Characteristics of materials and thermal treatments applied to
gearwheels obtained by plastic deformation

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Abstract. A variety of materials are used in the manufacture of gearwheels. These materials satisfy various working conditions for gears. Such gears are made of metallic materials – ferrous, non-ferrous and from plastic materials. Among ferrous materials the following are used: irons; cast, forged and rolled steels; among non-ferrous materials the following are used: bronze, aluminium alloys, brass, etc., and of plastics the following are used: textolite, polyamide, polyacetal. In the practice of exploitation and in the process of special research it was established that the permissible load, according to teeth contact resistance, is generally determined by the hardness of the material. The highest hardness and respectively, the smallest sizes and reduced mass of the transmission can be obtained in the manufacture of steel gears via thermal treatment. It is obvious that by plastic deformation at cold it cannot be obtained gearwheels with complicated configuration as deformed plastic metal will form cracks caused by low plasticity. To improve processability by plastic deformation the mouldings for gearwheels are heated. With increasing the heating temperature, plasticity increases and resistance to deformation decreases.

1. Introduction

The often ferrous materials used is irons, castings, forgings and rolled steel, the often nonferrous materials used is bronze, aluminium alloys, brass etc. and most plastics materials used is - hard plastics, nylon, polyacetal [1]. In exploitation practice and through special research it was established that the permissible contact resistance load of teeth is usually determined by the hardness of the material. The highest hardness, respectively, the smallest clearances and reduced mass transmission can be obtained by using gears from heat treatment steel.

At the present steel is the basic material for the manufacture of gears and, in particular, of the transmission power gears.

Recommended steels for gears, types of thermal and thermo-chemical and mechanical characteristics are shown in table 1 [1, 2]. Materials used for gears manufacturing by cold or hot pressing must provide: strength, hardness, rigidity and minimum weight appropriate to the lowest possible cost and possess plastic forming. On cold or hot plastic deformation the cost of labor is quite low - 60 ... 80% of product cost, essentially formed by material cost [3]. With this method can be processed following metallic materials (steel, copper and its alloys, aluminum and its alloys) and nonmetallic materials (textolit, plastics, organic glass). Figure 1 presents graphs influence on cold plastic deformation plasticity δ, limit of tensile strength σₚ, hardness HB for a low carbon steel. To improve processability using plastic deformation gear preforms are heated. With the increase in the
heating temperature increases plasticity and reduces strain resistance. As an example we will analyze the effect of temperature on the plasticity limit of δ tensile strength steel with carbon content of 0.42% (figure 2). Different metals and alloys processed by plastic deformation in a temperature range were established [4, 5].

Table 1. Gears typical materials, types of heat treatment and thermo-mechanical characteristics.

| Brand** steel | Section $S$, mm | Hardness | Tensile strength $\delta$, MPa | Yield strength $\sigma$, MPa | Heat treatment |
|---------------|-----------------|----------|-------------------------------|----------------------------|---------------|
| Preform forging (stamping, roll forming) | | | | |
| 40 $\leq$ 60 | 192 - 228 | - | 700 | 400 | Martempering |
| 45 $\leq$ 60 | 241 - 285 | - | 850 | 580 | Normalising Martempering |
| 50 $\leq$ 80 | 228-255 | - | 700-800 | 530 | Normalising Martempering |
| 40X $\leq$ 100 | 230-260 | - | 850 | 550 | Normalising Martempering |
| 45 X $\leq$ 100 | 230-280 | - | 850 | 650 | Martempering |
| 40XHMA $\leq$ 80 | 302 | - | 1100 | 900 | Martempering |
| 38XMA | - | 850-900 HV | 30-35 | 1050 | 900 | Azotation |
| Cast steel | - | * | - | 550 | 320 | Normalising |
| 45Л | - | * | - | 700 | 550 | Normalising |

* Indicative HB≈2,85δb, where HB MPa, δb MPa
** Marking: first number – the carbon content in hundredths of %; letters of alloying elements: X - Chromium, H- Nickel, M- molybdenum, A – high quality steel, Л – cast steel.

2. Heating blank gears before plastic deformation

The transmission of heat from the surface to the core of the preform is determined by the thermal conductivity and specific heat of the metal. Thermal conductivity depends on the chemical content of steel: the higher the percentage content of impurities the lower thermal conductivity is. At ambient temperature steel OLC 10 has thermal conductivity of 290 kJ/(m·h·grd), OLC70 has 243 kJ/(m·h·grd) and alloy steel X18H9 61 kJ/(m·h·grd) [7]. With temperature increasing, the alloy steels thermal conductivity increases and for carbon steels decreases. At 700-800ºC thermal conductivity for alloy steel and carbon steel became equals.

Higher specific heat required more time to equal the temperature of the interior of the blank. Table 2 shows the specific heat of carbon steel. In order to avoid deformation of the preform body during the rolling of teeth in the case of hot rolling, it is necessary to heat only the surface layer subjected to plastic deformation, for example, by electromagnetic induction.

Admitted to setting temperature range is envisaged deformability variation with temperature, determined by one of the methods used for this purpose. Is technologically temperature range in which the actual deformation and is determined in close connection with the time necessary for deformation. Technological temperature range must be within the range of permissible temperature.
Heated layer depth depends on the frequency of the current, the magnetic permeability of the material's electrical resistance and blank. This thickness can be determined by the relationship [6, 7]:

$$\Delta = 5,03 \cdot 10^4 \sqrt[4]{\frac{\rho}{\mu f}} \text{ mm},$$

where $\Delta$ is the heated layer thickness, mm;

$\rho$ – the electrical resistivity of the blank, ohm-mm²/m;

$f$ – Frequency of electric current Hz;

$\mu$ – the magnetic permeability H/m.

The required frequency can be determined according to the relation:

$$f = \frac{30000}{d^2}$$

where: $d$ – heated diameter blank, cm.

**Table 2.** The specific heat of carbon steel, kJ/(kg·grd)

| Temperature °C | Carbon, % | 0,22 | 0,3 | 0,54 | 0,61 | 0,8 |
|---------------|-----------|------|-----|------|------|-----|
| 1000          | 0,7045    | 0,7010 | 0,6896 | 0,6870 | 0,6784 |
| 1100          | 0,7045    | 0,7010 | 0,6910 | 0,6880 | 0,6815 |
| 1200          | 0,710     | 0,7036 | 0,6935 | 0,6901 | 0,6842 |

Because of this depth of penetration differs electric current cold, heating until the appearance of magnetic transformations, and depth of penetration of electric current hot temperatures when heating occurs, the magnetic transformations taking place [7-9].
Table 3 Temperature range for processing by plastic deformation.

| Metal or alloy     | Temperature range °C |                  |
|--------------------|-----------------------|------------------|
|                    | Beginning of deformation | Finish of deformation |
| Steel              | 1050-1350             | 700-950          |
| Copper alloys      | 750-850               | 600-770          |
| Aluminum alloys    | 470-500               | 350-400          |

3. Conclusions
As a result of research and observations [7] it was established dependence between temperature and degree of deformation that affect the grain growth. These behavior patterns metals undergo plastic deformation to be taken into account in developing technology for generating the teeth precessional gears by plastic deformation, especially due to high load transmission in Small, high capacity characteristics defined by the precessional planetary transmissions.

4. References
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