Mechanical Behavior of HDPE/Birch Composite Gears: A Numerical Simulation Approach

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ABSTRACT

The work presented in this document is the method of modeling normal and worn gear teeth and their mechanical behavior. In this approach, the use of the SOLIDWORKS software was necessary to conduct this study. For the modeling of straight cylindrical gears before and after wear in SOLIDWORKS, we have adopted the method of guiding curves. For the study of a new composite material with a thermoplastic matrix, high density polyethylene reinforced with 40% birch fibers called HDPE 40, we have therefore integrated this new material into the library of materials available in SOLIDWORKS.A program to calculate the forces at each point of the profile as a function of the normalized position has been developed. Then five zones were chosen for the application of forces. For this purpose, small areas have been created in these areas in order to apply the forces. This allowed us to obtain the stresses and deformations.

KEYWORDS: Composite, gears, natural fibers, modeling, Solid Works.

1. INTRODUCTION

Gears occupy an important place in mechanical systems for the transmission of power and rotational movement. For this purpose their designs require consideration of the geometrical aspect, the type of material and the operating conditions.

The metal gears that were most encountered at the beginning experienced deterioration by deformation, breakage, deterioration of surfaces. Nowadays gears of plastic and composite materials are increasingly used.
Although there are some common models for their characterization, each composite material, even if it is made up of the same matrix and reinforcement, has its own characteristics, unlike their constitution and additives, so that the norms of modeling of composites do not have generalized models as for metals. In addition, for some specific applications, the existing standards are incomplete insofar as they do not address all the relevant aspects, and this is the case for gears made of plastic materials and polymer composites [1].

It is therefore necessary to carry out studies and experiments on these materials to develop models that are appropriate for the characterization of their different properties.

To this end, the Mechanical and Eco-Materials Laboratory (LMEM) at the University of QUÉBEC, in Trois-Rivières (UQTR) has developed eco-composite wood-fiber reinforced plastics for various applications. Thus, a first part of this work carried out by the team of Professor KOFFI of the UQTR consisted in developing and characterizing composite materials based on polyethylene and polypropylene of plant origin, reinforced by wood fibers such as aspen and birch. The most efficient of these materials for the manufacture of gears, the HDPE40 is the subject of the present study.

The study of the influence of wear on the mechanical behavior of HDPE40-based gears becomes important to better understand this influence to predict the behavior of the latter.

2. METHODOLOGY

Modeling of teeth

Modeling of a normal teeth

For the modeling of straight cylindrical gears before and after wear in SOLIDWORKS, we have adopted the method of guiding curves. This method makes it possible to plot the curves from precise coordinates obtained in a text file provided by the VBA computer programming software. Indeed, the SOLIDWORKS software considers the macros from VBA, can read a file of points that it can represent with much precision in a form of curve

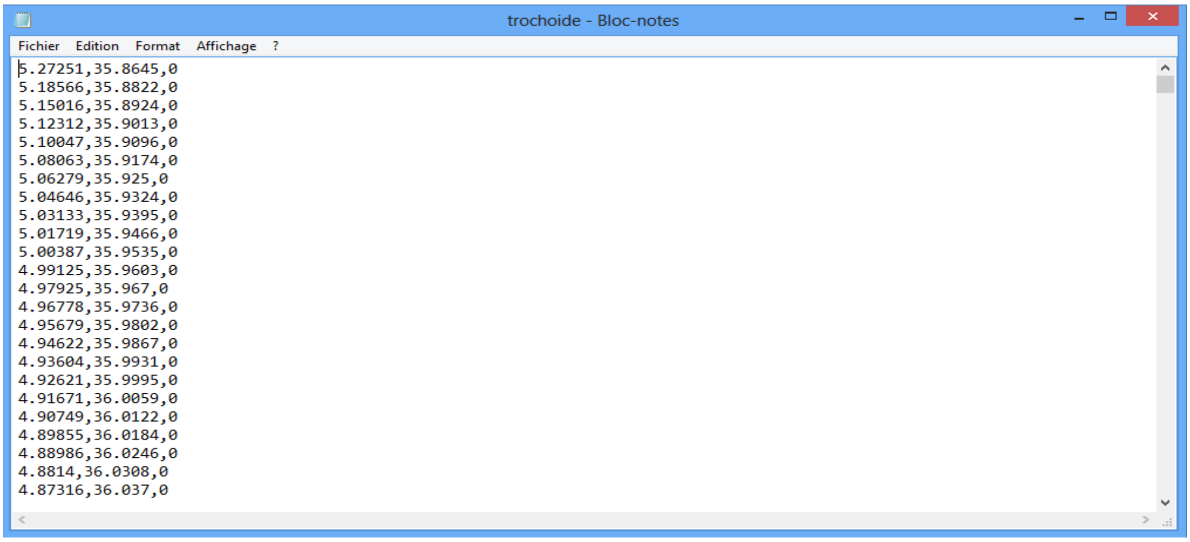
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Figure 1: Example of text file (First column: Abscisses - Second column: Ordinate - Third column: Dimension)

After reading all the curves of the tooth by the same method, we obtain precisely the representation of the latter consisting of the two main profiles which are the promoter of circle (in red) and the trochoid (in blue):

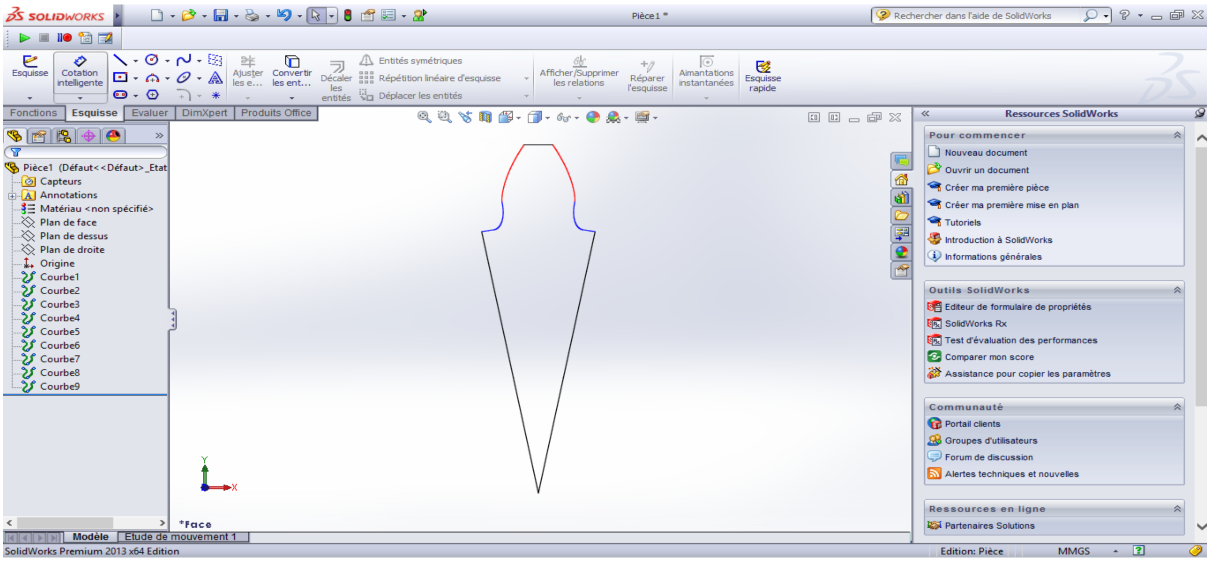

Figure 2 : Teeth profile in SOLIDWORKS

To pass from this two-dimensional curve to the representation of the tooth in three dimensions, it is sufficient to make an extrusion of the guide curve.

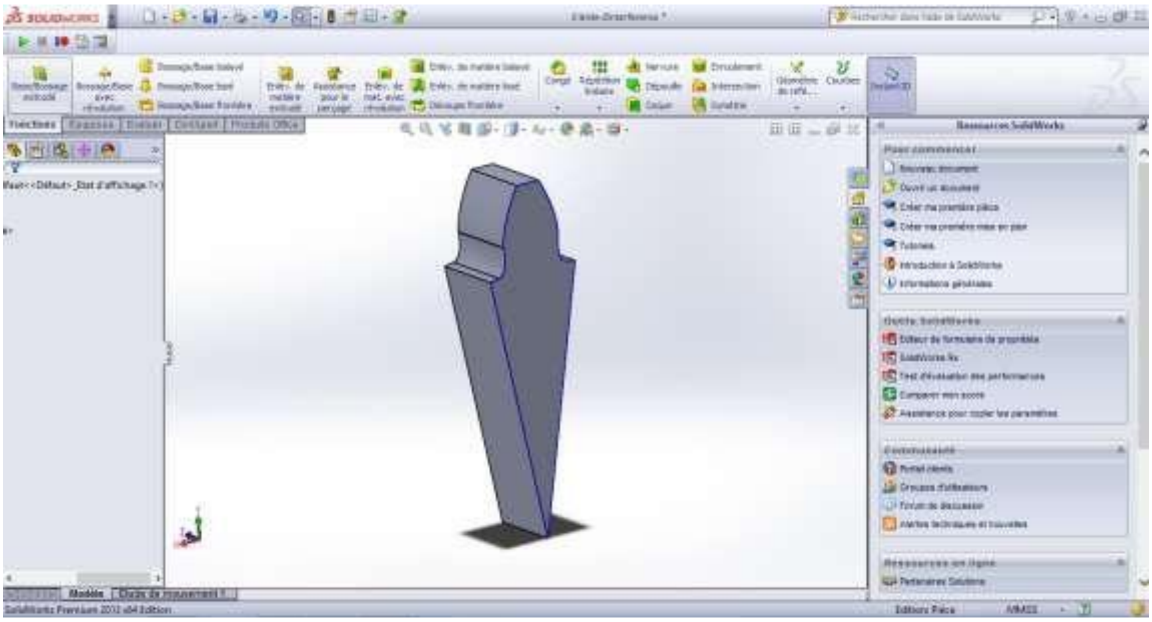

Figure 3 : Teeth profile extrusion

Obtaining a tooth with wear

FIG. 5 shows the tooth profiles obtained after a uniform wear of 2%, 4%, 6% and 8%.

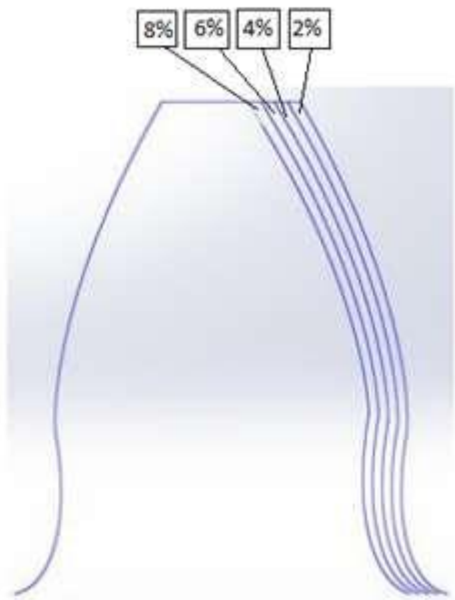

Figure 4 :Teeth profile with 2%, 4%, 6%, and 8%

Application of the material to the model

The SOLIDWORKS software has a library of materials ranging from metals to plastics and ceramics. However, the material that is the subject of this study is a new material not listed in the SOLIDWORKS material library.

As a reminder, it is the composite with a thermoplastic matrix (high density polyethylene) reinforced with 40% of birch wood fibers called HDPE 40 (see FIG. 5). We will therefore integrate this new material into the library of materials. FIG. 5 illustrates the creation of this new material:

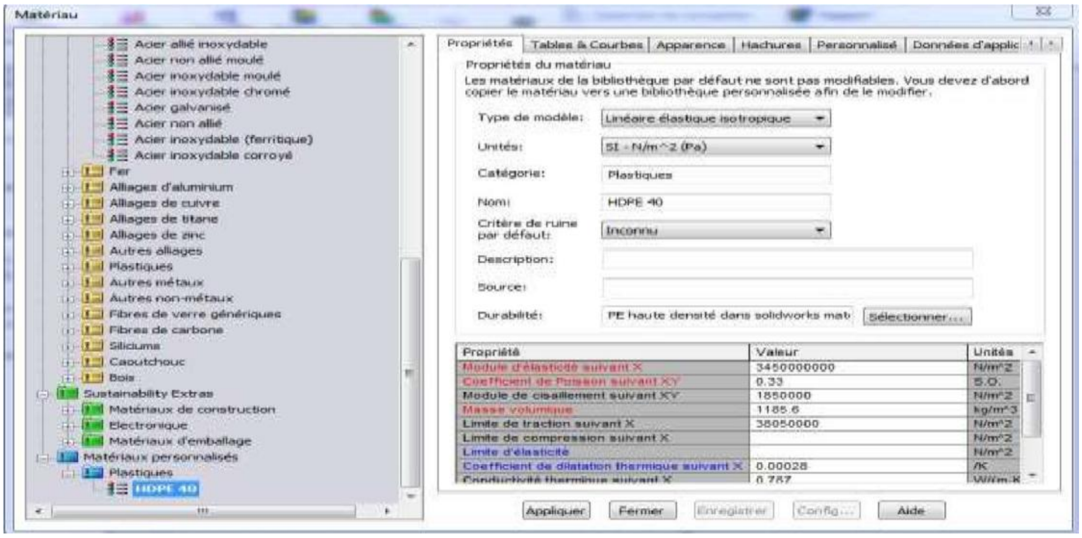

Figure 5: Creation of the HDPE composite 40 in SOLIDWORKS Materials Library

The figure below shows the full characteristics of the HDPE 40 material implemented in the software.

Propriété	Valeur	Unités
Module d'élasticité	3450	N/mm^2
Coefficient de Poisson	0.33	S.O.
Module de cisaillement	1.85	N/mm^2
Masse volumique	1185.6	kg/m^3
Limite de traction	38.05	N/mm^2
Limite de compression		N/mm^2
Limite d'élasticité	Dépendant de la température	N/mm^2
Coefficient de dilatation thermique	0.00028	/K
Conductivité thermique	0.787	W/(m·K)
Chaleur spécifique	1325.1	J/(kg·K)
Rapport d'amortissement du matériau	0.06	S.O.

Figure 6: Characteristics of HDPE 40 in the SOLIDWORKS Materials Library

Procedure for calculating forces on the profile

The calculation of the forces in thermoplastic-based composite gearing differs from that of conventional metal gears since the meshing of these types of gears has certain particularities. Indeed, there is an extension of the contact between the teeth more at least outside the line of action, before and after the theoretical start and end of the meshing. Thus, the significant deformation of the tooth during the meshing tends to relieve each pair of teeth in contact since the transmitted load is then distributed better [2]. This particular behavior of thermoplastic gears has already been studied by authors including Koffi who studied the magnitudes which characterize it in his previous studies [3] [4].

Koffi, in a practical approach, proposed a simplified model for the calculation of the load distribution factor [3] [4]:

For plastic / plastic mesh:

$$\frac{W_i}{W_n}\left(\frac{S}{P_n}\right) = \left.\frac{W_i}{W_n}\right|_0 \cos\left(\frac{\pi}{2}\frac{S/P_n}{S_2''/P_n}\right) \quad \text{(Eq 1)}$$

With:

$$\left.\frac{W_i}{W_n}\right|_0 = 0.48 E_2^{-0.28}(W_0 P \cos\alpha)^{-0.22} Z_2^{-0.4}\left(\frac{Z_2}{Z_1}\right)^{0.1} \quad \text{(Eq 2)}$$

Where $\left.\frac{W_i}{W_n}\right|_0$ is the value of the load distribution factor at the primitive point (s = 0).

The value of $\left.\frac{W_i}{W_n}\right|_0$ is a function of the load and the material and the geometry of the gear.

$$\frac{S}{p_n} = \frac{\sin\left(\frac{\pi}{2} - \alpha - \sin^{-1}\left(\cos\alpha \frac{R}{Ri}\right)\right)}{\pi m \cos\alpha} \frac{\sqrt{x^2+y^2}}{\cos\alpha} \qquad \textbf{(Eq 3)}$$

Where:

α: Primary radius
Ra: Head radius
Ri: Radius of any point taken on the profile
m: Module of the tooth

The calculation of the forces on the profile of a gear tooth passes through the various steps listed in the following flowchart:

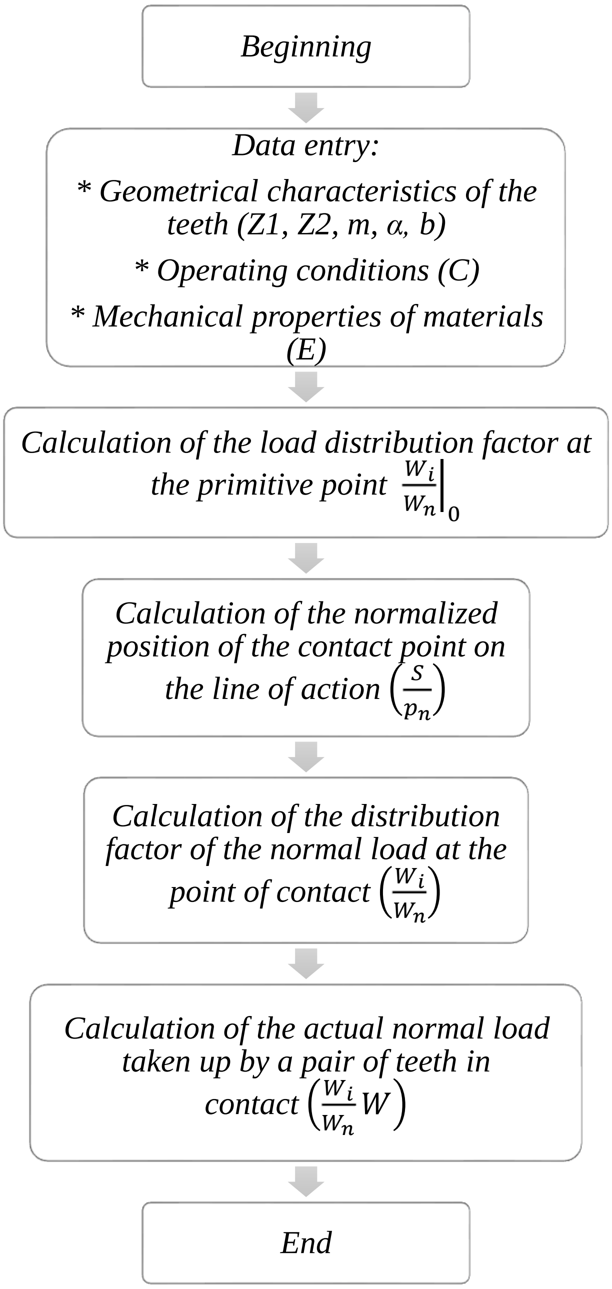

Figure 7 :Force calculation chart

Creation of the application surfaces of the forces

SOLIDWORKS only allows the application of forces on surfaces, so we had to create small areas of a few tenths of a square millimeter to be able to apply these forces. We created them small so as not to deviate too much from the real conditions (see figure 8). We have selected 5 contact zones on the tooth profile, areas where we will apply the forces.

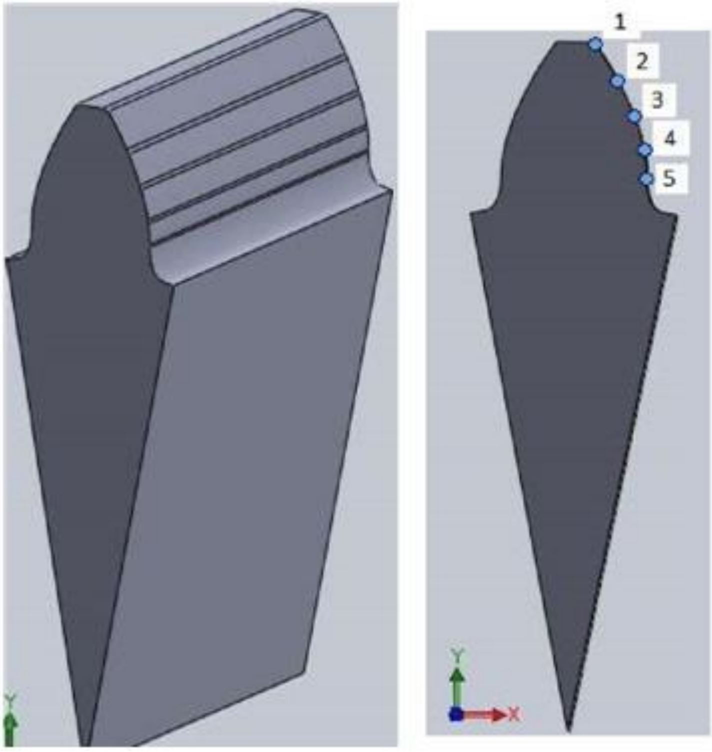

Figure 8 :Areas of application of forces

Calculation of stresses and deformations

Imposed displacement

With regard to the imposed displacements, this involves embedding on the lower surface of the tooth as shown in fig 9

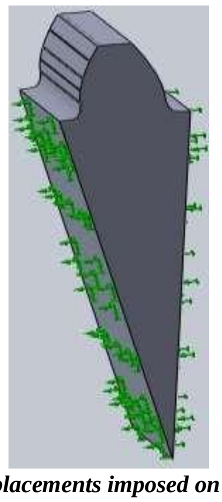

Figure 9 : Displacements imposed on the gear tooth

Meshing and executing calculations

Meshing is the process by which the elements and nodes of a field of study are defined. This mesh under SOLIDWORKS is automatic once the meshing parameters are introduced. For our case study, FIG. 10 shows an example of a mesh that the software proposes to us.

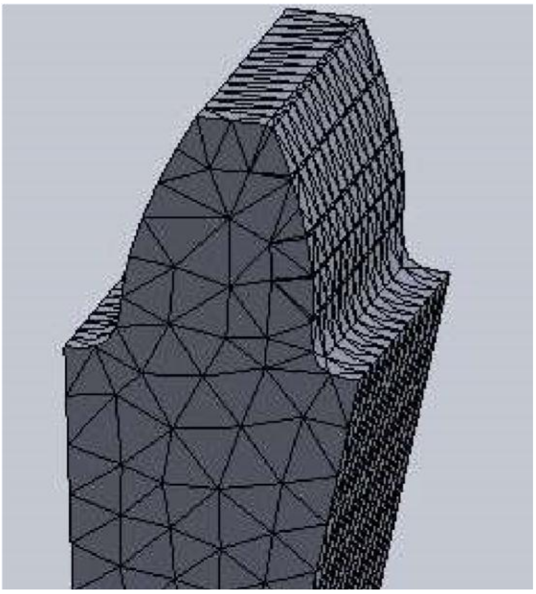

Figure 10 : Tooth meshing

Once the mesh is executed the calculation of stresses and deformations is launched.

3. RESULTS

The results display is graphic with a color code as shown in this example.

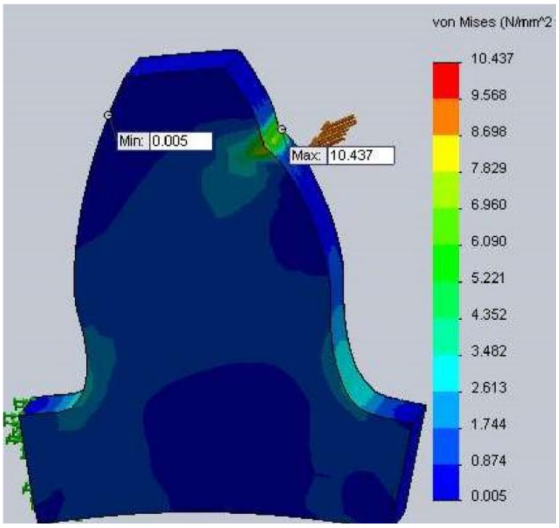

Figure 11 : Example of results display

We have shown the whole process of studying the stresses and deformations ranging from the calculation of the forces on the profile to the numerical simulation by finite elements of the mechanical behavior under SOLIDWORKS.

We will present the results of studies for wheels with the following characteristics:

Z1 = 17 (Pinion); Z2 = 19 (wheels); Modulus (m) = 5; Pressure angle (α) = 20 °; Torque (C) = 10Nm; Young Modulus (HDPE40) (E) = 3450E6 Pa; Tooth width (b) = 10mm.

Results of the pinion study

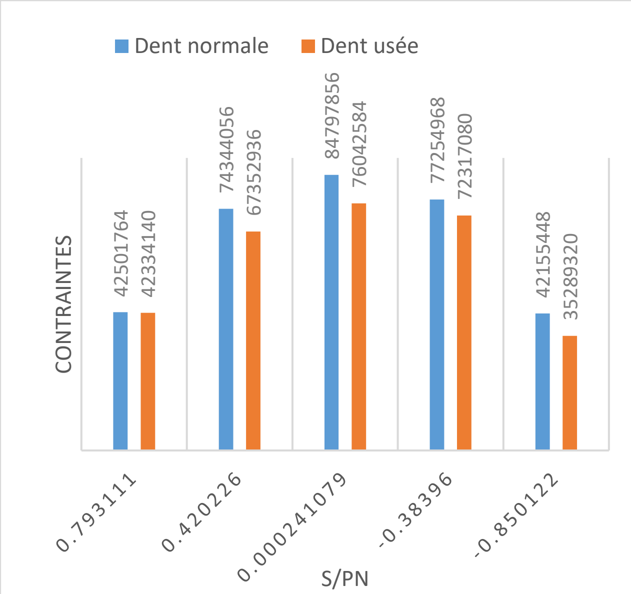

Figure 12 : Contact stress for a normal wheel and a worn wheel (4%) of 17 teeth

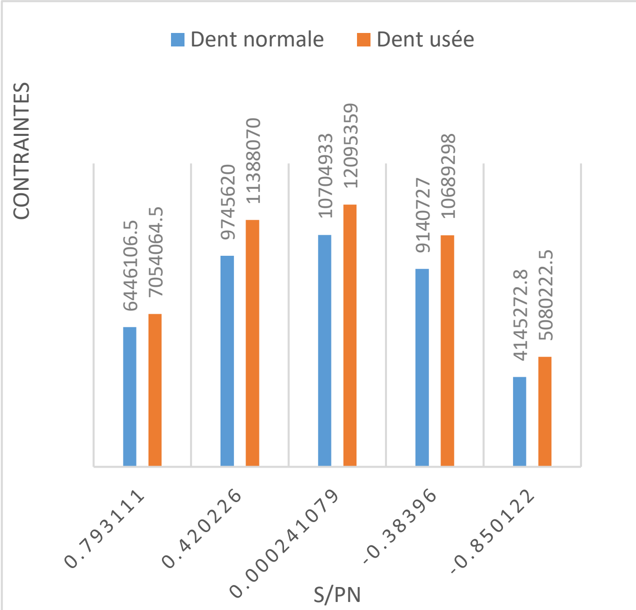

Figure 13 : Root bending stress for a normal wheel and a worn wheel (4%) of 17 teeth

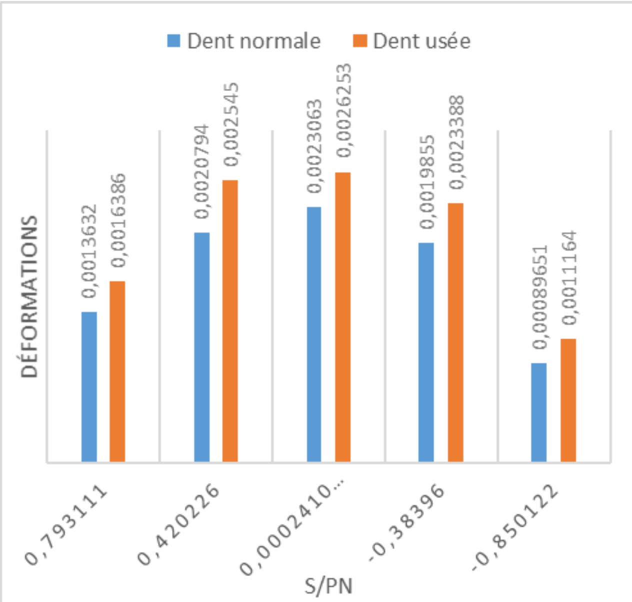

Figure 15: Deformations at the foot of the tooth for a normal wheel and a worn wheel (4%) of 17 teeth

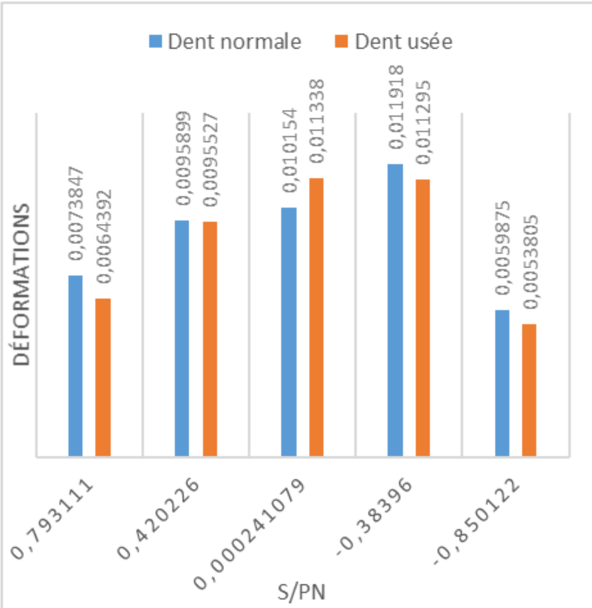

Figure 14 : Deformation in the contact area for a normal wheel and a worn wheel (4%) of 17 teeth

It should be noted that the bending stresses at the root for the pinion are maximal when the force is applied to the primitive point. This can be explained by the fact that the load distribution factor is maximum at this point. Moreover, if the same stresses are applied when forces are applied to the head (1) and to the root (5), the stresses are higher in the case of application of force at the head (1) than the root (5) because the load distribution factor is almost the same at these two points then the radius is greater in (1) than in (5).

In addition, the bending stress increases when the tooth wears out; which is logical. The deformations follow the same pattern as the stresses. The contact stresses are the same in (1) as in (5) especially for the normal tooth; since the load distribution factor is practically the same at these points. The maximum contact stress is at the primitive point since the load distribution factor is maximum at this point.

Results of the study of the driven wheel

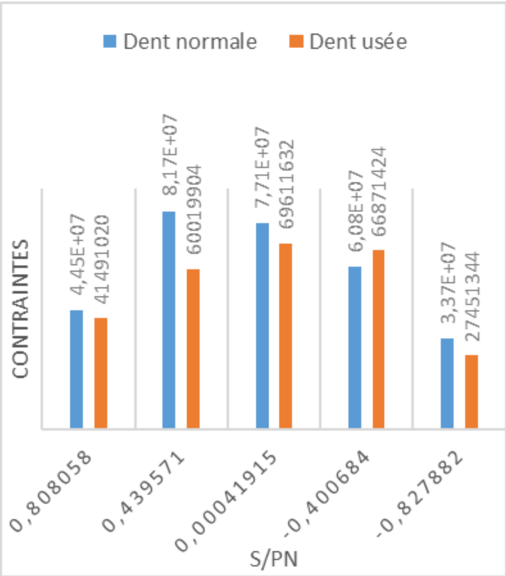

Figure 16 ***: Contact stress for a normal wheel and a worn wheel (4%) of 19 teeth***

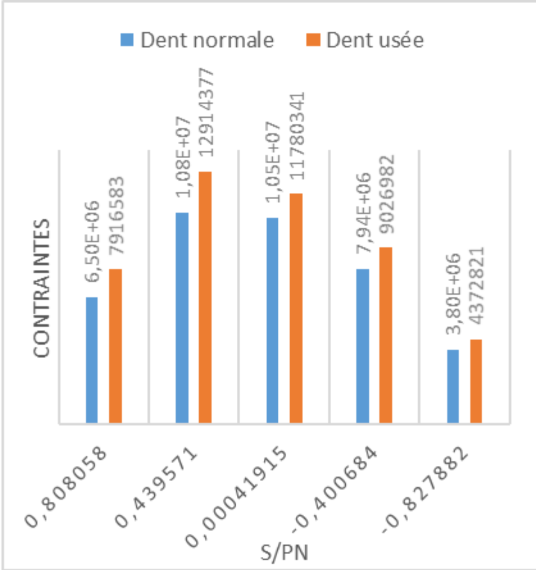

Figure 17 ***: Root bending stress for a normal wheel and a worn wheel (4%) of 19 teeth***

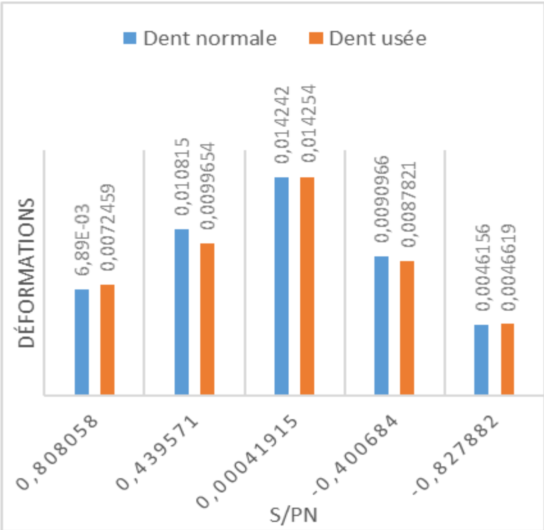

Figure 18 : Deformation in the contact area for a normal wheel and a worn wheel (4%) of 19 teeth

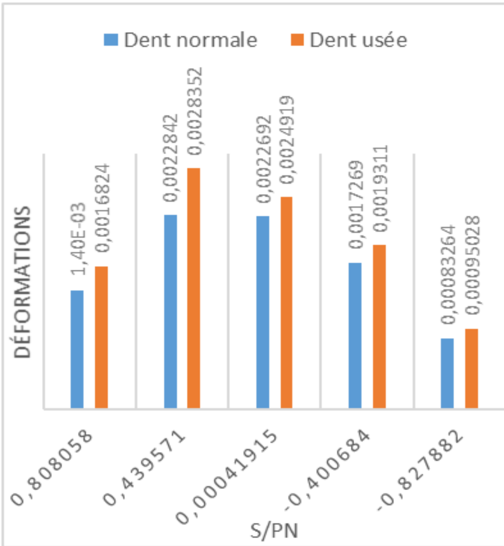

Figure 19 : Deformations at the foot of the tooth for a normal wheel and a worn wheel (4%) of 19 teeth

For the driven wheel, we have the same observations except that the maximum stress is no longer observed at the primitive point. It is closer to point (2). This will mean that the two wheels are not necessarily in contact at their primitive points during the meshing.

4. CONCLUSION

The method described in this document for the simulation of the mechanical behavior of gear teeth based on a new material, high density polyethylene with 40% birch fiber (HDPE40), is the basis for a study of the influence ofthe factors acting on the mechanical behavior of these types of gears. We will therefore present in a future document these studies of influences

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