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Virgil Dan Cărămidaru, Ion Vela

Heat Treatments and Materials Used in the Manufacturing of the Gear Wheels

For the reducers used for a certain application, a relative reduced number of materials joins the discussion, respectively procedures of heat treatment, the decision was taken conditioning aspects, as: functions solicitated to the transmission (movement transmission, durability, behaviour to the noise), number of the pieces and the manufacturing procedure.

Keywords: *Steels and cast irons, hardenability, depth of quench hardening, superficial hardness and wear resistance***.**

1. Generalities

The article is intended to be a study material for designers being helpful in choosing the materials and heat treatments used in the gear wheel manufacturing. This article is a summary of the used main materials and heat treatments, analyzing also the influence of these ones on the wear resistance, on the fatigue, on the fatigue, on corrosion and on the shocks taking over ability of the gear wheels teeth.

A great number of materials is suitable to the manufacturing of gear wheels. Of these ones, the steels have the greatest importance, from technical and economical reasons, they offer a great variety of practical solutions, with many opportunities to influence the properties.

The most important premises of the quench hardening and of the quenching+tempering of the steel are the structural modifications to which it is subject to the heating and cooling (especially obtaining *martensite* constituent). The choosing of the steels for quench hardening is based on two important characteristics [3]:

- *hardenability* which defines the propriety of the steels of acquiring a certain hardness, which cannot be exceeded and which, in terms of ensuring a sufficient cooling speed, depends only on the carbon content of the steel;

- *the hardening depth,* which, in terms of cooling date, defines the depth of the hardened zone or the diameter of the hardened section, being mainly dependent on the concentration of the alloying elements and to some extent on the grain size steel.

2. Choice of the materials

In choosing the materials it is taken into account the following particularities [1]:

- *materials mating:* It can be chosen the same material type of queching and tempering for pinion and wheel, but the pinion must be harder with cca. 30 … 40 HB than the wheel, due o a higher speed.

A wheel hardened superficially (HRC > 50) with rectified teeth smoothes the teeth flanks of the conjugated quench+tempered wheel, decreasing the profile deviations and thus improving the resistance at pitting. At the mating of the quench hardened wheels, it is not required (except the lapped gearings where it is recommended that the pinion should have cca. 2 HRC more than the wheel, and, if it is possible, a higher carbon concentration) a hardness difference, moreover, at the reduced peripherical speeds (v_t < 0,5 m/s) it is desirable the same hardness on the flanks at pinion and wheel;

- *the purity degree* influences decisively the resistance of duration, the elaboration in vacuum leading to a bigger uniformity of the maaterial (mechanical resistance relatively constant in the volume). A concentration of sulfur (S) of maximum 0,05% influences positively the resistance, while a minimum concentration of 0,03% is desirable, due o a good cutability;

- *alloying elements* decreases the critical speed of hardenability. Thus, at quenching+tempering great sections (great modules) high resistances can be obtained along the whole section. At small dimensions, in order to obtain the resistance values it is sufficient the using of carbon or low alloy steels

For the same reason, when using alloy steels, cooling enviroments which ensure lower cooling speeds can be used, for example, oil instead of water. This, however, reduces the level of the internal tensions and the danger of cracks at the same hardness;

- *a higher carbon concentration* increases the resistance at the contact solicitation (wear) for the quenching+tempering steels and the resistance at the tooth foot, but it decreases the tenacity. Steels with carbon (C) concentrations up to 0,25% cannot be used for transmiting forces, without heat treatments;

- pinions *forging* or tooth crowns *rolling* can, depending on the assured deformation degree (best > 5), eliminate defects or structure inhomogenities, leading to a favourable orientation of the material fiber. In comparison with the wheels made from bars, the forged wheels present mechanical characteristics more homogeneous, it can be taken into account a long term resistance at the contact solicitation and at the tooth foot higher with cca. 20%.

A higher deformation degree at forging can be lead, in the case of the steels with a lower purity degree, to the increasing of the fragility;

- at wheels of higher dimensions, the using of *cast steel* is economically more advantageous, in comparison with the forged wheels. But foundries must be chosen which should prove they can obtain castings wihout defect, pores and inhomogenities;

- *weldability*. In the case of the wheels in the welding execution with the tooth part of quenching+tempering steel, the best is suited 34CrNiMo4 or CrMo4 (after the old symboli zation 42MoCr11), due to the higher concentration in carbon. By the help of the special technology, which involves, for example, intermediate welding cords, special electrodes or higher welding temperatures, other brands of steel can be welded;

- *sanding* attenuates the defects from the area of the conection ray of the tooth foot as a result of a faulty heat treatment (superficial decarburizing, superficial oxidation, etc.) or of the rectification thresholds. The influence above the duration resistance is more significant as the wheel is affected too at the wheels higher quench hardened than at the quench+tempered wheels. The roughness of the flanks is damaged by sanding, at the higher quench+tempered wheels than at those quench-hardened. Therefore, at large wheels, the flanks protection with plates is practised;

- *phosphating* **(**layer thickness of 3 … 8 μm) facilitates the process of running, i.e. the smoothing of the flanks, leading to the improvement of the efficiency and of the wear resistance. At the processes executed correctly one could notice an increasing of the resistance to pitting, not having any distinguishable influence on the noise level;

- *galvanic copper plating* (not chemical) decreases the risk of corrosion, improves the resistance to pitting and makes more visible the contact patch (pattern) under load. The disadvantage is that the layer is attacked by certain oil additives.

3. Hardened wheels versus superficial unhardened ones

At many reducers an optimization of the costs can be made by manufacturing of the wheels of high alloy steels, applying special heat treatmens and manufacturing technologies (i.e.: case-hardened wheels, with rectified gearing) [1].

At the sizing of the hardened wheels one must take into account of the following aspects: the ratio width / diameter is low; the precision of the gearing execution is high; mostly, there are necessary corrections at the gearing (higher forces from the gear determine greater deformations); bigger bearings are necessary, therefore more exspensive.

High theoretical resistances at the superficially hardened gearings are obtained only if there are accomplished numerous conditions, such as: *suitable* *choice of the material, a processing and a heat treatment performed and verified with utmost care.*

Superficially unhardened wheel processed of quenching+tempering steels have the following advantages:

- although the reducers are somewhat higher, this is not necessarily a disadvantage for applications such as heavy machinery or rollinglines;
- the heat treatment and the processing are easier to master;
- the quench hardening and the gearing rectification are eliminated and therefore the costs and the adjacent risks too;
- higher b ratio are possible;
- the material which is somewhat soft permits a faster correction of a detrimental pattern by running;
- if necessary, the pattern can be corrected manually, too;
- the deformations and the forces from the bearings are lower at the same diameter.

4 Used materials in the construction of the gear wheels

4.1 Cast iron and cast steel

a) Gray cast iron (FC) is used [1] at the gear wheel with complex shape, having the advantage of a machinability by a good cutting being a noise absorber too, but having a disadvantage of a lower carrying capacity, especially at the solicitations by shock. It is recommended the using for the production of the wheel bodies on which steel bandages are shrinked.

b) Nodular graphite iron cast (Fgn) It is used at the gear wheels from the paper industry, at the agricultural machines and at the production of the wheel with complex shape. The resistance to wear and corrosion increases with the increasing of the graphit concentration, while the resistance to pitting is improved with the increasing of the perlite concentration. The influnce of the roughness on the formation of the pitting is more reduced and the behaviour at running is better than at the steel wheels; the resistance at the tooth foot is not improved by quench tempering, but by sanding.

Over Fgn 700 the machinability by cutting is worsened, the obtaining by milling of a common precision and roughness being more difficult to achieve, being necessary an attentive application of some heat treatments of the cutability improvement.

c) Cast steel (OT) It can be non alloy (OT 52, OT 60) or alloy (corresponding to the quenching+tempering steels from the paragraphe 4.2). The differentiation towards the forged steel as described in the paragraphe 2.

4.2. Steels without superficial quench hardening

a) Construction steels (such as: OL 37, OL 60, OL 70) They are used at the manufacturing of the gear wheels with reduced loads and at production by welding of the wheel bodies.

b) Quench+tempered steels (s. also SR EN 10.083. For minimizing the deformations and for reducing the internal tensions, a uniform heating must be ensured, the maintaining at the temperature of the austenite until the complete transformation and the uniform cooling in a suitable cooling medium.

A too low quench hardening temperature determines the appearance of areas with ferrite which worsens the resistance at the tooth foot and at the contact pressure, while the overheating and the increasing of the maintaining time lead to the increasing of the grain size and of the fragility, thus the risk of cracks appearance is increased too. A too reduced cooling speed can lead to the obtaining of free ferrite and thereby to the decrease of the long-term resistance and the wear one.

The common carbon steels, especially OLC 45 normalized, proves a very good behaviour in running, the flanks being smoothed and hardened at 50…100 HB. Due to the low yield point, the flank tear is quench+tempered and the shape deviations are attenuated. The alloy steels for quench+tempering, with hardness of about 300 HB, react, mostly, somewhat more sensitive; the processing deviations rather lead to a worsening of roughness, favoring the increase of pitting stress.

4.3. Case-hardened steels

Case-hardened steels (s. also EN 10.084) are used both in the manufacturing of great serial (car industry) and in the unigque production (marine reducers, reducers for rolling stands). The diameter is limited by the oven capacity and by the size of the gearing rectification machine.

By case-hardening it is aimed to the obtaining of the tooth surface very hard, while the core remains relatively soft. The hard layer from the surface gives the teeth o large resistance to the wear and a contact pressure, while the tooth core remains with a good tenacity, so with good proprieties oftaking over the shocks.

In fig. 1 a section of a case-hardened tooth is presentend [1].

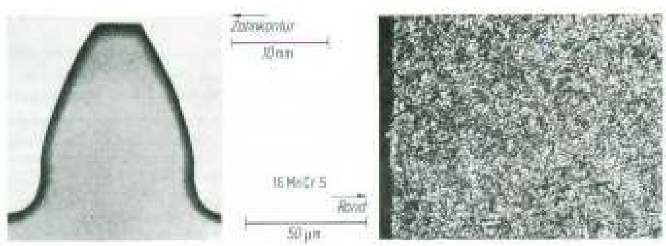

Figure 1

The main characteristics of these steels:

- *superficial hardness. The hardness variation* In order to obtain a high carrying capacity, it must be assured, due to the residual austenite, a smooth decrease of the hardness, from the surface to the core. Otherwise, the internal tensions would be too high and the hardened layer could exfoliate [5]. In order to avoid the appearance of rectification cracks (especially at the higher hardening depths)a stress-relieving is applied at 180… 210ºC, which reduces the hardness of cca 2 HRC;

- *the case-hardening depth* is important for the resistance at the contact solicitation, being defined as the distance from the surface up to the depth at which the hardness is 550 HV. In figure 2 it is presented the variation of the carbon concentration and of the hardness for 2 maintaining times at carburizing and the graphic method for the determination of the case-hardening depth [5].

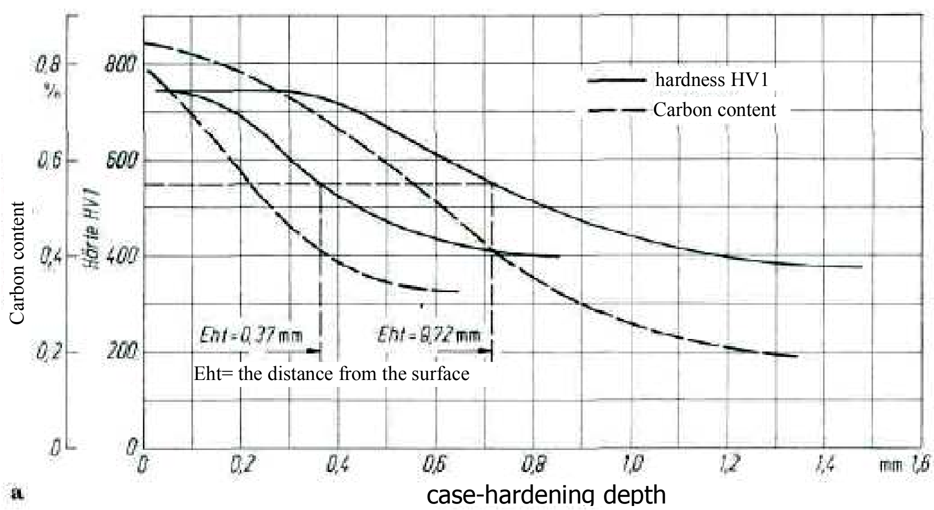

Figure 2

4.4. Quench+tempered steels, quench hardened superficially with flame and by induction

The processing procedures according to those presented in fig.3; hardness of 45…56 HRC and depth of 1…2 mm are obtained [1].

Quench hardening on the circumference (of all the teeth) (fig.3, a) is practised mainly in the case of quench hardening with flame. In the case of the quench hardening by induction procedure, it would be necessary an inductor adapted to the item sizes and a greater power of the generator.

The procedure is applied economically at the small wheels up to those medium. In the domain of medium hardness (45…56 HRC) the procedure is mastered easily, for higher hardnes the risk of cracks appearance is increased.

The devices of tooth by tooth quench hardening are mostly relative simple and secure inductors, which ensures a uniform distribution of the energy. The procedure, per se, is more difficult to control than the quench hardening on the circumference in order to obtain a constant hardness, having to be assured the following:

- an exact matching and ghiding of the inductors, respectively of the burners;
- a calibration of the proces on the hardness tests (the checking of the hardened contour and of the structure;
- ensuring of some uniform conditions of quench hardening on the contour (the constant maintaining of the wheel body temperature);
- the ends of the teeth (on cca. 1x m in width must not be quench hardened (reduces the risk of breaking the teeth corners.

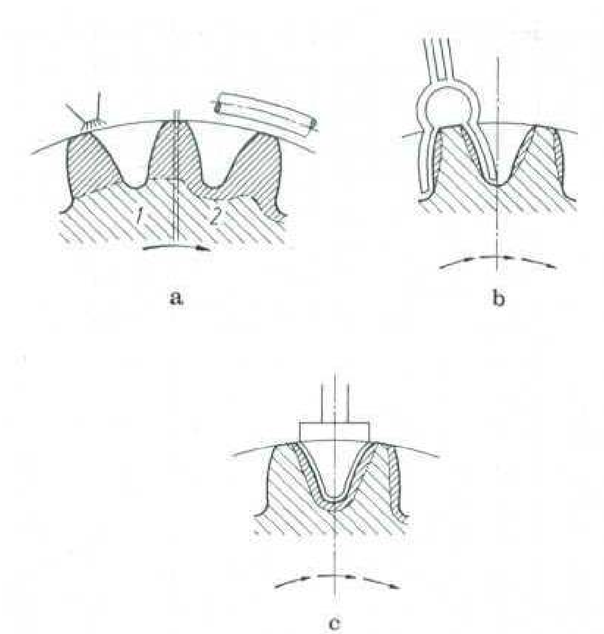

Figure 3

The tooth by tooth guench hardening by copying the tooth fullness (fig. 3, b). The procedure is economically advantageous at large wheels, being well controlled in the domain of the medium hardness (HRC = 45…56).

Since it determines major deformations, mostly the subsequent rectification is not necessary.

It is recommended that the hardened area to be ended above the critical area from the section of the tooth foot. The tension concentrator resulted from the metallurgical considerations reduces the resistance at the tooth foot, a improvement can be brought by increasing the connection radius at the tooth foot.

The tooth by tooth guench hardening by copying the tooth gap (fig. 3, c). The method is economically advantageous at large wheels, being well controlled in the domain of the medium hardness ((HRC = 45…55). The risk of cracks appearance is reduced only in the case of an attentive.
preparation and survey of the process, being necessary both a long experience and optimal materials and heat treatment conditions.
The procedure often requires a further rectification.

Materials. The obtaining of an acceptable hardness requires carbon concentrations of 0,30 … 0,45% (over this value the risk of the cracks appearance increases). In order to avoid the cracks appearance, it is necessary a high purity of the material.

Stress-relieving. For reducing the risk of cracks appearance, a stress-relieving at cca. 180…200ºC is recommended, immediately after the quench hardening.

4.5 Steels and cast for nitriding

The nitriding is the thermo-chemical treatment of enrichment the surface with azote. Subject to the nitriding are the gear wheels manufactured from non alloy or alloy steels, aiming to increase the superficial hardness of the teeth, the wear and fatigue resistance, and even the corrosion resistance [1].

The nitriding offers the following advantages: small thickness of layer are obtained, tenth of millimeter order (important for small items) and very high superficial hardness up to the level of 1100 HV, under the conditions in which the core maintains its characteristics previously acquired (large tenacity). So, the teeth have an assembly of special features, such as: high contact resistance, at wear and fatigue, as well as a good capacity to take over the shocks [1].

Besides these incontestable advantages, nitriding presents some disadvantages too, of which the most important is the very long duration of the operation (40-100 hours), due to the slow diffusion of the azote in the ferrite [1].

Hardness in the layer and resistance and tenacity in the core is ensured by the alloy quenching+tempering steels and, in a less extent, by irons.

The best steels for nitriding are these alloy ones with Al, Cr, Mo, and, V, the typical representative being 38MoCrAl09. Good behaviour at nitriding confer also the steels with Cr-Mo, Cr-V, Cr-Ni, Cr-Mn and Cr-Mn-Ti, at which the obtained superficial hardness are located between 500 and 800 HV. Among the most used grades, there are mentioned: 33MoCr11, 42CrMo4, 34MoCrNi15, 30MoCrNi20, 21TiMnCr12, 18MnCr10, a.s.o .

Although the cast irons confer less spectacular results than the steels, they are subject to nitriding too, especially the ones alloy with Al, Cr or Al-Cr, the most indicated being the nodular cast irons.

The passing from the superficial hard layer, at the core, is made by a connection layer, named also white layer (s.fig.4). This layer must not be thicker than 10…15 µm, not to promote the separation of the nitrided layer [1].

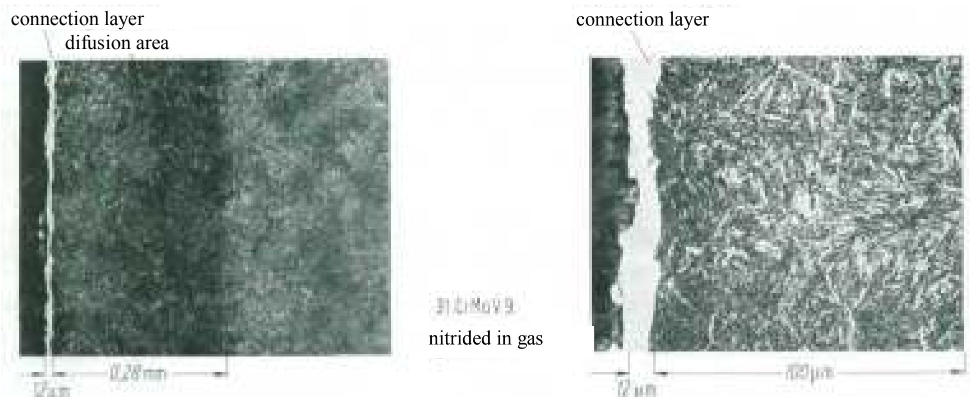

Figure 4

4.6 Steels for carbonitriding

By the thermochemical treatment it is ensured the enrichment of the teeth surfaces, simultenously cu carbon and azote.

After this treatment, the gear wheels are provided with superficial layers having 0,8 …0,9% C and 0,3…0,4 %. N, in thicknes of 0,7…0,8 mm, with hardness over 700 HV, given that the core remains with smaller hardness, so tenacious [1].

The range of the temperatures at which the carbonitriding is performed is very large, from 550º C to 870º C, sometimes even at 930º C. Under these conditions, it is obtained a very great difference regarding the composition, the structure, the extent, and especially, the mechanical characteristics of the superficial layer, as the treatment was performed towards the superior limit or the inferior one of the temperature range.

At high temperatures the diffusion of the carbon prevails, and so, the superficial layer will approach that obtained by case-hardening, and at the low temperatures the azote diffusion prevails, respectively the obtained results approach these ones of the nitriding. The behaviour of the carbonitrided layers depends, ultimately, on the ratio in which there are the azote and the carbon layers, ratio which depends on the temperature.

A wide range of steels is subject to the carbonitriding, with good results, starting with those of the non-alloy case-hardening (OLC10; OLC 15; OLC 20) or alloy (13CrNi30, 21MoMnCr12, 21 TiMnCr12, a.s.o.) and continuing with the non-alloy quench+tempered steels (OLC 45, OlC 50 ş.a.) and alloy (40Cr10, 33MoCr11, 35Mn16 ş.a.) [4].

The treatment itself can be achieved in the gaseous medium (endogas with the addition of ammonia and methane), when, normally it is called carbonitriding, also, in the liquide medium or even in the solide one, in the presence of cynides, when it is called cynization.

Among the disadvantages of the carbonitriding at high temperatures, comparative with the case-hardening, it is mentioned, on one hand, the slightly smaller thickness of the carbonitrided layer, usually between 0,7…0,8 mm, and, on the other hand, the increasing of the residual austenite (following the descent of the points M_s şi M_f) and on this account a slightly reduced hardness is obtained after the quench hardening and the dimensional modifications that may occur in time are larger.

Conclusions

The presented material has shown the main materials and heat treatments used in the gear wheels manufacturing, concluding that the most advantageous materials technically and economically are the steels, such as: the construction steels, the quench-tempering steels, the cementing steels, the nidriding steels and the carbonitriding steels. The most used heat treatments are: quench-tempering, cementing, quench-hardening, nitriding and carbonitriding.

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Addresses:

- Phd. Stud. Virgil Dan Cărămidaru, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, caramidarudan@yahoo.com
- Prof. Dr. Eng. Ion Vela, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, presedinteuniv@uem.ro