of a metal must by taken into consideration too. For example, calorific efficiency is changed 3-4 times, thermal diffusivity in 2-3 times. For carbon steel thermal conductivity increases up to 900°C, for alloyed steel it is reduced.

It is very difficult to calculate real time needed to heat a stock. With cross sectional area increasing there is disproportional increasing of a heat time because of nonuniform distribution of a temperature in furnace, of oxidation of surface layer of a stock, so at 400°C blackness of a stock somewhere increases and absorption of the heat increases. For approximate calculation one can use the following equation:

$$\tau = \alpha D_0 \sqrt{D_0}$$

Coefficient α is equal 10 for carbon steel and 20 for alloyed steel. It is assumed that temperature difference in furnace reaches 150°C.

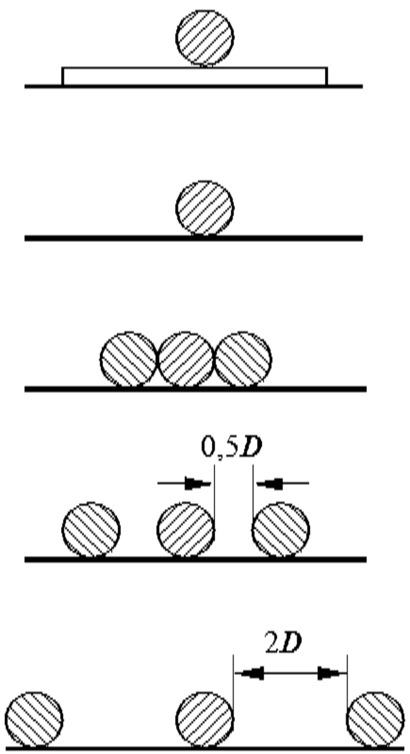
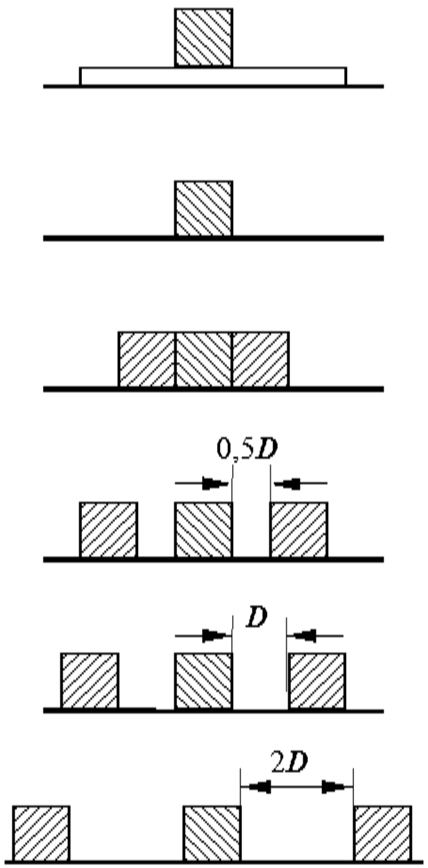
Time of heating of ingot mass equal to 5 – 10 kg

temperature of loading, °C	$t_{р.п.}$, °C	τ, ч	$t_{р.п.}$, °C	τ, ч	$t_{р.п.}$, °C
	low carbon steel		carbon steel (0,15–0,3% C)		high carbon steel (0 C)
20*	900	6,0	700–800	8,0	600–700
400	100	4,7	900	5,3	800
500	1000	4,3	1000	4,7	900
600	1200	4,0	1100	4,0	1000
700	1200	3,2	1200	3,2	1100
800	1200	2,5	1200	2,5	1200
900	1250	1,8	1250	1,8	1250
1000	1250	1,5	1250	1,5	1250

Forged stocks

Forged stocks are stock from already deformed metal and their sizes are smaller than sizes of ingot so heating procedure is more simple. It is advisable to heat the forged stock with maximum temperature difference. One should begin forging at maximum temperature and finish it at temperature more than 1000°C. In chamber furnace the stock diameter range from 10 to 100 mm are heated. Heat time is equal 1 min per 1 mm of cross sectional area. For alloyed steel this time increase 2 time. For sheet metal stock time of heating is equal 1,5 min per 1mm of thickness.

location of the stocks	coefficient «α»	location of the stocks

	1 1,3 2 1,4 1,3		1 1,4 4 2,2 2 1,8

Scale represent itself layer structure. The upper layer is oxide of iron Fe_2O_3, next layer is protoxide of iron and next - FeO. Some alloying element like silicon, aluminium, tungsten, chromium prevent oxidation and generate dense layer of oxides. Because of scaling some weight is lost. Waste of metal per one heating reaches 2–3%.

As for decarbonization the most influential reagent are hydrogen, water vapour, carbonic acid, oxygen, nitrogen.

NONOXIDATION HEATING

1) Speeding up of heating, increasing of temperature difference with a help of ceramic gas-jet.
2) Speeding up of heating using of inductive and electric contact heating.
3) Heating in electrolyte