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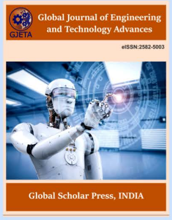

(RESEARCH ARTICLE)

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Replacement analysis of ceramic insert by CBN insert in vertical lathe

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Abstract

This work analyzes replacing an insert made of ceramic with an insert made of CBN (Cubic Boron Nitride). The inserts are cutting tools used in machining. We will start by presenting a brief account of what machining is, what is applicable in this research and the properties of the two cutting tools. We will also include our objective and justification for carrying out the project. Next, we will describe all of the equipment and tools used in the process to verify results, detailing the function of each one. We will explain our method step by step and show the properties of each insert and their use. We will compare the inserts during operations, and some results will be analyzed graphically in order to obtain a better picture of the behavior of the inserts. We will finish the paper by summarizing and calculating the results, on a cost-benefit ratio, thereby allowing us to determine the most viable replacement insert for use in industry.

Keywords: Inserts; Ceramics; CBN; Machining; Tool; Vertical Turning

1. Introduction

The uses of metals have always been a constant in the life of man, since prehistory. The first recorded uses were of bronze and copper in the production of tools for combat and hunting, which required tools that are resistant to the stress of combat and the production of rigid instruments for everyday use at the time. After the Iron Age, around 1200 B.C., many studies were carried out, leading to the discovery of steel, which is the addition of carbon to iron. It was noted that the material resulting from this binary alloy had different mechanical characteristics from conventional iron. And these alloys could be applied in different segments of that time [1].

The increasing demand for higher quality products in the world, associated with the growing competition between companies in the global market, also drives companies to find processes that ensure lower costs, higher productivity, and greater quality in the industrial sectors [2].

This great industrial and technological push has increased the search to find machining processes that promote, for example, less tool wear, greater chip removal capacity, less tool damage, and materials that have greater resistance to wear, oxidation and corrosion [3].

According to *Ojolo (2014)* [4] machining could be defined simply as “a cutting method whose removal of metal is favored in the process by producing high quality finished surfaces”.

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Machining is one of the most widespread manufacturing processes in the metallurgical industry today. It is a very practical process in relation to other processes and has numerous advantages, especially in regard to dimensional tolerances [5].

As for machining operations, we mean those that, when giving the part the shape, dimensions or finish, or even any combination of these three items, produce chips. We define chips as the material portion of the piece which has been removed by the tool and is characterized by having an irregular geometric shape [6].

However, the tool made of ceramic material is has been considered essential due to its characteristics and its cost benefits. Although recently cubic boron nitride (CBN) holds some promise as a replacement due to its durability, process time, and finished product quality.

Tool life is defined by the time that it works within specified parameters and is worn out or taken out of service when it loses its cutting characteristic within a predetermined criterion and some process variable is affected, such as surface finish and roughness, vibration and noise of the machine, chip shape etc [7].

CBN's and Ceramics are the best tools for this type of operation due to their hardness and high wear resistance. The CBN tool has a lower coefficient of thermal expansion than that of the ceramic, which is extremely important for turning hard metals. Some properties and characteristics of the inserts are shown in Tables 2 & 3.

Our objective with this research was to increase efficiency in the machining processes at metallurgical companies. We analyzed, through practical tests, the feasibility of exchanging Ceramic tools for CBN tools in vertical lathe operations with a hardness of 55 HRC, which was achieved by means of induction heat treatment.

2. Manufacturing Process

2.1. Vertical Lathe

Today, large companies still use outdated conventional machinery which is not capable of producing a wide variety of different parts, and there are several manufacturers that only manufacture a single product, because they depend on the use of machines and tools that that lack flexibility. Machining is a manufacturing process that consists of the release of excess metal from the part, through shearing forces, giving final shape to the raw material. [8]

Machining is a highly requested manufacturing process in industries, and it takes place by removing material from a product until it takes the desired form or gains the desired structures.

Turning is a mechanical process aimed at obtaining surfaces with the aid of one or more mono-cutting tools. For this the part rotates around the main axis of the machine and the tool moves simultaneously following a coplanar trajectory with that axis. [6]

There are several machining processes carried out on two different types of machines: conventional lathes and CNCs (Computer Numerical Control). In this referenced work, the assessment is done on a vertical lathe CNC machine, where its movements are controlled by a computer.

According to *Severino (2011)* [9], *Chen & Kurfess (2006)* [10], *Baek et al. (2020)* [11], *Jiang et al. (2020)* [12], *Erameh et al. (2016)* [13] and *Urbikain et al. (2015)* [14] vertical lathing is a machining process of relative complexity, since it is a roughing operation carried out simultaneously on the external and internal diameters of the parts. Machining takes place using two twin cutting tools with special geometry and with abundant cooling throughout the cutting process. At least one out of every five machining operations is turning.

The process is one of the most used in industry, it is responsible for 40% of the total time spent on machining and for 30% of the operations. The wide use of the turning process is characterized by its ease of operation, good production rate and economic advantages. One example from the various types of lathes is the vertical lathe as shown in Figure 1.

However, shaping a material requires several parameters to studied, from the type of material and the machine to the cutting tool used to perform this process.

Figure 1 Vertical lathe machining a bearing ring

2.2. Machined Material

DIN 42CrMo4 steel (SAE 4140) is the material used for the manufacture of bearings, it features a controlled hardenability of high mechanical resistance, medium machinability, high toughness and low weldability.

The external bearing ring is forged and hot rolled and seamless, seasoned with oil or water (pure or with salt), in order to obtain martensitic structures. After this process, the ring is tempered to achieve the required properties.

According to *Otto and Dirk (2010)* [15], DIN 42CrMo4 steel alloy, when subjected to these treatments, achieves properties such as high mechanical strength and good impact resistance, in addition to good wear resistance. **Table 1** shows the chemical composition of 42CrMo4 steel alloy.

Table 1 Chemical composition, according to German DIN standard, of the steel alloy

ANSI SAE	DIN	C	SI	Mn	P	S	Ni	Cr	Mo
4140	GS 42C Mo4	0.38 0.45	0.30 0.5	0.50 0.80	0.035	0.035	0	0.80 1.20	0.20 0.30

2.3. Seamless Ring Forging Process

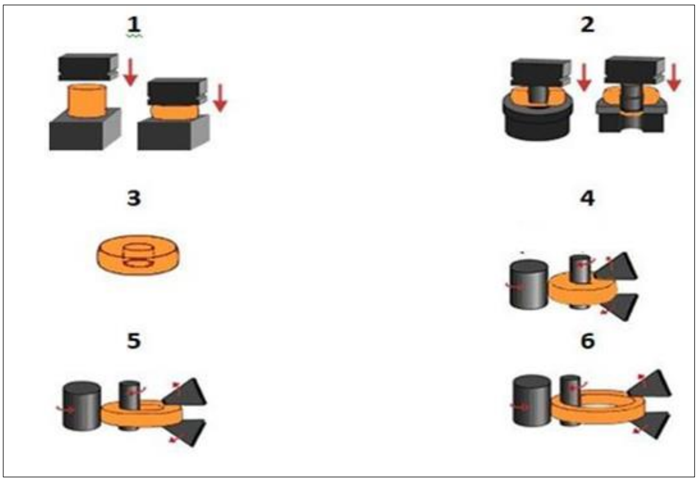

Figure 2 Seamless Ring Forging Process

For the ring to obtain this shape, it is necessary to go through the mechanical forming process, which is forging. The illustration demonstrates how the material structure is changed Figure 2.

- 1. The billet is selected by weight, heated to a defined temperature and pressed to reach the necessary structures and orientations;
- 2 & 3. The piece is punctured with the help of a device and is shaped like a do-nut;
- 4, 5 and 6. The hot part is then placed in the laminator and with the help of axial and radial rollers it is dimensioned to a desired internal and external diameter and height.

2.4. Electromagnetic Induction Tempering

Due to the various applications in which large-sized bearings are used, high mechanical stress occurs as result of large axial and radial forces and their resulting torques. The induction hardening process is performed to increase the dynamic and wear resistance in order to increase the performance of the bearings. [15]

According to *Boaventura et al. (2021)* [16], *Giroto et al. (2020)* [17], *Gonçalves et al. (2020)* [18] and *Yekinni et al. (2014)* [19] an interesting fact about this type of heating, via electromagnetic induction, is that it is widely used in the Jominy temperability test. According to *Behrens et al. (2021)* [20], *Tang et al. (2021)* [21], *Gupta et al. (2021)* [22], *Zelazny et al. (2021)* [23], *Lee & Ha (2014)* [24], *Tavakoli & Mostagir (2012)* [25], *Umasankar & Kumar (2016)* [26], *Kucukkomurler & Selver (2010)* [27], *Kocich (2020)* [28], *Yang et al. (2021)* [29], *Li et al. (2021)* [30], *Chen et al. (2021)* [31], *Du et al. (2014)* [32], *Fang et al. (2018)* [33], *Drienovsky et al. (2020)* [34], *Wang et al. (2020)* [35], *Wang et al. (2019)* [36], *Ferreira et al. (2020)* [37] because with this method it is possible to more precisely control the temperature and the heating process as a whole in order to obtain a more homogeneous tempera or heating.

The tracks (the place where the balls or rollers "run") are the points of greatest mechanical stress, so this is where most of the hardening is done.

This process consists of transforming the hardness in the tracks. They begin with a hardness ranging from 29 to 32 HRC, and finish with a hardness between 55 and 59 HRC, resulting in a martensitic surface. This process is carried out by a machine from the manufacturer Elotherm SMS Group, is found in the production line where we conducted our research.

3. Cutting Tools

3.1. Ceramic Insert

The use of the ceramic insert has become beneficial for several companies in their machining processes, due to its ability to withstand high temperatures and its huge cost-benefit advantage.

Ceramic tools can be subdivided into two main categories; oxidized and non-oxidized. The family of oxidized ceramics, which includes pure oxide, mixed oxide and whisker-reinforced ceramics, is also known as alumina-based ceramics as the base material in all of them is aluminum oxide or alumina. [38]

Table 2 Performance of SH4 Ceramic Insert

SH4 Ceramic Insert Performance	Data
Roughness (Surface Finishing)	0.8 ▽ / 1.6 ▽
Machining Parameter Recommendations for Rigid Turning	
Cutting speed (V)	80 – 180 m/min
Feed rate (F)	0.1 – 0.4 mm/rev
Depth of cut (Ap)	0.1 – 0.5 mm

Ceramic tools have a wide applicability in machining operations, as they enable the machining of highly resistant materials at high cutting speeds, which reduces the total manufacturing time per piece. Ceramic tool characteristics, such as a less wear and the need for fewer tool changes, means that the increased performance can be realized without a significant increase in cost. [39]

Due to these characteristics, the use of the ceramic insert depends on the companies need in relation to its processes. In this case study, the current insert, being the SH4 ceramic tool, is composed of aluminum oxide (Al2O3) with the addition of titanium and tungsten carbides.

The SH4 ceramic tool is a grade of mixed ceramics that offers excellent characteristics for machining processes, especially in hard and complex turning applications with its maximum edge strength, greater hardness and excellent wear resistance of the cutting tool material. The SH4 ceramic tool is also suitable for conventional finishing and fine turning of cast iron materials [40]. **Table 2** shows the specifications of the ceramic insert SH4, including the parameters for the process.

3.2. CBN Insert

Cubic Boron Nitride is a cutting tool made of synthetic material, which is called CBN, created through a chemical reaction forming a hexagonal cubic structure and guaranteeing a high hardness.

The CBN tool, despite its high cost, has an long history of use in machining processes for the manufacture of carbide parts because of its high performance in roughing and especially in finishing, in addition to being able to machine a larger number of parts compared to other tools.

In general, the CBN tool is classified into two categories. One for roughing, with a higher concentration of boron nitride, which increases its toughness and is used for machining interrupted surfaces. The other for finishing machining where a ceramic finishing phase is added so that the result has less toughness, hardness and chemical stability and thermal stability. [41]

According to Diniz et al. (2011) [41], even though CBN is a useful tool, some in-formation must be kept in mind, among them:

- Materials that are easy to cut, for example SAE 1020 and SAE 1045. Non-hardened steels, should not use CBN;
- The machine-tool-workpiece clamping system must be as rigid as possible;
- The edge must be chamfered, which directs the cutting efforts towards the center of the tool and, thus, reduces the possibility of breaking the edge;
- The geometry of the tool must be negative to guarantee shock resistance and the greatest possible lateral position angle to minimize cracks in the edge;

The CBN tool, without alloy additions, is a material that varies in color depending on the manufacturer and the color does not change its properties. The insert used in our process was purchased through third-party suppliers. From all of the available inserts, we chose the insert shown in Figure 3.

Figure 3 CBN insert

The WXM 355 insert is of the CBN class, being a high-performance insert that helps to optimize hard turning processes for the entire range of applications, from light, to highly intermittent, to continuous cutting. It meets the quality requirements for process reliability and opens up a wider variety of machining strategies. Below are the performance specifications of the CBN WXM 355 insert. **Table 3** shows the specifications of the CBN WXM 355 insert, within the required parameters for our process.

Table 3 CBN Insert Performance

CBN Insert Performance	**Data**
Roughness (Surface Finishing)	0.4 / 0.8
Machining Parameter Recommendations for Rigid Turning	
Cutting speed (V)	140 – 200 m/min
Feed rate (F)	0.2 – 0.35 mm/rev
Depth of cut (Ap)	equal or greater 0.1 mm

The use of this insert in the process guarantees better stability in the internal turning of the material due to its hardness and toughness. The possibility of cracking the insert is minimal, ensuring that there are no interruptions in the process and, finally, resulting in a good finish on the material.

4. Methodology

The project was carried out at a German multinational company that has a strong presence in the field of large machinery, cranes and bearings, located in Guaratinguetá-SP in Brazil.

The project was carried out on a vertical lathe manufactured by the German company Waldrich Coburg. Created especially for the finishing process of large bearings, the lathe has a magnetic plate, with double head (working simultaneously or not), a magazine for tool storage with automatic changes, automatic tool gauging and dimensioning of the manufactured parts.

This lathe, in its original form, has the capacity for rings with diameters of 2500mm and 1000mm in height, however, due to the market's need to increase the diameter of bearings, the machine was modified to accomodate rings with diameters of 2800mm and height of 1000mm. We used some calibrated measuring instruments, as can observed in Table 4.

Table 4 Calibated Measuring Instruments Utilized

Quantity	**Manufacturer**	**Measuring Instruments**
1	Mitutoyo	Digital Caliper 150 mm
1	Starrett	Digital Caliper 300 mm
1	Mitutoyo	Digital Rugosimeter
1	Mitutoyo	Comparator Probe Clock

4.1. Machining Parameters

The parameters are established by the supplier of the inserts, and the same values were used for both the Ceramics and CBN tools. The values can be observed in Table 5.

Table 5 Machining parameters

Parameters	**Values**
Cutting Speed (V)	150 m/min
Feed Rate (F)	0.2 mm/revolution
Depth of Cut (Ap)	0.5 mm

4.2. Machining Procedure

For each machined part, we used 3 edges for each of 3 different cutting tools. The tools were prepared to machine the faces, the spokes and the tied diameter of the ring, as can observed in Figures 4 & 5 below.

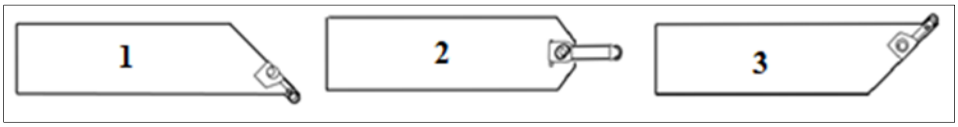

Figure 4 Edge of the inserts. Tool for bottom face (1), for diameter (2) and for top face (3), respectively

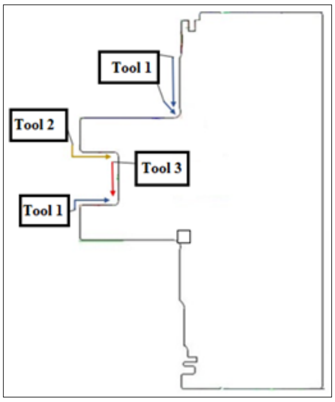

Figure 5 Location to be machined on the part

5. Results and discussion

5.1. Ceramics Tool Results

The ceramic inserts were used first, and after the end of the operation all the necessary geometric information was collected. The results obtained for the first edge can observed in Table 6.

Table 6 First edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.735 Ra
Lower axial roughness	Maximum 1.0 Ra	0.738 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	0.636 Ra
Radial roughness tool (3)	Maximum 1.6 Ra	0.705 Ra
Upper axial flatness	Maximum 0.02 mm	0.01 mm
Lower axial flatness	Maximum 0.02 mm	0.02 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.01 mm
Tied Diameter	Ø2625.0 ± 0.03 mm	Ø2624.97 ± 0.03 mm
Thickness	32.00 ± 0.1 mm	32.1 ± 0.1 mm

As noted in Table 6, all measures taken were within the established tolerance. The next step was to check with the supplier about the possibility of using the inserts again with the same edges already used, after a wear analysis. It was decided not to use the edge again. Then, the second edge was positioned and the machining sequence continued at another place on the same part. The results found for the second edge of the insert can observed in Table 7.

Table 7 Second edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.802 Ra
Lower axial roughness	Maximum 1.0 Ra	0.763 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	Insert break
Radial roughness tool (3)	Maximum 1.6 Ra	0.807 Ra
Upper axial flatness	Maximum 0.02 mm	0.01 mm
Lower axial flatness	Maximum 0.02 mm	0.015 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.01 mm
Tied Diameter	Ø2625.0 ± 0.03 mm	Ø2625.015 ± 0.03 mm
Thickness	32.00 ± 0.1 mm	31.95 ± 0.1 mm

An important factor to note is that, as the insert used in Table 7 broke, it was necessary to rework the diameter of the ring. The rework took fifteen minutes to perform.

5.2. CBN Tool Results

The next step was to use the CBN insert, with the same conditions as the previous operation. The results from the first edge can observed in Table 8.

Table 8 First edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.416 Ra
Lower axial roughness	Maximum 1.0 Ra	0.398 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	0.503 Ra
Radial roughness tool (3)	Maximum 1.6 Ra	0.478 Ra
Upper axial flatness	Maximum 0.02 mm	0.00 mm
Lower axial flatness	Maximum 0.02 mm	0.01 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.00 mm
Tied Diameter	Ø2625.0 ± 0.03 mm	Ø2625.98 ± 0.03 mm
Thickness	32.00 ± 0.1 mm	32.00 ± 0.1 mm

Table 9 Second turning of the first edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.503 Ra
Lower axial roughness	Maximum 1.0 Ra	0.635 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	0.708 Ra
Radial roughness tool (3)	Maximum 1.6 Ra	0.502 Ra
Upper axial flatness	Maximum 0.02 mm	0.02 mm
Lower axial flatness	Maximum 0.02 mm	0.00 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.00 mm
Tied Diameter	Ø2625.0 ± 0.03 mm	Ø2625.01 ± 0.03 mm
Thickness	32.00 ± 0.1 mm	32.00 ± 0.1 mm

Table 10 Second edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.418 Ra
Lower axial roughness	Maximum 1.0 Ra	0.515 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	0.601 Ra
Radial roughness tool (3)	Maximum 1.6 Ra	0.651 Ra
Upper axial flatness	Maximum 0.02 mm	0.00 mm
Lower axial flatness	Maximum 0.02 mm	0.00 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.00 mm
Tied Diameter	Ø2625.0 ± 0.03 mm	Ø2625.01 ± 0.03 mm
Thickness	32.00 ± 0.1 mm	32.05 ± 0.1 mm

After machining and obtaining the results Table 8. The edge was also analyzed by the supplier and it was decided to use the edge again with the same conditions as before. The results obtained were can observed in Table 9.

After the results obtained as listed in Table 9, again with the help of the supplier, the insert was analyzed and it was decided not to use the edge again, so the insert was turned over and the process was repeated. With the second edge it was also possible to machine two parts as can observed in Table 10 & 11.

Table 11 Second turning of the second edge

Items	Wanted	Obtained
Upper axial roughness	Maximum 1.0 Ra	0.633 Ra
Lower axial roughness	Maximum 1.0 Ra	0.777 Ra
Radial roughness tool (1)	Maximum 1.6 Ra	0.706 Ra
Radial roughness tool (3)	Maximum 1.6 Ra	0.856 Ra
Upper axial flatness	Maximum 0.02 mm	0.02 mm
Lower axial flatness	Maximum 0.02 mm	0.01 mm
Radial parallelism tool (3)	Maximum 0.01 mm	0.00 mm
Tied Diameter	Ø2625.0 mm ± 0.03 mm	Ø2625.023 mm
Thickness	32 ± 0.1 mm	32.1 mm

It can be observed that, in order to manufacture a piece, it is necessary to use 1.5 ceramic inserts or 0.75 CBN inserts. Another important point is that, according to the data obtained and shown in the tables, the two types of inserts easily meet the established specifications.

5.3. Tool wear

Figure 6 shows a comparison of wear between the Ceramic and CBN inserts with a geometry similar to the one we used in our project and on a similar material, but used with interrupted cutting.

One can notice a significant change in the shape of the ceramic tool's nose and this was due to the increase of abrasive scratches which contributed to its rupture and to the increase in roughness values. Similar to the results in the previous operation, the CBN tool maintained a uniform point shape. These results indicate that the CBN insert is ideal for turning hardened steels, guaranteeing stability during the process due to its longer life when compared to the ceramic insert.

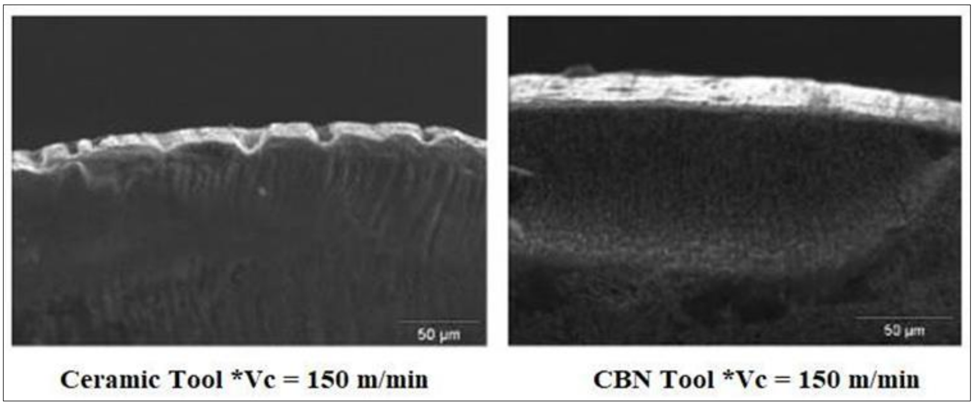

Figure 6 Nose shapes of ceramic and CBN tool tips, respectively, in edge break. [41]

However, it is convenient to use CBN due to its various benefits according to Bouacha et al. (2010) [42], Suresh et al. (2012) [43], Suresh et al. (2013) [44], Hou et al. (2010) [45], Chou et al. (2002) [46], Ezugwu et al. (2005) [47], Arunachalam et al. (2004) [48], Luo et al. (1999) [49], More et al. (2006) [50], Huang et al. (2006) [51], Yun et al, (2020) [52], Gao et al. (2021) [53], Zebala et al. (2021) [54], Ociepa et al. (2021) [55], Nayak et al. (2015) [56], Chavan & Sargade (2020) [57], Tu et al. (2010) [58], Wada (2012) [59] and Sugihara et al. (2016) [60] which emphasize the quality of this tool, as confirmed by the machining processes.

6. Cost Benefit Relationship

Analyzing the results obtained in this project as observed in Figure 7, the CBN insert has a longer life, during the turning process and the tool wears more slowly compared to the ceramic insert, if we just take these factors into consideration, then a replacement of the CBN insert would be justified, however when we include cost, the ceramic insert is far superior to the CBN insert.

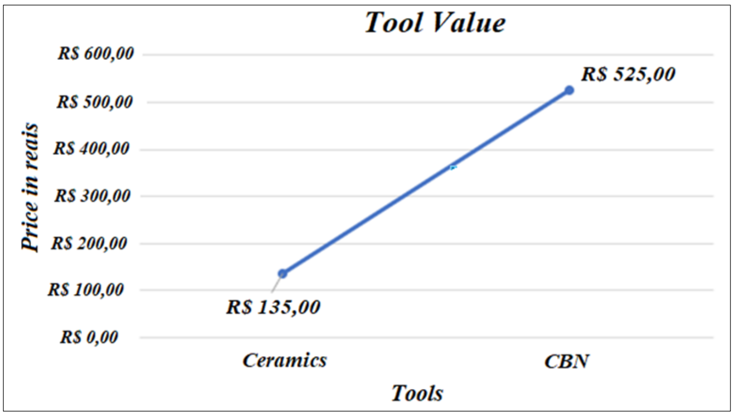

Figure 7 Cost-Benefit Relationship of Inserts

If we consider an annual demand of six hundred pieces, this difference is even more apparent, while the ceramic insert would cost R$ 81,000.00 the CBN insert would cost R$ 315,000.00. Thus, it was not possible to justify the exchanging the inserts.

7. Conclusion

In view of the results of this research Analyzing the Replacement of the Ceramic insert by a CBN insert, which operates in the turning of rings for carbide bearings, it can be concluded that:

- At both edges, when turning the inside diameter and faces, the wear on the surface of the CBN tool was visually less than the wear of the ceramic insert at a cutting speed of 150m / min.

- The roughness values with the use of the Ceramic insert during its useful life were higher due to its early wear, which caused these higher values. According to *Bonhin et al. (2016)* [61] and *Santos et al. (2016)* [62] in his paper he obtained similar results for machining with the ceramic tool. With the use of the CBN insert, however, there were not very many variations in the shape of the tool's nose, thereby allowing the roughness values to remain low throughout the process and its life.

Based on the results of this research, it can be concluded that, in terms of economic feasibility, the Ceramic insert has an advantage for a company that works with mass production, which supported not substituting the ceramic tool for the CBN tool. However, in terms of useful life, the CBN insert performs well with better values of roughness and surface finish and has a longer lifespan. Due to CBN being the only tool besides ceramic capable of turning hardened metal. It is suitable for replacing the ceramic insert for those who are aiming for quality and a greater finish on the piece. Despite the non-implementation of the CBN Insert, a great deal could be learned from this process. When the material is treated, it behaves in a very difficult way for machining which makes it difficult to choose the correct insert. Every potential change must be analyzed because it is a continuous improvement in the process, as it was done with the CBN insert, because if it were implemented without this analysis it could have generated losses for the company.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

This article contains no conflict of interest

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