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PHASES OF THE MECHANICAL THERMAL TREATMENT APPLIED TO SPUR GEARS.

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Abstract. *In this work spur gear were submitted to a mechanical - thermal treatment (MTT), which consists of combining the plastic deformation with artificial ageing, with the intention of raising the safety and longevity of his superficial layers, with a minimal environmental impact. In this study it was used the Finite Elements Method (FEM) to model the contact of the tooth's flanks. Are discussed the following results, transit of the elastic strain to elastoplastic strain, development and distribution of the residual stress insofar as the plastic deformation grows, determination of the complex field of tensions that prevail around the contact of a tooth of typical gear meshing during operation as well as the determination of the local yield stress.*

Keywords: *Gears, combined hardening, FEM, micro-hardness, plastic deformation, ageing.*

1. INTRODUCTION

Technologies that guarantee without faults and lasting work of the gears generate a high cost of production, requiring costly, prolonged and sometimes harmful to human health, treatments and / or surface coatings and heat treatment in any of its variants, plus abrasive costly grinding operations.

In addition, in the current regulations and in the literature there is no information available with a description of the contact position, orientation and subsurface stresses experienced by the teeth of the gears during operation, particularly in the elastoplastic regime allowing explain the viability of substructural hardening cylindrical spur gears. Thus, the objective of this study is to establish the characteristics of substructural hardening process on the flank of teeth of spur gears considering an elastoplastic stress rate.

With the mechanical-thermal treatment in this research, in a medium content carbon steel, a stabilized cellular structure, which can hinder the processes taking place at high temperatures, is created (Guliaev, 1983). Moreover, the strain hardening directed (plastic deformation of the workpiece completed with the help of load that coincides by the action direction with the working load) with hardening procedures that create compression residual stress in the surface layers, lead to increased resistance to machine elements. (Dobrovolski et al, 1980; Hearn, 1997; Callister, 1999). Additionally no stress concentration arises at the juncture of the hardened layer and the soft given that the transition from one to the other takes place gradually.

2. MATERIALS AND METHODS.

2.1 Substructural Hardening Modeling.

The substructural hardening modeling was performed using a professional package for Finite Element Analysis ANSYS.

The boundary conditions for the simulation are illustrated in Figure 1. Three forces concentrated in the body of the pinion teeth at a known radial position simulate the load, as shown in the figure, so that the total torque that is loaded the meshing tooth is equal to the torque in the gear shaft.

In this analysis is used the value of von Mises stress for predicting flow of material in the analyzed surface layer. The von Mises stress (see Figure 2) shows how intense the state of tension on the yield strength is. Table 1 shows the value of the stress at the subsurface nodes.

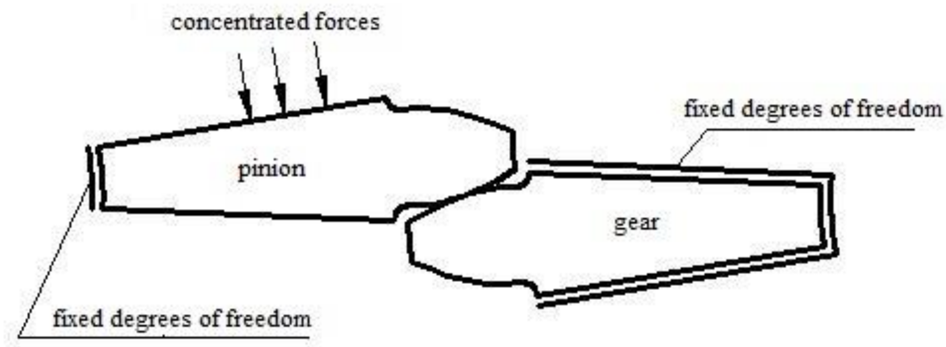

Figure 1. Boundary conditions applied to the model of a gear pair.

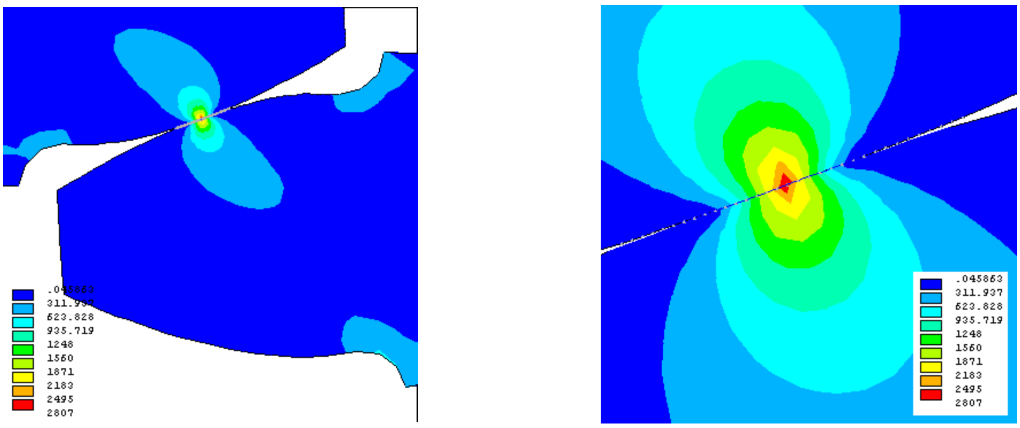

Figure 2. Von Mises stresses contour in the loaded toothed pair.

Table 1: Values of von Mises stresses (MPa) at nodes below the point of contact.
SEQV1 and SEQV 2 correspond to loads 1,07E+04 N and 7,56E+03 N, respectivily.

Δ mm	NODE	SEQV 1	SEQV 2
0,00	434	544,79	556,53
0,07	496	2123,00	1995,00
0,14	494	1759,10	1472,50
0,21	492	1475,10	1164,40
0,29	490	1246,20	946,16
0,36	488	1071,30	795,38
0,43	486	936,60	685,73
0,50	484	831,53	603,53
0,57	467	748,45	540,24
Average		**1192,90**	**973,27**

Where the average equivalent stress, SEQV, in the table above represent new local yield strength for analyzed models.

2.2 Experimental planning.

The experiment consisted of operating a gear, where the impeller is the deforming tool, gear steel AISI D2, with a hardness of 56 HRC and the element moved is a probe, AISI 1040 steel gear, as delivered, as illustrated in Figure 3.

The specimen is subjected to loading conditions that generate compressive residual stresses in the surface layers, which promote increased mechanical strength thereof.

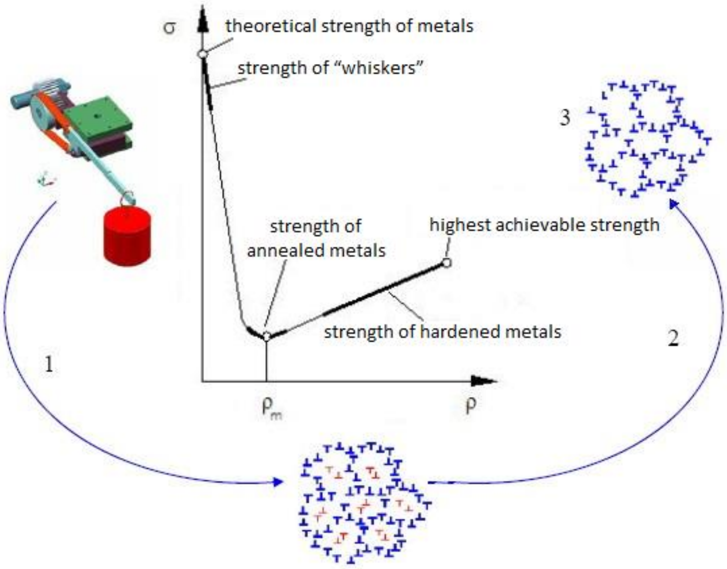

Figure 3. Schematic Mechanical Thermal Treatment:
(1) plastic deformation
(2) Artificial ageing. (T = 110 ° C)
(3) Cooling inside the oven (formation of a free cellular
dislocation structure within each sub-grain)

Mechanical-thermal treatment contains the following phases: increasing the density of dislocations through the plastic deformation and restructuring of dislocations in sub-boundary by artificial ageing, as illustrated in Figure 4.

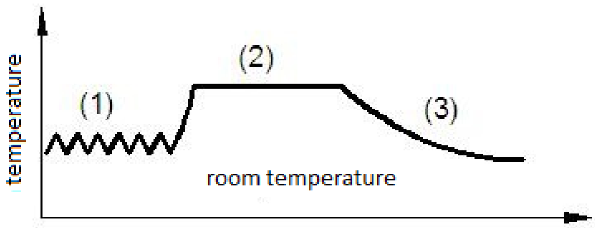

Figure 4. Phases of the mechanical thermal treatment applied to spur gears:
(1) plastic deformation
(2) Artificial ageing.
(3) Cooling inside the oven

Insofar as gears turn, there is a combination of movements of rolling and slide (Baranov, 1979; González, 2006; Hsi and Chuen Huei, 1998), causing this last, additional surface tensions, in front, a narrow and of compression and behind the area of contact exists a tensile area, Figure 5. As result, a point on the surface of the gear tooth, raises through a variety-complicated stresses condition while his cycle passes of engage.

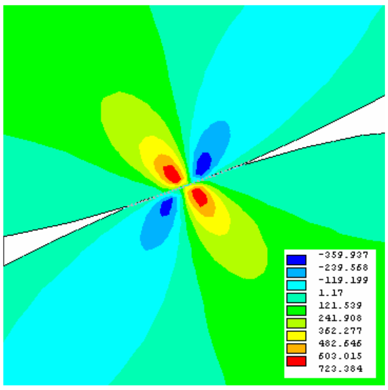

Figure 5. Tensile conditions than prevail around the contact of
a typical gear meshing (Hearn, 1997; Wei, 2004).

3. SOME RESULTS AND DISCUSSION.

Yield stress in the surface layer resulting from the simulation by the finite element model, and microhardness values, experimentally obtained are shown in Table 2.

As can be seen for every regime in the simulation work, two experiments, of 1 h (6,48e4 charge cycles) and a 3 h (3,24e4 charging cycles) were performed. Fn is a normal force transmitted in a gear meshing.

Table 2: Behavior average micro hardness (Hv) by experiment and yield strengths obtained in the simulation (σys)

Regime	Experiment	Time h	Normal force, Fn N	Hv MPa	σ_{ys} Ansys (SEQV) MPa
R1	CASE 1	6	1,10E+04	2082	1193
R2	CASE 2	6	7,60E+03	1800	973
R1	CASE 3	3	1,10E+04	2000	1193
R2	CASE 4	3	7,60E+03	1720	973

Elastoplastic transition, Equation 1, concerning materials high yield stress in which the magnitude of the elastic deformation is significant in response to contact is set in the range:

$$1{,}1 < Hv/\sigma_{ys} < 3 \quad (1)$$

The validation of the finite element model is shown in Figure 6, based on the above relationship.

The results of the estimated micro hardness corresponding to the yield strengths obtained by the MEF, compared with the proven experimentally confirm the elastic-plastic material model system, finding values with an error of less than 15%, focusing on the range established.

The materials with body-centered cubic (BCC) crystal structure tend to deform by slip due to the large number of available slip systems. After slip dislocations are accumulated in the micro-structural obstacles increasing the sliding resistance for more deformation, leading to embrittlement with characteristic stress-strain curve, in this respect a high density of dislocations means high resistance plastic deformation.

Calculating the density of the dislocations with the new limits yield, according to Equation 2, yields the results shown in Table 3.

$$\sigma_y = \sigma_o + \alpha b G \sqrt{\rho} \quad (2)$$

Where σo is the yield strength before strengthening; α is a numerical constant generally between 0,3 to 0,6, that considers another mechanisms of formation of dislocations; G is the module of displacement; b is the magnitude of the Burgers vector, oscillates among 0,24 0,28 nm and ρ is the density of dislocations

Table 3. Results of calculating the density of dislocations.

Fn N	σy Pa	σo Pa	α	G Pa	b m	ρ m^{-2}	**ρ cm^{-2}**
1,07E+04	1,19E+09	3,90E+08	0,3	8,00E+10	2,60E-10	1,66E+16	**1,66E+12**
7,56E+03	9,75E+08	3,90E+08	0,3	8,00E+10	2,60E-10	8,8E+15	**8,80E+11**

The value of density of dislocations calculated is in correspondence with the corresponding resistance of the hardened metals reported in the literature values (Dieter, 1986; Alfonso, 1991; Keller, 1998; Callister 1999; Alfonso, 2002).

Allowable error (15%)

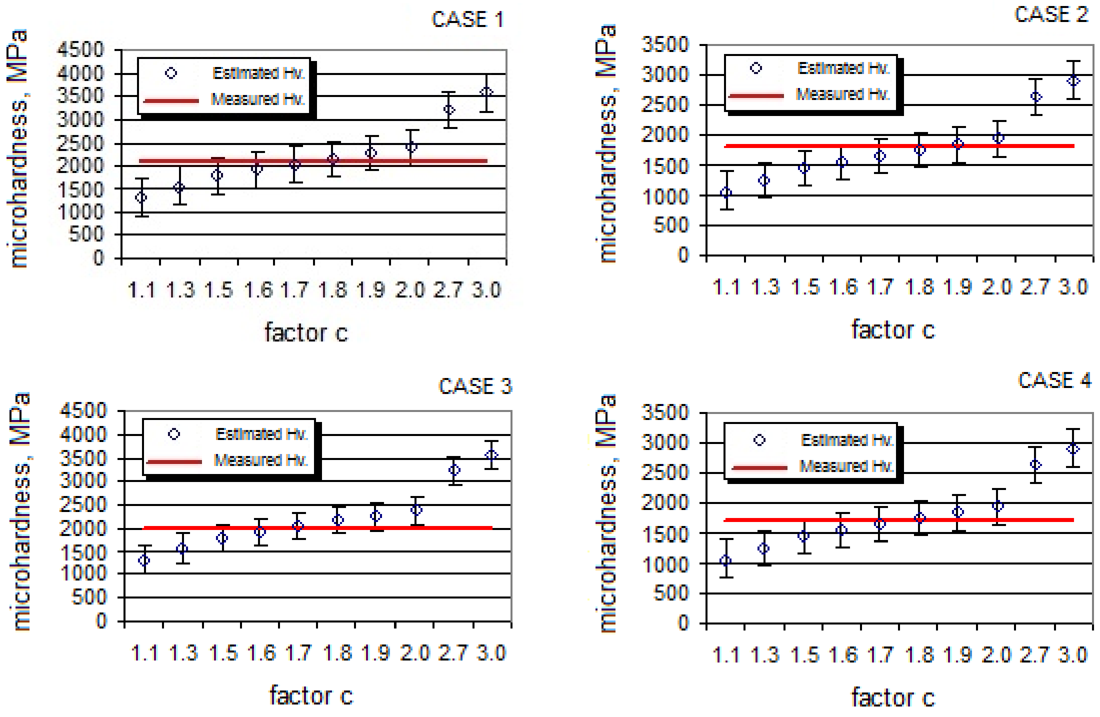

Figure 6. Comparison between estimated microhardness and experimentally determined microhardness for the four studied variants.

4. CONCLUSIONS.

1. The development of the distribution of the residual stress grows in plastic deformation and to predict the orientation of the same sign. Similarly, monitoring of the von Mises stresses again allowed determination of yield point, which in turn provided by applying the theory of dislocations determine the density of dislocations in selected variants the two being located in the resistance range hardened metals.
2. MEF versatility combined with reduced manufacturing of prototypes to be tested and iteratively improved significantly contributes to reducing the costs of testing. Similarly, spending on human and material resources are significantly reduced through the efficient use of combined hardening, as a final step of the manufacturing process helping to turn the thermal distortions are significantly reduced.
3. In all cases studied, values greater than the hardness of the pattern sample, ranging from 4% higher in the sample less loaded up to 26% in the most loaded were obtained..

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