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Application of CAD/CAM/FEA, reverse engineering and rapid prototyping in manufacturing industry

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Abstract— The paper presents some aspects about rapid prototyping which stays at the base of manufacturing design using CAD/CAM/FEA programs, scanning and measuring machining and its integration in industrial field. A big economical advantage is that products made by rapid prototyping express a low risk failure and the manufacturing process takes less time and lower costs than the conventional techniques. A new gasket for a ball screw used in a bending tube machine was produced by rapid prototyping techniques starting from a broken one. First the broken gasket was scanned by Modela Roland LPX-600 scanning machine obtaining the primary 3D model which is imported to CAD/CAM programs and the final product is achieved on ISEL GFM 4433 milling machine..The gasket mechanical characteristics were investigated by finite element analysis (FEA). FEA provides a way of simulating the gasket design under working condition and an opportunity to understand interactions with the mating machine. Therefore, problems in tooling or mold mating would be minimized. After FEA simulation a new material was chosen in order to increase the mechanical characteristics. The new gasket material improves the tool wear and life, scuff resistance, breaking strength and handling characteristic After that the gasket is assembled on the ball screw of the bending tube machine in order to observe its functional behavior.

Keywords— rapid prototyping, reverse engineering, gasket, scanning, milling, FEA.

I. INTRODUCTION

Rapid prototyping (RP) by definition means the ability to generate models directly from computer-aided design (CAD) data in a very short time.

There are two distinct RP processes:

- subtractive processes
- additive processes.

The RP processes include, amongst others, Subtractive Rapid Prototyping (SRP), Stereo Lithography (SL), Laser Sintering (LS), Fused Depositions Modelling (FDM), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS) and 3- Dimensional Printing (3DP) (Chua et al., 2005). RP technologies have gained diversity, complexity, sophistication and popularity since their introduction in the late 1980’s [1].

These techniques allow designers to produce tangible prototypes of their designs quickly, rather than just two-dimensional picture. For small series and complex parts, these techniques are often the best manufacturing processes available. After all, CNC technology and injection molding are economical, widely understood, and available for wide material selection. [2]

In RP, the term “rapid” is relative, it aims at the automated step from CAD data to machine, rather than at the speed of the techniques. Depending on the dimensions of the object, production times can be as a few days, especially with complex parts or when long cooling times are required. This may see slowly, but it is still much faster than the time required by traditional production techniques. This relatively fast production allows analyzing parts in a very early stage of designing, which decreases the resulting design cost. The use of RP in product design and development has had a significantly positive effect and has been shown to reduce development costs by 40 to 70% and the time to market by as much as 90 %. [3],[1]

The techniques of RP contribute to minimizing the risks of project failures. The economic stakes are a key factor.[17]

Subtractive Rapid Prototyping (SRP) is a process who transforms 3-D digital models content into physical objects. The term subtractive suggests that taking away material during the process. This is precisely what CNC RP does. The original source model can be of any 3-D content or software origin. Any CAD, CAM, or 3-D modeling can be machined. [4]

SRP is a low cost prototyping and parts manufacturing process. The digital model is recreated an transformed into a real world physical object that can be held in the hand. The final milled parts can be used for preproduction models ready for manufacturing, product prototypes, sales samples, proofs, displays and concept development.

SRP provide many benefits some of them are as follows:

- increase productivity and save cost
- no more wasted internal resources and man-hours
- wide variety of material can be machined
- high tolerance machining

surface quality rivals any other RP system on the market. [4],[5]

This paper presents a description of how CNC milling can be used as a rapid prototyping process. Subtractive prototyping is another way to create prototypes in which material is removed from a larger piece of material. Subtractive prototypes are typically created using more traditional manufacturing processes. These include standard machining process such as milling, turning or drilling and more modern

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tools like CNC machining. So with subtractive prototyping, we might start with a block of metal or plastic and cut away material until the prototype part is created.

In RP, there are advantages and disadvantages to any choice of technology. Subtractive prototyping is limited to relatively simple shapes –complex geometries are not possible. The material must be readily available in the size and shape needed. And SRP usually takes longer. Its main advantage is that is made in the final production material. Others advantages: accuracy- machine tools are more accurate than RP layer-by-layer or drop-by-drop methods, finis- machine tools can produce a very smooth finis, mass production, more materials- many different materials can be machined. [1],[4]

The Reverse Engineering technique (RE) is one of the working tools in the Integrated Engineering that permits the optimization of the products' design and performance, so that the aim for a flexible production with minimum costs, high quality and offered to its beneficiaries as soon as possible, become more and more a tangible reality.

This technique of recent date in terms of modern production systems, still has a relatively limited application, it being accessible particularly to specialists from important universities and industrial units, who possess already structured knowledge and procedures and what is more important, who can afford modern, but still expensive, equipments and facilities.

To many specialists, mainly those from small and medium enterprises or universities, the Reverse Engineering technique still seems an exotic alternative, although the advantages of its use are evident. Although the use of the Reverse Engineering technique as working tool is more and more spread in USA and Europe, in Romania it seems to be still in the exploration phase.

In the absence of some sufficiently cogent information in the industrial field, existing data shows that in institutes of research and universities, although approached with interest, this technique stands at the beginning. In Romania, at present, the scientific publications do not give evidence of woks on this issue except a few articles published or presented at conferences for academics or researchers. One of the limitations of the development of this study is also the concern that many of the fully developed Reverse Engineering techniques require expensive equipments (three-dimensional measuring and scanning machines, rapid prototyping machines, computers with considerable hardware and software resources.).[6][3]

Solid modeling is a technique for representing solid objects suitable for computer processing. Other modeling methods include surface models and wire frame models. [7] Primary uses of solid [7] modeling are for CAD, engineering analysis, [8] computer graphics and animation, rapid prototyping, medical testing, product visualization and visualization of scientific research

Computer-aided design (CAD) is the use of computer technology for the design of objects, real or virtual. The design of geometric models for object shapes, in particular, is often called computer-aided geometric design (CAGD). However CAD often involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD often must convey also symbolic information such as materials, processes, dimensions, and tolerances, according to application-specific conventions. CAD may be used to design curves and figures in two-dimensional ("2D") space; or curves, surfaces, or solids in three-dimensional ("3D") objects. [9]

While computer-aided manufacturing (CAM) is the use of computer-based software tools that assist engineers and machinists in manufacturing or prototyping product components. Its primary purpose is to create a faster production process and components with more precise dimensions and material consistency, which in some cases, uses only the required amount of raw material (thus minimizing waste), while simultaneously reducing energy consumption. CAM is a programming tool that makes it possible to manufacture physical models using computer-aided design (CAD) programs. CAM creates real life versions of components designed within a software package. CAM was first used in 1971 for car body design and tooling. Integration of CAD and CAM environment requires an effective CAD data exchange. Usually it had been necessary to force the CAD operator to export the data in one of the common data formats, such as IGES or STL, that are supported by a wide variety of software. The output from the CAM software is usually a simple text file of G-code, sometimes many thousands of commands long, that is then transferred to a machine tool using a direct numerical control (DNC) program. [10][11]

The finite element method has appeared as a consequence of the necessity to calculate complex strength structures for which the analytical methods of calculation are not available.

The basic idea is that in case the structure is divided in more parts named finite elements , for each of them there can be applied the calculation theories corresponding to the adopted mapping (beam , plate or massive theory). Division of a whole in parts of small dimensions, operation called mashing will have as result the obtained of simple forms for the component finite elements of the structure. The model of calculation used in the finite element analysis is an approximate model, obtained by assembling the component finite elements, taking into account the geometry of the structure. The finite elements connection is performed only in certain points named nodal points or nodes. The nodes represent the intersection points of the straight or curved boundary lines of the finite elements. [18]

The finite elements can be uni, bi or three-dimensional depending on the geometry of the structure they are modeling.

The nodes are usually placed on the element boundary where the adjacent elements are connected one to another. As the real variation of the field variable (such as displacement, stress, temperature, pressure or speed) inside continuous is not known, we admit that the field variable variation on the domain of a finite element can be approximated by a simple function. These approximation functions (named interpolation models) are defined depending on the values of the field variables in the nodes.

The approximate character of the finite element method results as a consequence of the fact that the real geometry is always replaced by a mesh of finite elements which follows the

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real shape but cannot reproduce it exactly but only for certain special geometries, because of the finite number of elements, and the unknown dimensions of the problem are calculated only in the nodes of the structure. It follows the conclusion that the accuracy of calculation increases with the increase of the finite elements number. The continuity of the results obtained depends on the continuity character which the approximation functions must secure at the level of interelement areas.

The finite element method formulation is based on expression of the extreme conditions which some sizes arising in the studied phenomenon must satisfy.

The finite element method is a method with a wide field of applicability which is pleased by the advantage of a relatively simple formulation. The generality character of the method confers it the advantage to adapt with simple modifications to the most complex and various problems such as the linear, nonlinear problems, static and dynamic loads at beam structures, plane or curve plates and three dimensional structures, contact loadings, problems of fracture mechanics, classified in three types of problems: equilibrium problems, and propagation problems. [12]

II. Problem Formulation

The case study presents the replacement of a gasket in a ball screw assembly at a pipe bending machine, which has given up during the operation (*Figure.1*), with a new one performed by using modern techniques of reverse engineering and rapid prototyping. Also, it was aimed to replace the material with another one that shows a superior “quality / price” relationship.

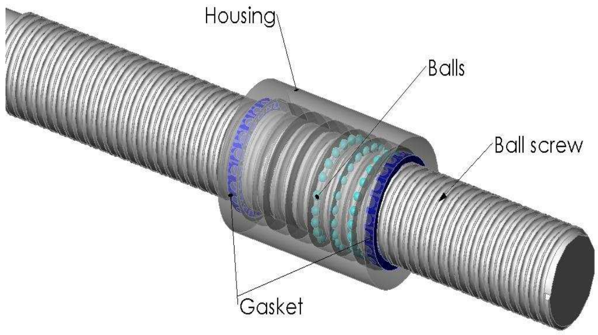

Figure 1. Ball screw assembly

Only the whole assembly is on sale and because ordering the gasket individually is not possible, it was decided that the part be performed.

III. Problem Solution

Even since the appearance of the first rapid prototyping system (RP) on the market, in terms of product development, the objective consisted of performing models in a quick manner in order to allow an efficient review and testing of the design even from its conceptual phase. Currently, at more than 10 years of its inception, RP technology has evolved in many directions, such as faster processing, better quality products and new materials. [6][13]

Performing the gasket by using modern techniques of rapid prototyping and reverse engineering include certain steps which are schematically represented in (*Figure.2*).

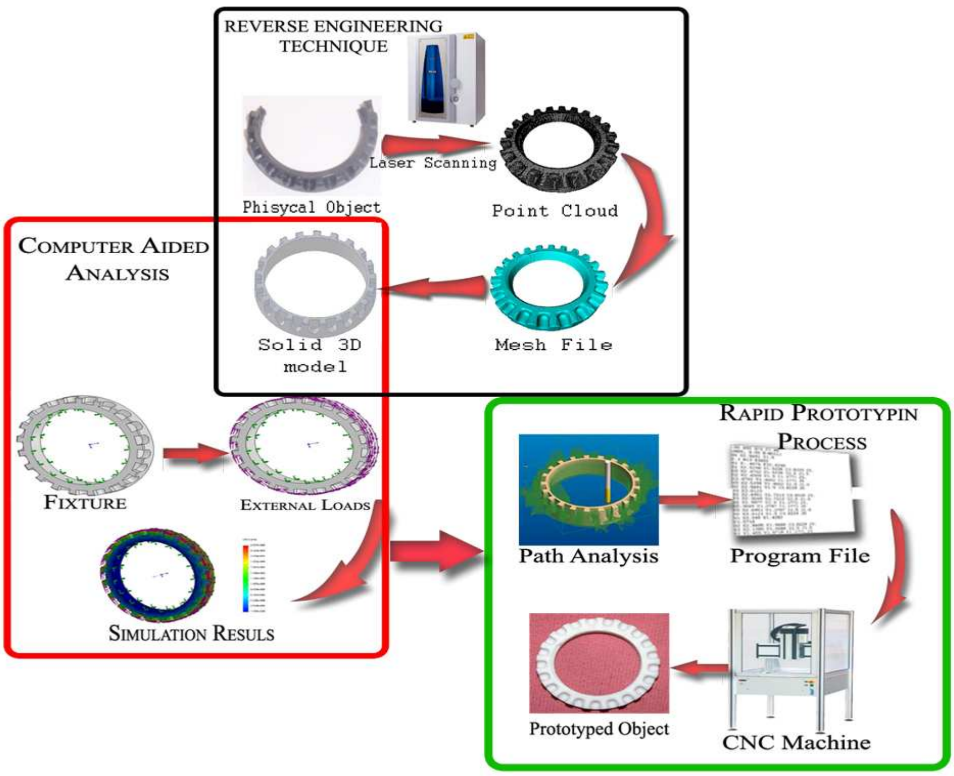

Fig. 2. Main steps in the gasket implementation

Due to its complex form, it has been decided that the gasket be scanned by Modela Roland LPX-600 machine.
For the gasket is black and absorbs the light of the laser, the scanned model resulted is unsatisfactory, and therefore, it has been decided that the part be covered with a fine layer of white paint.

After scanning the part, the point cloud (*Figure.3*) obtained was exported into an STL format of the CAD program.

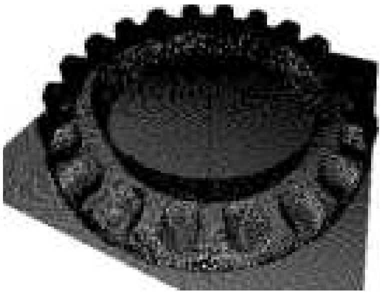

Figure 3. Point cloud

The easiest way to approximate a 3D geometrical model is by approximating it with a lot of triangular facets. In other words, the borders of the model are provided with equal triangular facets.

The 3D model was performed by executing a polar multiplication of a section obtained after scanning the known external diameter (*Figure.4*).

3D model obtained from the cloud of points is a faithful copy of the actual product its actual achievement being subsequently made.

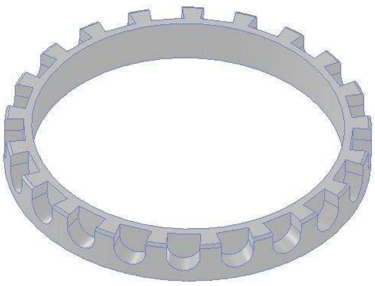

Figure 4. 3D Gasket

Upon the completion of the 3D model, the second issue was taken into consideration: choosing the material. The gasket that gave up during the operation (*Figure.5*) was made of ABS, therefore we studied the mechanical characteristics by FEA simulation.

Figure 5. Broken gasket

Gaskets show nonlinear behavior in loading and unloading conditions.[7]

A load mechanical test has been carried out for finding the mechanical characteristics of the gasket material which are in turn used in the FEA. [8]

The finite element analysis offers wide variety elements to the model. These elements consider geometric and material nonlinearities and transverse shear are neglected. Thus the pressure–versus–closure behavior can be directly applied to characterize the gasket material.[14][15]

Simulation was done using the ABAQUS software and a study related to the resistance at torsion stress was carried out. For meshing, linear tetrahedral elements with 4 nodes were used (C3D4 type). The mesh model has 14,356 nodes and 61,859 elements. (*Figure.6*).

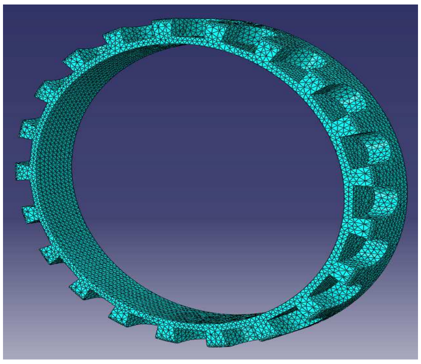

Figure. 6. Gasket mesh

The model was fixed on the inner cylinder's surface *(Figure.7).*

Two stresses of 1.4MPa were applied to the model: one stress was applied to the cylindrical surface *(Figure.8)*, which represents the section of balls, and another stress to the outer cylindrical surface of the gasket *(Figure.9).*

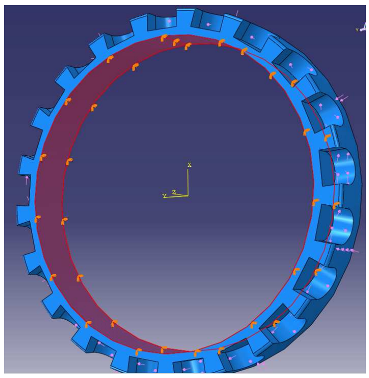

Figure.7 Fixed surface

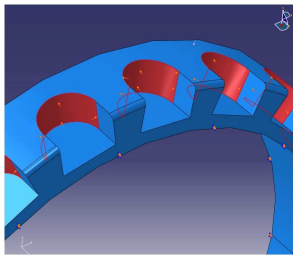

Figure.8. Stress applied to the section of balls

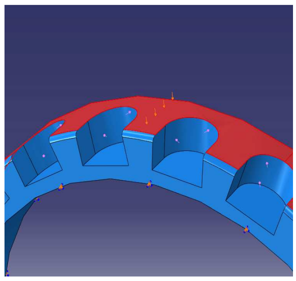

Figure.9. – Stress applied to the outer surface of the gasket

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Upon simulation, a maximum equivalent Von Mises stress of 3.21MPa *(Figure.10).* was recorded.

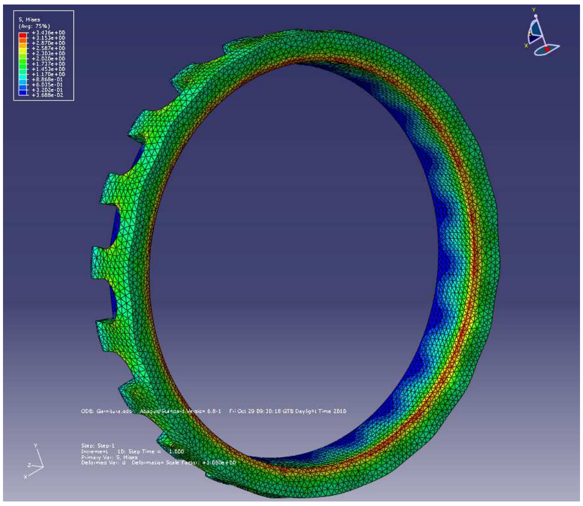

Figure. 10 – Equivalent Von Mises stress variation

To reveal stress variation, a route has been defined on the gasket's thickness, as shown in *(Figure.11).* The equivalent Von Mises stress variation upon the defined route is presented in *(Figure.12).*

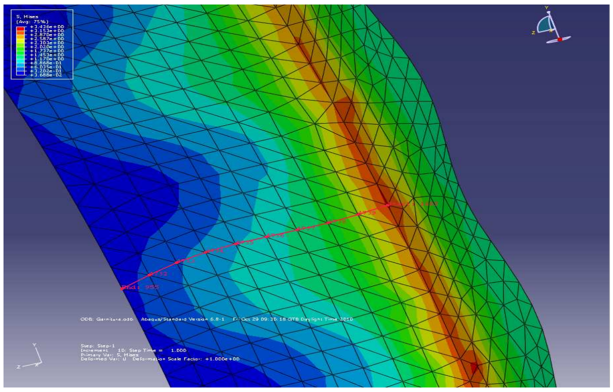

Figure. 11 – Route defined for the stress variation

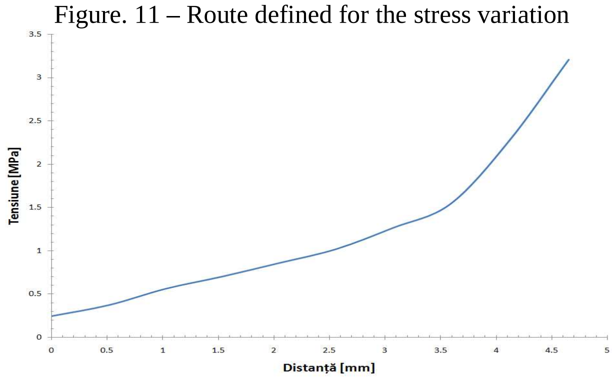

Figure. 12 – Stress variation after the defined route

A comparison between the distorted and the undistorted model is shown in *Figure.13.*

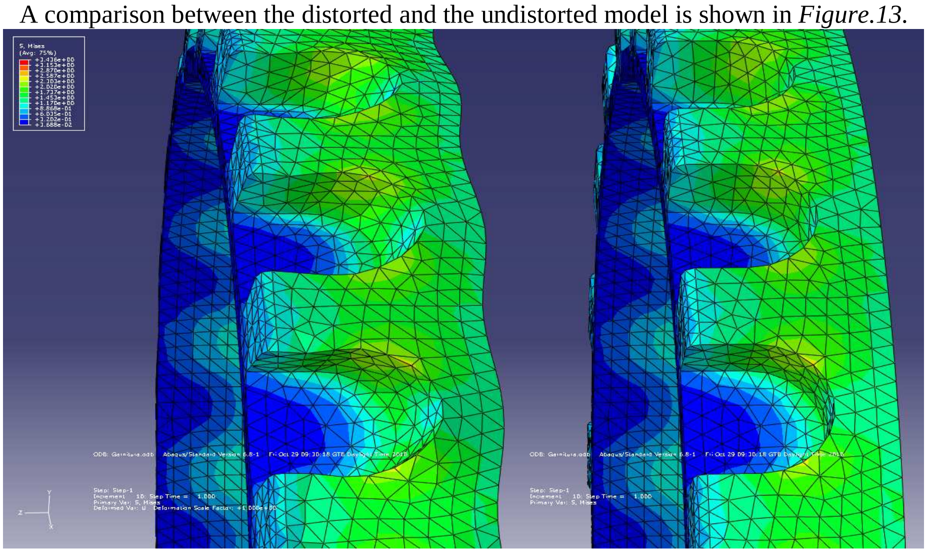

Figure. 13 – Comparison between the distorted model (right) and the undistorted model (left)

According to figure number 12 also helped by figures 11 and 13 help us draw a first conclusion which is: the ABS material has a good mechanical resistance at shocks and at breaking and also show a broad elasticity but a limited one. As it is known it is not a spongy material.

After FEA simulation, a maximum equivalent stress Von Mises was detected of 3.21MPa (fugure10). Figure 11 shows the variation of the stress on the thickness of the model. The variation of equivalent stress Von Misess after the set run is presented in figure number 12. A comparison between the deformed and undeformed is presented in figure number 13.

According to the figure number 12 we can see that on the gasket model we have already a stress value of 0.25 Mpa, stress given by the montage condition (the fixed interior).

From this montage condition a maximum stress of 3.21 Mpa is registered, above this it would break if it would charge more. It is observed that the stress in ABS has a moderately up run up untill 3.5 mm in the direction of measurement after which it continues going up but abruptly up untill 4.7-4.8 mm, which makes us draw the conclusion that the maximum stress of 3.21 MPa is registred on the line of the interior surface of the layout of the ring as in figure 10. Because fo the fact that

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ABS as a material is less elastic shows us that the initial stress applied is found in the material, this not having the possibility to eliminate the tension in the physical and chemical structure of the material.

The strong chemical boundings from ABS give high resistence to breaking, the small interstitial spaces, the rigidity of the grains makes the tension to propagate in an amortized raw form, keeping the matetial at a high enough stress. The balls that press in places are in plane state of stress function with a tangential component on the ring producing an inflection of the inferior part towards the interior as seen in figure 10 where the yellow-greeneish colour presents also the stretched fiber of this ring. Acoording to figure 13 the balls operate with a normal component on the place for the balls deforming it. As a conclusion for the graph in figure 12 ABS takes a lot from the 1.44 MPa tension applied and keep it up untill 3.21 MPa the voltage going up on two landings. The first up untill 3.5 mm and then the more abrupt one 3.5-4.7mm. ABS is more rigid and less elastic but very resistent to shocks long time and intense ussses.

After FEA simulation results we have noticed that this material does not provide the best mechanical properties and therefore we have decided to replace the ABS with Teflon (PTFE) which is a spongy material and have high breaking resistance.

A FEA simulation was made also for this material in order to investigate its behavior.

Upon simulation, a maximum equivalent Von Mises stress of 1.22MPa *(Figure.14)*.was recorded.

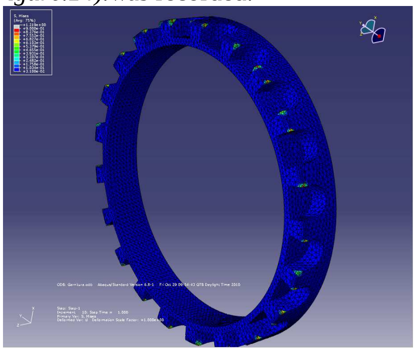

Figure. 14 – Equivalent Von Mises stress variation

As there is a very big difference between the maximum stress and the rest of stresses in the gasket, a maximum stress limit of 0.05MPa in the sketched outline has been defined. Stress variation on the model is shown in figures 15 and 16.

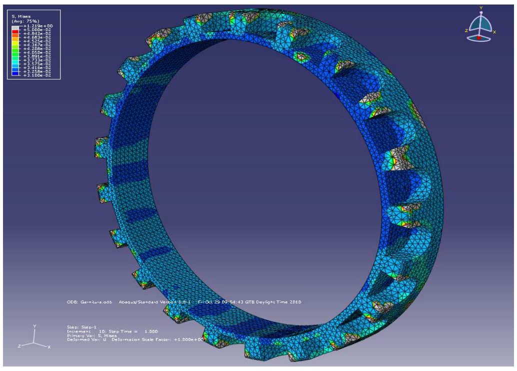

Figure. 15 – Equivalent Von Mises stress variation

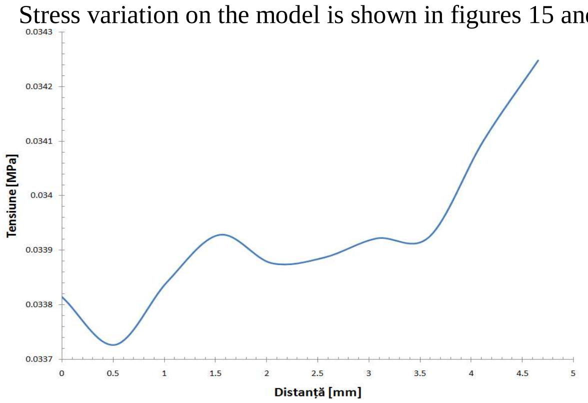

Figure.16 – Stress variation after the defined route

A comparison between the distorted and the undistorted model is shown in Figure 17.

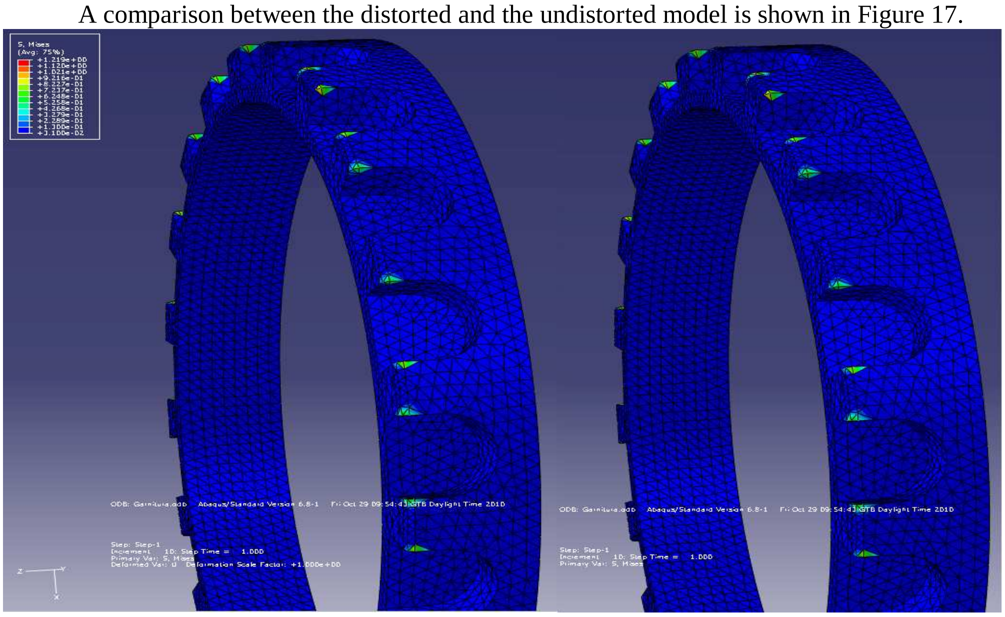

Figure. 17 – Comparison between the distorted model (right) and the undistorted model (left)

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According to the graphic in figure 16 we can see PTFE that has a big enduring capacity and we could say it plays very well the part of a shock absorber.

After the simulation a maxium equivalent stress Von Mises of 1.22 Mpa *(Figure.14).*was obtianed.

According to the fact that there is a big difference between the maximum and the rest of the stresses from the set, a maximum was set from the 0.05 Mpa contour..The variation fo the stress in the model is shown in figures 15 and 16. The variation equivalent Von Misess stress after the defined contour in figure 11 is presented in figure 16.

A comparison betwen the deformed and undeformed model is presented in figure 17. Started stress at over 0.0338 Mpa is given as in the previous example from the montage condition of the ring. An aplied pressure of 1.22 Mpa was impossed and a maximum of 0.05 Mpa stress was obtained. It is seen that on the first 0.55 mm there is a going down of the stress values down till almost 0 and then a moderate growth up untill 1.5mm followed by a fluctuation till 3.5mm and only after that a growth between 3.5-4.8 mm just as in case of ABS. The Teflon plays a lubricant role because it has a small friction resistence which helps the compaction under pressure and reduces the ejecting forces. Also from it can be obtained tabloids with good disintegration times and breaking resistance even though it presents certain disadvantages such as: reduced toughness, processing difficulties, fragility and the inclusions presence.

Because of accessabilities, chemical inertia, good physical properties (taughness,flexibility, permeability, adhesion, shock ressitence, haul, elongation,) the reduced coefficient of friction between the tabloids and moulds, PTFE was tested for different aplications. As it is seen in figure 13 the friction applied is absorbed by the material because of the elasticity and high tenacity and the big interstitial spaces (being spongy).

The first stress is lost in the material giving dangerous areas in the upper part of the ring where the balls are. The stress moves up and down because of the amortisation induced by the material and the abrupt part just as in the case of ABS is slower and is somewhere around 0.5 MPa. Different from ABS the maximum stress with a lower value is all trough the material and like this it does not have dangerous areas. The dangerous part is lowered by its amortization.

The real manufacturing of the part began after the material had been chosen and the simulation had been made, starting from the 3D model which was imported into a CAM program.

The Isel GFM 4433 machine software was thought to run under DOS, permitting solely the import and design of 2D drawings, with no possibility to run under Windows. Knowing that the machine is able to work in 2.5D, it was aimed to be achieved the manufacture of 3D geometrical models. The department has adopted a software provided with a new post-processor which generates programs that are recognized by the milling machine.[6][16]

The CAM program for implementing the gasket comprises two main stages: roughing and finishing. In the first stage a end milling-cuter of 3 mm was used and for the finishing - a 2 mm ball-nose mill. Gasket manufacturing simulation is shown in *(Figure.18).*

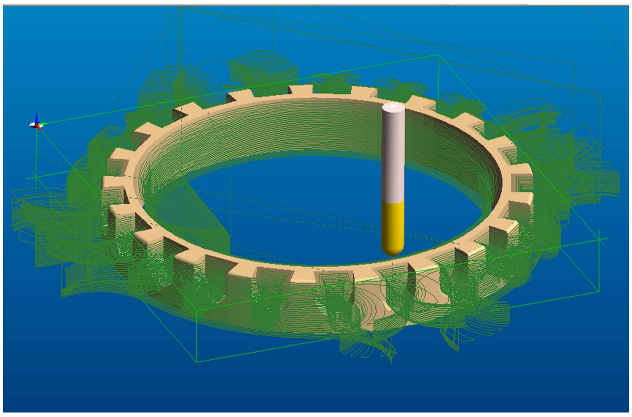

Figure 18. Manufacturing process

The program was implemented to the ISEL GFM 4433 milling machine which made the gasket in its final form, presented in *(Figure.19).*

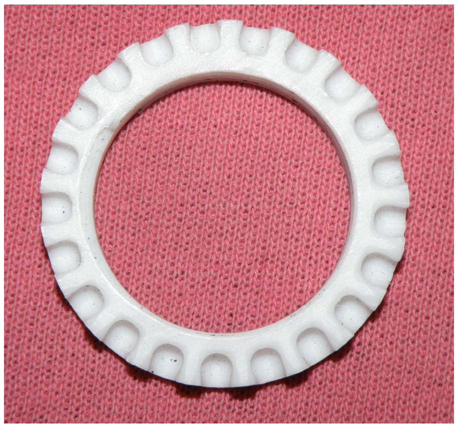

Figure 19. The final gasket

IV Conclusion

In this paper, an example of co working between the industrial environment and the university is shown. Resources of the university were used in order to respond to a need in the industry.

By using the RP and RE techniques and the related equipments, the requirements of the industrial partner have been met in a very short time and with minimum costs.

The physical model of the gasket behaves normally, during the operation process, it fulfills its functional role demonstrating effective results obtained from the FEA simulation.

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