ISSUES ON THE COMPARATIVE STUDY OF MILLING RUBBER AT CRYOGENIC AND AT ROOM TEMPERATURES

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ABSTRACT: In a company specialized in the production of V-belts, which use milling to generate the final surface of an assortment of V-belts, we have encountered problems starting from fastening up to milling the rubber. At vulcanized rubber any error makes the workpiece to be rejected without the possibility to fix it, or not even to reuse the material. After we studied the literature from domain, we observed that the cutting issue of vulcanized rubber type 3540 and 3003, is not defined from some points of view, for this reason we made an experiment to observe the behavior of rubber milling at cryogenic and room temperatures, with a cutting speed of 3297m/min at a feed range between 0.0025 mm/tooth and 0.02 mm/tooth. As a result of the experimental study, we observed that for the workpieces that were cooled with liquid nitrogen, the reject rate was reduced down to 20%. We also observed that, at cryogenic temperatures, feed milling had a small influence on the obtained surface quality.
KEY WORDS: Cryogenic Milling, Rubber Cutting Data, Surfaces quality.

1 INTRODUCTION

According to ASTM D1566-00, vulcanized rubber is a flexible material which can swell, capable of large elastic deformations and able to return to its original state quickly and forcefully. The processing of synthetic rubbers is generally accomplished by molding, extrusion, injection etc.

Soft polymeric material parts are common in modern products, and their manufacturing is done usually by molding, but given the variety of produced models and by the fact that they are constantly changing it is preferable to use cutting process, which is the most flexible method of processing from this point of view (Teramoto, Kuroishi, & Yamashita, 2009).

The issue of milling vulcanized rubber and obtained surface quality through the cutting process, was disputed by other authors (Jin & Murakawa, 1998, Lewis, 2002; Luo, 2005; Nayak, Shetty, & Shetty, 2012; Rivera-Moreno, Hernández-Castillo, Siller, Elías-Zúñiga, and Rodríguez-González, 2013); which through the experimental studies they concluded that the cutting of vulcanized rubber depends on many factors. The main factors stated are temperature of the polymeric material, the cutting regimes, the cutting tool geometry, etc.

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The machined surface is an important feature of a processing operation, since it is the final goal. The quality of the surface is important for the functionality of the assembly which includes rubber parts.

Surface integrity is a term that involves several considerations: the surface quality, no cracks or chemical changes thermal damage and no stress in the material (Shaw, 2005).

2 THE CONTEXT OF THE ISSUE

The issue of non-metallic materials cutting aroused the interest of many researchers in view of the continuous product development and the consumer market requirements in this branch of industry. Researchers have conducted experimental research on cutting flexible polymeric materials by turning, milling, drilling etc. with various cutting tools, cutting régimes and cutting conditions to optimize processes.

Milling the rubber is an important operation for producing specific surfaces otherwise hard to produce (or even impossible). In order to obtain a high quality surface we must use cutting régimes, tools and machining technologies suitable for each type of flexible material. A high quality obtained for rubber parts ensures safety and reliability in service, since the heat damaged surfaces, the ruptures of material, the non-conforming dimensions etc., are often the source of nonconformities occurrence.

After we studied the literature from domain, we observed that the cutting issue of polymeric materials is not well defined from some points of view:

-Thermal expansion is up to 10 times greater with polymeric materials than metals;

- Polymeric materials lose heat more slowly than metals, so avoid localized overheating;

- Softening (and melting) temperatures of polymeric materials are much lower than metals;

- Polymeric materials are much more elastic than metals.

Also in a company specialized in the production of belts, which use milling of vulcanized rubber to generate the final surface of the belt, have met difficulties starting from fastening up to milling the rubber. At vulcanized rubber any error makes the workpiece to be rejected without the possibility to fix it, or not even to reuse the material.

In this context an experimental study in cutting tools, materials, and manufacturing technologies identical to those identified in the factory has been developed.

3 EXPERIMENTAL CONDITION

As a result of the studies preceding to this experiment, we found that in the rubber machining industry, are gaps regarding cryogenic rubber machining. Based on these observations we developed an experiment where to reflect as accurately and objectively as possible the influence of cryogenics on the milled rubber with a specific cutting regime.

The aim of the experiment is to study comparatively the behavior of rubber during milling at cryogenic and room temperature, with a cutting speed of 3297 m/min in the range of feeding from 0.0025 mm/tooth to 0.02 mm/tooth.

As a result of the experimental studies prior to this experiment, we found that in the rubber machining industry there are some gaps regarding the machining of rubber in cryogenic condition. In the experiment we tried to follow properly and objectively the influence of cryogenics on the milling of rubber (Cosma, 2011). Workpieces were chilled with liquid nitrogen, up to -195 °C, and then we had let warm up to -40 °C. The measurement of the temperature was achieved with Fluke 561 Infrared and Contact Thermometer.

In the experiment we used the materials-code 3540 and 3003, mainly used in the production of trapezoidal belts (Antony, 2014). Due to the fact that the 3540 material contains textile micro-fibers sized 0.5-2 mm, the experiment addresses the issue of machining in the direction and perpendicular to the direction of the fibers. The rubber vulcanization process parameters are as in Table 1.

For these two types of rubber we have made several attempts considering the properties on some samples to ensure that the materials on which we were going to perform the experiments are within the prescribed tolerances and especially supported by the manufacturer. The resulting properties of the

Table 1. Vulcanizations parameters

Nr. Crt	Characteristics	Set	Obtained	Tolerance
1	The temperature (Upper plate)	170 °C	168 °C	± 2.5°C
2	The temperature (Lower plate)	170 °C	169 °C	± 2.5°C
3	Pressure	150 Bar	149.5 Bar	± 5 Bar
4	Time Duration	40 min	40 min	-
5	Toughness	86 Shore A	84 Shore A	83-89 Shore A
6	Weight	198.4 g	199.1 g	± 2.4 g

Table 2. Cutting regimes used in experiment

Materials	Temperatures	Cutting directions	Feed	Cutting Speed
3540	20°C	On Fiber Direction	0.0025 mm/tooth	2355 m/min
3003	-40°C	Perpendicular to the Fiber Direction	0.005 mm/tooth	
			0.0075 mm/tooth	
			0.01 mm/tooth	
			0.0125 mm/tooth	
			0.015 mm/tooth	
			0.0175 mm/tooth	
			0.02 mm/tooth	

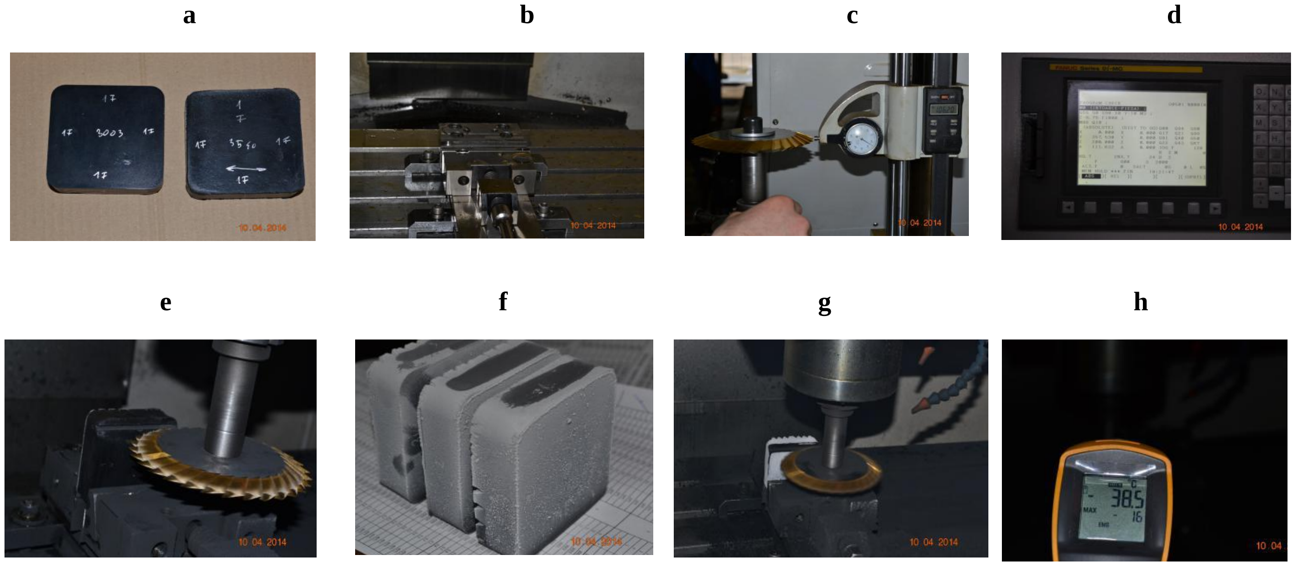

Figure 1. Representative images from the Experiment

two materials were compared with those of the specimens.

On the samples and specimens were attempted elongation operations, electrical conductivity and viscosity.

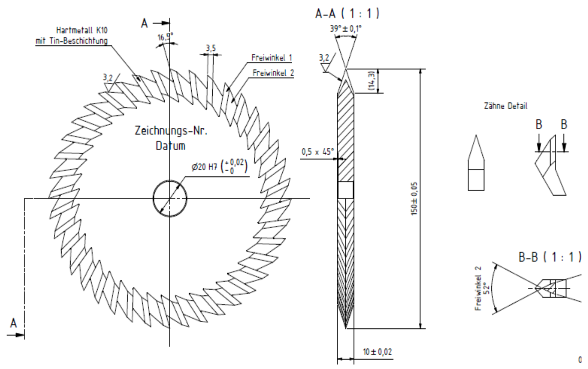

Figure 2. Tool used in experiment

In the second phase, we investigated the possibilities of rubber machining while we consider its physical properties, and the fact that the more difficult is fixing the machining center the more flexible the material. In this context we designed a mold in which we vulcanized specimens of 80x80x22 mm (Figure 1). The rubber samples were vulcanized for 30 minutes with a laboratory electrical press LaboPress P 300S type, and the vulcanization parameters are given in Table 1.

Milling the two types of specimens was performed on a 5-axis milling CNC AWEA BM 1200 type. The milling speed and the feeding were checked and calibrated before the experiment. The tool used in the experiment was checked and centered to ensure a maximum run out of 0.01 mm.

The cutting tool used was a profiled disc milling tool (Figure 2). This type of mill is currently used in the manufacturing process. The cutting régimes used are presented in Table 2.

The 5 mm depth of the cut was assured for all milling, this value being taken from the manufacturing specifications used by the said manufacturer. A total number of 48 experimental millings were performed with these parameters.

The results of the rubber cutting process are evaluated and classified into quality classes according to a set of characteristics determined by the visual analysis method. In this context in the paper Aspects regarding the comparative study of the cryogenic milling and conventional milling of vulcanized rubber (Mocerneac & Lobontiu, 2014), we proposed a model for assessing the rubber surfaces quality of the machined parts.

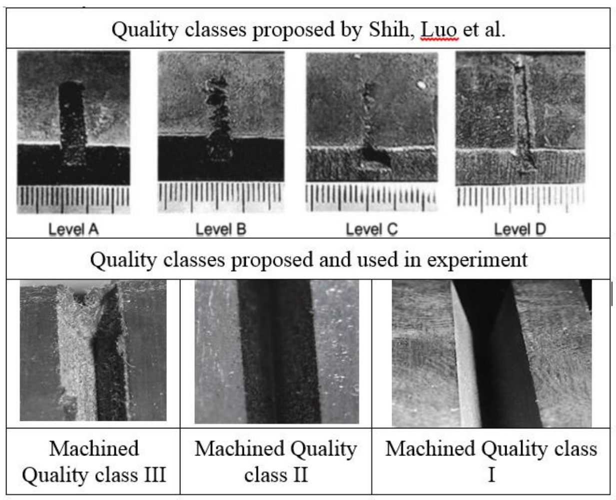

Figure 3. Equivalence of the proposed quality classes

Table 3. Characteristics of quality classes

Quality Class	Dimensional and Shape deviations	Thermal damage	Fractures of material	Roughness	Other Defects	Percentage range
I	0 – 0.1 mm	0 – 1 mm	0 – 0.5 mm	Without Porous surface	-	75 -100%
II	0.1 – 0.2 mm	1 – 5 mm	0.5 – 1 mm	Slightly Porous surface	-	50 -74.9%
III	Greater than - 0.2 mm	Greater than – 5 mm	Greater than – 1 mm	Porous surface	Other Defects	0 -49.9%

This concept of quality classes is based on ratings for a product category in the same range, designed and made for a specific purpose, of certain materials, by a technological process, with characteristic values between the conventionally specified limits (Stephenson & Agapiou, 2005).

In our paper (Mocerneac & Lobontiu, 2014), we proposed three quality classes of the surfaces obtained after milling and, according to the comparison and approximation dependent on calibration cues, we obtained percentage ratings of the maximum feasible quality. The concept of quality classes (5 classes) was also used by (Shih, Lewis, & Strenkowski, 2004) for the setting of grades (A to D) to the quality surfaces resulting from the rubber milling. Figure 3 presents the comparison between the quality classes proposed by Shih and those proposed and used in our paper. It is noted that the maximum level of quality proposed our paper is higher to the quality level proposed by (Shih, Lewis, & Strenkowski, 2004).

The existence of several approaches in this area of machined surface quality by rubber cutting requires a stronger focus on the problem and the development of approaches leading to proposing a standard quality with international acceptability.

The classification of benchmarks in quality classes was done according to the following characteristics, as shown in Table 3.

4 RESULTS ANALYSIS

In Figure 4, we can follow the evolution of surface quality obtained by milling the material with code 3540 with a cutting speed of 3297 m/min, the variable introduced in this diagram corresponding to the feed used in machining. It is noted that the development of the quality obtained with milling at cryogenic temperature is superior compared with milling at room temperature. The values of the quality level are within the range of 83.5% (when milling in the direction of the fiber and a feed of 0.02 mm/tooth) and 89.5% (which is reached with a feed of 0.01 mm/tooth and of 0.02 mm/tooth when milling perpendicularly on the fiber). With milling at room temperature we found that the maximum point in this case is 81.5% (when milling on the fiber direction with a feed of 0.0075 mm/tooth and 0.01 mm/tooth) and the minimum point is approaching the value of 70% (when milling perpendicularly on the fiber and at feed of 0.0075 mm/tooth and 0.0125 mm/tooth).

Comparing the results of milling at room

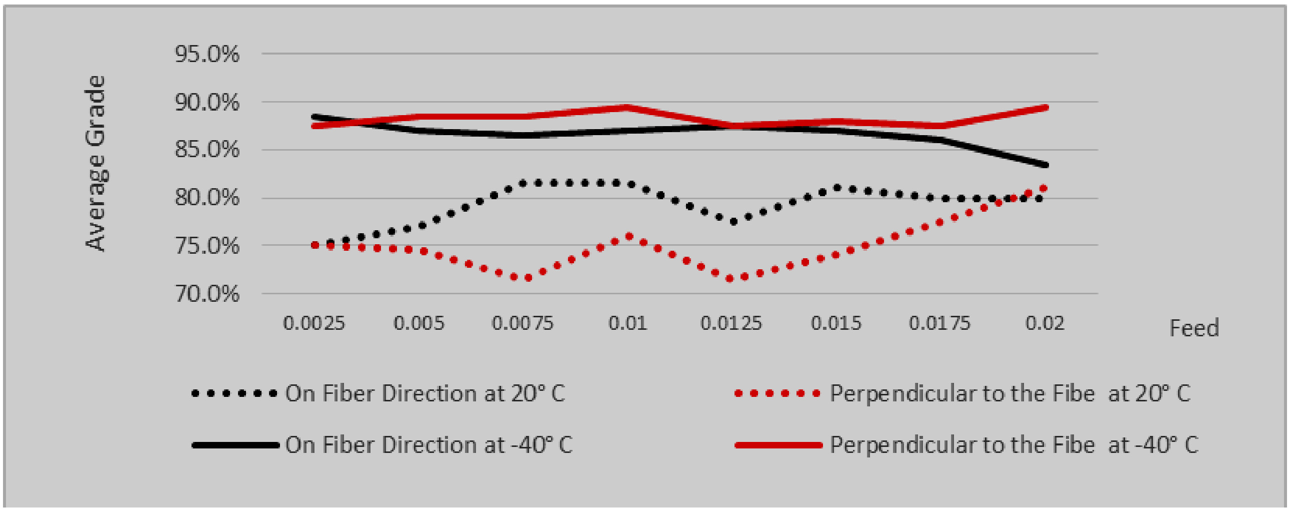

Figure 4. Evolution of the quality at milling vulcanized rubber with the cutting speed 3297 m/min, at the material 3540, depending on the feed

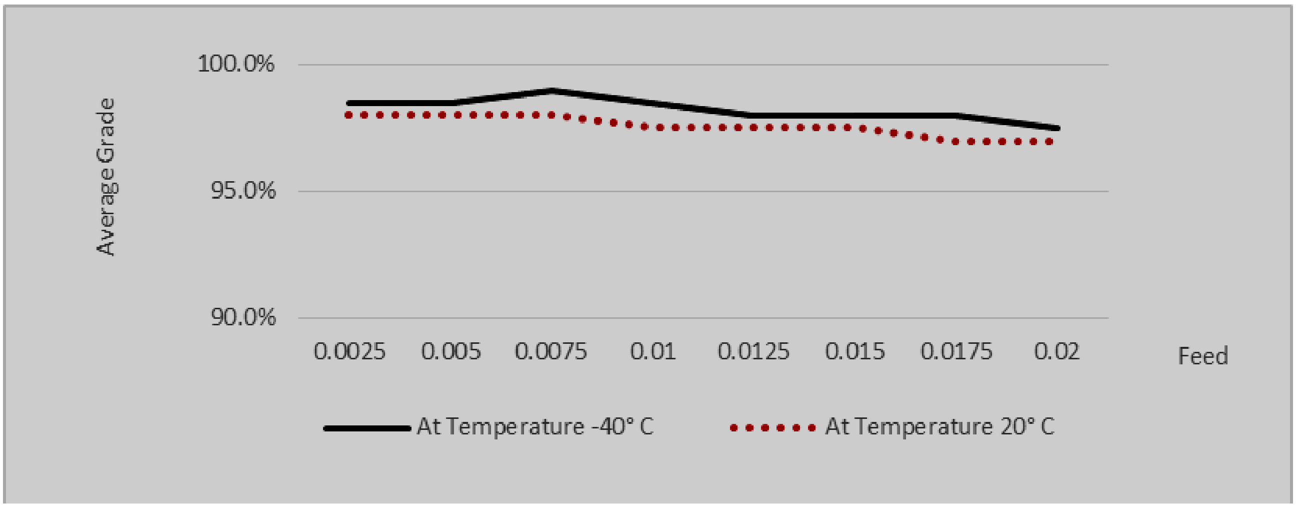

Figure 5. Evolution of the quality at milling vulcanized rubber with the cutting speed 3297 m/min, at the material 3003, depending on the feed

temperature with milling at cryogenic temperature, the material 3540, on the direction of the fibers, it appears that all cryogenic machining have superior results compared with machining at room temperature, the biggest difference between the qualities obtained by millings made on the direction of the fibers are recorded at feed of 0.0025 mm/tooth, where there is a difference of 14 percent.

Comparing the results of milling at room temperature with milling at cryogenic temperature, of the 3540 material, perpendicularly to the fibers, it appears that all cryogenic machining have superior results to machining at room temperature, the biggest difference between the qualities obtained by millings made perpendicularly to the fibers are recorded at feed of 0.0025 mm/tooth where there is a difference of 17 percent.

When using a feed from 0.0025 to 0.02 mm/tooth, milling at cryogenic temperature is superior to the milling at room temperature.

In Figure 5, it is highlighted the evolution of surface quality obtained after milling the 3003 material with a cutting speed of 3297 m/min, depending on the feed used in machining.

One can notice that at the cutting speed of 3297 m/min, in both cases, there is a constant track curve of quality, which is in a slight decrease. For both treatments one may notice decreased levels of quality once the feed increases. The minimum values in the schedule for both machining are recorded at the feed of 0.02 mm/tooth and the maximum point at the feed of 0.0025 mm/tooth at milling at room temperature and at 0.075mm/tooth at cryogenic temperature milling. With milling at room temperature machining quality is emphatically decreasing, from 96% (at the feed of 0.0025 mm / tooth) to 94% (at the feed of 0.0125 mm/tooth) this value is also the minimum point on the diagram. Comparing milling at room temperature with milling at cryogenic temperature, for the 3003 material, it appears that cryogenic machining is superior to machining at room temperature (on average 0.5%), the biggest difference between the qualities obtained is recorded at the feed of 0.0075 mm/tooth, where there is a difference of 1.5 percent.

As can be seen, all millings at cryogenic temperatures are superior to the millings at room temperatures.

5 CONCLUDING REMARKS

The main conclusions of this study are as follows:

1. The highest coefficient of quality, obtained at the milling of the 3540 material, on the direction of the fibers, with cryogenic temperatures was 88.5% and it was obtained under the conditions of using a cutting speed of 3297m/min, a depth of 5 mm and a feed of 0.0025 mm/tooth;

2. When machining at ambient temperatures, the 3540 material milled on the direction of fibers, the highest quality coefficient was 81,5% and was obtained at the cutting speed of 3297m/min, a depth of 5 mm and a feed of 0.0075 mm/tooth and 0.01 mm/tooth;

3. The highest quality coefficient obtained when milling the 3540 material perpendicularly to the fibers, at cryogenic temperatures, was 89,5% and was obtained under the conditions of using a cutting speed of 3297m / min, a depth of 5 mm and a feed of 0.01 mm/tooth and 0.02 mm/tooth;

4. In the case of ambient temperature machining of the material 3540 milled perpendicularly to the fibers, the highest quality coefficient was 81% and was obtained at the cutting speed of 3297 m/min, a depth of 5 mm and a feed of 0.02 mm/tooth;

5. Comparing the quality coefficients obtained from milling at room temperature with milling at cryogenic temperature of the 3540 material, both on the direction and perpendicularly to the direction of fibers, it is observed the quality dominance of the process parameter under cryogenic régime at all the cutting régimes used;

6. The highest coefficient of quality, obtained with the material 3003 milled at cryogenic temperatures, was 99% and was obtained under the conditions of using a cutting speed of 3297 m/min, a depth of 5 mm and a feed of 0.0075 mm/tooth;

7. With machining at ambient temperatures the material 3003, the highest quality coefficient was 98% and was obtained at the cutting speed of 3297m/min, a depth of 5 mm and a feed of 0.0025 mm/tooth, 0.005 mm/tooth and 0.0075 mm/tooth;

8. Comparing the quality coefficients obtained from milling at room temperature with milling at cryogenic temperature of the material 3003, it is observed the quality dominance of the process parameter under cryogenic régime, at all the used cutting régimes;

9. Comparing the quality coefficients obtained from milling at room temperature with milling at cryogenic temperature of the materials 3540 (both in the direction and perpendicularly to the direction of the fibers) and 3003, it is observed the quality dominance of the process parameter for the material 3003 in cryogenic régime, at all the used cutting régimes.

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