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Chips Generated During the Machining of SAE-8620 Using Carbide Inserts Coated with (TiAl)N by the PVD Process

Dilson de Souza Silva[1], Anderson Figueiredo da Costa[2-1]

1. Production Engineering, University Ibirapuera, Avenida Interlago 1329, 04661-100, São Paulo, Brazil.

2. Engineering and Materials Science, Federal University of São Paulo, Rua Talim 330, 12231-280, São José dos Campos, Brazil.

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Abstract: Due to the development of the industry and the constant search for greener processes, it is increasingly common to reduce pollutants such as soluble oils in production processes. In the turning process, the greatest problem is the generation of the chip during machining without lubricating fluid, since the temperature generated in the part / tool contact tends to increase considerably, which can impair the shear of the chip and its flow, besides considerably increasing the wear of the tool and heating of the machined part. This research aims to contribute to the development of the industry, as well as assisting in the development of new ecological production processes, and for this, we analyzed the formations of the chips generated during the turning of AISI 8620steel without refrigeration. For this research, we used varied cutting speeds, keeping the depth of cut and the feed constant. For the characterization of the chips an optical microscope and thermometer were used to identify whether or not there was any change in chip formation during tool wear or when cutting speed was changed. Finally, it was observed that, even though the cutting speed was increased considerably from 350m/min to 500m/min, the formation of the AISI 8620steel chip remained the same and there was no abnormal formation during the process, on the other hand, there was a considerable increase in the temperature of the chip generated. This process can be applied in several segments of the industry, however, due to the high heating during chip formation and its dissipation, it is recommended that the technique analyzed in this research be implemented only in machines and / or equipment closed due to safety.

Key words: insert, carbide, coating, PVD, wear

Corresponding author: Dilson de Souza Silva, Anderson Figueiredo da Costa

1. Introduction

1.1 Machining

To achieve a stable process during machining some factors should be analyzed with extreme care. These factors are: chip generation, cutting efforts and roughness. As machining operations, we mean those which, when giving the part the shape, or the dimensions or the finish, or even a combination of any of these three, produce chips. We define chip, the piece of material of the piece removed by the tool, characterized by irregular geometric shape [1].

Machining is the most common manufacturing process in the world, making chips about 10% of all metal production and employing tens of millions of people [2].

1.2 Machinability

Usability is the term used where several factors and effects are found. Usually expressed in numerical value, machinability is a technological quantity, where the indicated value evidences the ability of a given material to be machined in several cutting parameters, with ease [1][3]. One can define the machinability of a material which is expressed by a numerical comparative value through a set of properties of a given material during machining, with reference to another material [4]. These properties can be tool life, cutting temperature, chip, resistance to cutting, surface finishing and cutting time and chip characteristics.

Table 1 Effects of Machinability [5]

Properties	*Good Machinability*	*Bad Machinability*
Tool life	Long, Stable	Short, Unstable
Cutting temperature	Not high	High
Chip	Easily Controlled	Continuous, Successive Vibrations
Cutting Resistance	Low	High
Surface Finishing	Good	Develops Burrs Easily
Cutting Time	Short	Long

The machinability usually depends on the material to be machined and its properties. Thus, from the understanding of the basic mechanical properties of the materials can be defined or evaluated as the machinability of the same. With this, it can be concluded that the machinability is directly linked to the mechanical properties of the materials. Therefore, it would be the ability of the materials to be worked by cutting tools [6].

1.2.1 Effects that affect machinability

There are effects that greatly affect the machinability of materials, such as those shown below [1]:

Toughness: The increase in hardness of a part arises with flank wear. During the process, the cutting edge meets the machined part, the impact occurs and the cutting resistance increases. If the machined part is tenacious, problems such as: the chip edge and chip control may occur and contribute to the surface finish being impaired.

Adhesiveness: Adhesion refers to the viscosity of a material, in other words how easy it is to cut a chip from the part. In machining materials that are adhesives, it is difficult to cut / break the chips and as a result large cutting forces are generated at the cutting edge. This will lead to an increase in temperatures at the cutting edge.

Resistance of material: When referring to force, it refers to how easy or difficult it is to deform or change the shape of a material. When speaking of machining of materials which have high strength and are difficult to deform and as such, high forces are required at the cutting edge or in the shear plane to generate the chips. As the forces at the cutting-edge increase, temperatures rise, which can lead to plastic deformation and oxidation of the cutting edge.

Malleability: It relates to how easy it is to deform or roll a workpiece material. Materials which have high malleability are generally materials that are tenacious. Therefore, when the machined part is tenacious, the chips generated are difficult to break / break. This will result in the stretching of the chips. When this happens, the chips may become entangled around the tool and / or the machined part.

Thermal Conductivity: Thermal conductivity refers to how easy or how difficult it is to dissipate / radiate heat. Therefore, if thermal conductivity is low, then heat is not dissipated easily, it cannot escape, but is in one place.

Coaching: We can take as an example a colorless plastic ruler, when folding a few times, the point on the curve becomes white and hard, if it continues then will surely break. This is an example of hiring. When machining parts that have the facility to harden during the process, the section at the machining point and the surrounding area becomes more difficult to machine[5].

Hard Particles: The hard particles may exist within the composition of a machined part material, for example Si (Silicon) particles in aluminum. If solid particles are present in the material, then when planting them they may scratch the surface of the cutting edge. The type of wear pattern would be like that of a comb.

1.3 Materials for cutting tools

The first metals to be used as cutting tools were copper and gold. However, it was only after the invention of a technique of obtaining metal from the ore using the heating and a technique to refine the molten copper that one began to use the metals for cutting. Brass, with the advantage of being harder than copper, has become widely used in cutting. After some time, the iron refinement process was developed, so there was a rapid change in the use of brass for the use of iron as cutting tools [7].

1.3.1 Carbide

Carbide appeared in the 1920s in Germany, when Dr. Schroter first produced toilet powder in the laboratory. The mixing of this powder, especially with Co also in powder, brought to the market the group of cutting tool materials called hard metals. When the Germans perceived the excellent properties of hardness and resistance to wear, they soon baptized him as Widia de (Wiediamant, as a diamond). This was the second milestone in the evolution of materials for cutting tools after fast steel [8].

1.4 Coating

The first coating data on cutting tools for machining dates back to the second half of the 1960s, with Sandvik as the first manufacturer. At the outset these coatings were made of steel tools fast (HSS) and later applied in Carbide. Since then the coatings in cutting tools for machining see evolving greatly with new techniques and materials. The deposition of coatings aims to alter the properties of a surface [9].

Tool coatings include chemical vapor deposition, known as CVD (Chemical Vapor Deposition), which occurs through chemical reactions at temperatures, generally between 850 - 1050 ° C, and the physical vapor deposition process PVD (Physical Vapor Deposition) that occurs by means of vapors generated inside furnaces at low pressure with temperatures, generally in the range of 400 - 600°C [2]. The high hardness coating, which maintains it at high temperatures, contributes to increased wear resistance, reducing the tendency for abrasive wear to appear [8].

1.4.1 PVD process

The PVD process forms a layer on the substrate by physically depositing atoms, ions or molecules of the element to be deposited, thereby creating a coating. Among the existing techniques we have three main ones, being: Evaporation, Sputtering and Ions. The PVD physical deposition process arose in the 1970s with the deposition of TiN on fast-steel tools. Ten years later it was adapted to coat Carbide tools. The main characteristic is the temperature around 500ºC, which brings benefits as [8]:

1. The possibility of coating fast steel substrates;
2. The prevention of the formation of the "eta" phase;
3. The obtaining of coatings with finer granulometry;
4. The possibility of coating sharp edges.

In PVD, the deposition occurs through vapors generated inside furnaces at low pressure. This pressure allows the solids that will participate in the formation of the coatings to pass directly into the gaseous state by heating. The vapors, which constitute the coating material, are obtained from reactive gases or sublimated solids inside the furnace by electric discharge [8].

In this process, the high purity solid coating material (metals such as titanium, chromium and aluminum) can be either heat evaporated or bombarded with ions (cathodic spray). At the same time, a reactive gas (eg, nitrogen or a gas containing carbon) is introduced; forming a compound with the metal vapor that is deposited on the tools or the components in the form of a thin, highly adherent coating [10].

1.4.2 Characteristics of PVD Coating Materials

Materials that are used in the PVD coating method include TiN (titanium nitride), (Al, Ti)N (aluminum nitride and titanium), (Al, Ti, Si)N (titanium aluminum and silicon nitride), CrN (chromium nitride) and hard amorphous carbon. Additionally, TiC and TiCN which are generally used in the CVD process can also be used with the PVD process. Each material has its own specific properties and can also be used either as multiple or single layers according to its application [5]. The properties of Carbide coated with PVD are defined in the following ways:

Hardness (Edge Wear Resistance): The (Al, Ti)N, is a complex of titanium and aluminum nitride. The particles of Al and Ti have different atomic rays, creating a distorted microstructure. It is because of this distortion that a hardened coating line is generated in its layer. A further hardened coating line is (Al, Ti, Si)N and this is due to the Si particles within the coating layer which provides high flank wear properties. TiN is one of the first-generation coatings materials which is harder than Carbide and can be effectively used to extend the tool since it is more chemically stable.

Oxidation Temperature (Cutting Edge Notch Resistance/Catherization Wear Resistance): The (Al, Ti)N is thermally stable at elevated temperatures and has excellent wear resistance during cutting at high speeds. This is because Al oxidizes under high temperatures and pressures during machining and forms an amorphous Al 2 O 3 protective film. O (Al, Ti, Si)N has a higher thermal stability than (Al, Ti)N and is used for milling for hardened steel machining. TiN with its high resistance to oxidation and low energy free formation, ie, thermally stable and is also effective in increasing tool life.

1.4.3 The main characteristics of the coating layers are:

Chromium Nitride (CrN): CrN is an excellent coating for aluminum alloys, copper alloys and low alloy steels. CrN can also be used as an alternative to titanium and nickel alloys. This coating has a low tendency to form false edges.

Titanium Nitride Aluminum and Silicon (Al, Ti, Si)N: (Al, Ti, Si)N has a higher thermal stability than (Al, Ti)N and is used for the coating where a more positive cutting edge is needed. This type of coating is employed in the machining of hardened materials, mostly in milling.

1.4.4 Substrate Used in Carbide PVD Coating

As a result, PVD coating can be applied to a wide range of substrates, such as Carbide and cermet, as well as high speed tools and welded Carbide tools, both of which have reduced hardness and resistance to high temperatures [5]. The PVD coating is also often used for drills, top mills, threading tools, etc. This is because the PVD can maintain the force of the cutting edge of the tool that requires a sharper (positive) cutting edge without it being damaged.

Fig – PVD Coating[11]

1.5 Cutting tool wear

The wear and tear that the tools suffer is mainly caused by the friction between the chip and the tool and between the tool and the part. Several factors intervene in this wear, such as shear micro welding, mechanical abrasion, intermetallic diffusion and oxidation. The action of these factors is related to the cutting temperature, which depends mainly on the cutting speed [12]. During the machining process generate some damage to the cutting edge, these damages are classified into normal damages such as flank wear and crater, and abnormal damages such as fracture, breakage, welding, micro blasting, notching, cracking, plastic deformation and coating displacement.

1.6 Steel

The steels are basically a mixture of iron and carbon, that is, an alloy. Some alloys use elements such as silicon, phosphorus or other elements depending on the purpose of the steel to be constructed. In general, steel is an iron and carbon alloy, where carbon has a variation of 0.05% to 2% in the composition[13]. Alloys that contain carbon contents greater than 2% are called cast iron. Thus, to be called steel, the chemical composition should contain less than 2% of carbon. AISI 8620 is an alloy used in carburizing and carbonitriding applications. In addition, nickel in the alloy improves some properties of the material such as toughness and ductility, while chromium combined with molybdenum assists in the wear resistance and in the increase of the cementation hardened layer. This alloy is well balanced, tends to obtain a high hardness in the cementing layer and also an excellent resistance to wear[13][14]. The AISI 8620 alloy has several applications with machine elements and parts of the automotive industry such as the manufacture of gears, pins, bushings and parts where there is requirement of surface hardness obtained by the process.

1.7 Types and characteristics of chips

The chip is a very important machining element. The Study of the chip can bring information relevant to the knowledge of the process and, consequently, its use. Although it does not seem and most of the professionals that deal with manufacturing, especially in the companies, underestimate or discard this fact. As a rule of thumb in the industry, the chip becomes the main focus only when it negatively interferes with the final product, scratching it in the machine tool itself by excessive volume during machining or causing difficulty in storage or disposal[12].

1.7.1 Types of chips

The ductility of the material and the conditions of machining, the formed chip can be classified in different types and forms. For ductile materials the chip generated is called the continuous chip and the fragile materials give rise to the chip breaking, which are broken into pieces (discontinuous)[1]. They present a classification in the following types: continuous chip, partially continuous chip or shear, discontinuous chip or rupture chip and segmented chip[15].

1.7.1.1 Chip forms

The chips, besides being classified through the four types, can also be classified according to their shape. Some chip shapes are undesirable, as they may hamper machining operations, damage the machined part's surface finish, endanger the integrity of the operators and may cause tool malfunctions. Is normal that we have four forms of chip:

a) Ribbon chip

b) Helical chip.

c) Spiral chip.

d) Chip in chips or pieces.

1.7.2 Chip shape control

Numerous practical problems are related to the shape of the chip produced in the machining, since it has implications in the following areas [12]. Operator safety: Long tape-shaped chips can, when struck at the operator, seriously injure them. Possible damage to the tool and the part: ribbon-shaped chips may cause the part to be rolled up, damaging its surface finish. In addition to damage to the part, the chip on tape can also harm the tool, as in some operations it runs the risk of rolling over the part and trying to penetrate between the tool-part interface, which may cause tool breakage, among others. Cutting forces, temperature and tool life: when trying to deform the chip more in order to increase its breaking capacity can greatly increase cutting efforts, with consequent increase in temperature and decrease tool life. It can cause the shape change of the chip in different ways [1].

The increase in the breaking capacity of the chip for non-overly tough materials can be obtained by increasing the deformation of the chip in the shear plane. As for cutting conditions, in general, an increase in cutting speed, a reduction in feed or an increase in the output angle, tends to produce chips on tapes (or continuous, as to type). The advance is the parameter that more influence, the depth of cutting which less influences the shape of the chips.

2. Materials and Methods

GL204M CNC lathe: for this research, the GL204M CNC lathe was used, machining AISI 8620 billets with dimensions of 85x335mm, using a program done manually in the FANUC system. The samples were submitted to different cutting speeds and will have a criterion of pre-determined useful life (VB=0.3mm).

The cutting speeds were set at 350, 400 and 500 m/min. In the CNC Lathe, the tunnel inserts of the Tungaloy brand were fixed to capto holder, as shown below:

Insert: WNMG060408-TM AH120

Toolholder: C3-PWLNL22040-06

To perform the tests, the inserts were mounted on the capto support alternately, that is, tests were performed one at a time with the objective of a previous analysis of the data throughout the tests.

During machining some data has been collected (power consumed, vibration, temperature, acoustic emission). The acquisition of this data was performed by sensors input to capto and with direct communication to the computer. The software used to acquire the data was LabView 8.1, in which software was developed for the acquisition of vibration, power, temperature and acoustic emission data. In the program the variable condition for each test was the cutting speed, since all other conditions remained unchanged.

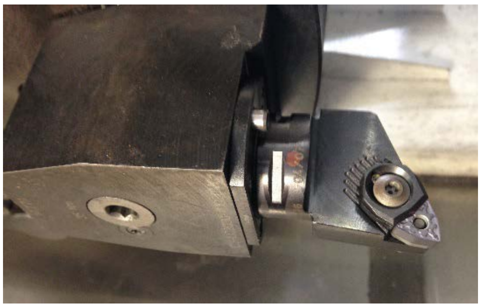

Fig – Capto System (Costa, 2016)

Microscope Mahrmodelo MarVision MM200: In this microscope, the insert was analyzed for the identification of flank wear, so that when the VB limit of 0.3mm was reached, the test was interrupted and a new part and insert were assembled for testing, changing the variable that was the cutting speed when necessary (as programming).

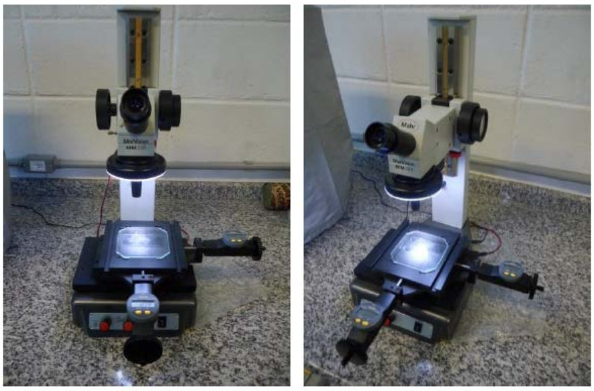

Fig – Microscope (Costa, 2016)

AISI 8620: it is a steel for cementation and later processing connected to nickel, chromium, and molybdenum which gives it better temperability. The carburizing is used to increase the wear resistance in a core of good mechanical strength and fracture. After cementation the surface hardness can reach 62 HRC. Being a very used material in the metalworking industry and in high scale in the segment automotive, this steel AISI 8620 was used in this research. In addition, this is a steel with high resistance to wear and has a good machinability.

Fig – Workpiece (Costa, 2016)

Carbide Insert: In this research we will use carbide inserts using the PVD coating process. The geometry according to the manufacturer is WNMG080408-TM. The PVD carbide insert will be of the AH725 coating grade with a hardness of approximately 91.5 HRA, with a cross-rupture strength of 3.0 GPa and a coating thickness of 2μm.

Fig – Carbide Insert (Tungaloy, 2015)

3. Results and Discussion

During the machining, the removed material undergoes great deformations until it is drained over the surface of he tool, in this way the chip is formed, where the chip in turn has its thickness changed and as a result it becomes thicker and the length becomes thinner. In the region where this transformation takes place, a greater need for power or energy to deform the material, for this reason there is a great heat generation and an increase in cutting resistance. It can be observed that the chips had similar performances and with that their formation was spiral and with a maximum length in approximately 30mm at the lower cutting speed. This fact is expected, because even altering the cutting speed, the feed was kept constant and thus the material removed remained within the zone of formation of the chipbreaker therefore, all having the same appearance as the change of length, this is gives due to the fact that the higher the cutting speed, the smaller the length of the stay, for this type of chip formation.

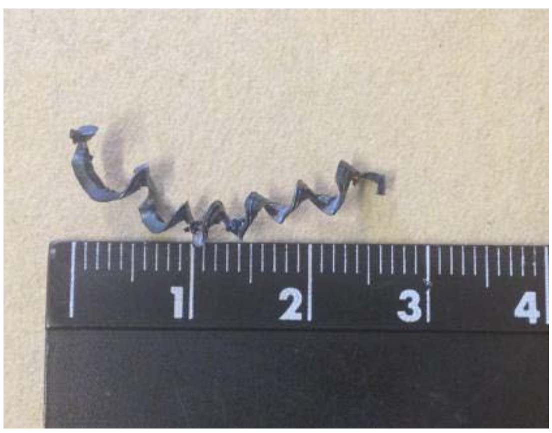

Fig – VC=350 m/min (Costa, 2016)

Fig – VC=400 m/min (Costa, 2016)

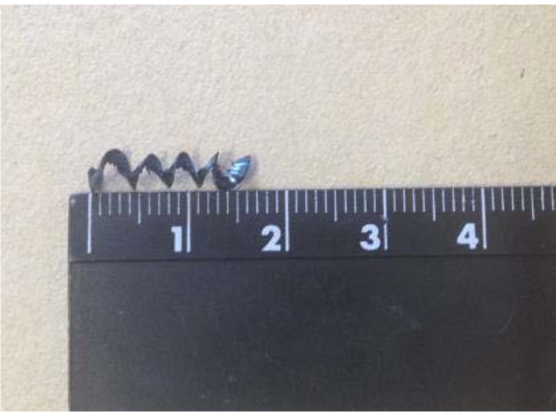

Fig – VC=500 m/min (Costa, 2016)

Even the machining being without refrigeration, which tendentiously increases the temperatures throughout the process still, harms the life of the tool, the chip former worked very well and perfectly fulfilled its role, remembering that the fixed parameters were the advance (fr=0.2mm/rev) and depth of cut (DOC=1mm in radius). In this research we can observe that even without the refrigeration, the chip formed still stays within the ideal chip profiles and has its behavior expected when it comes to chip formation in steel machining.

The tools coated with the PVD process usually support cutting speeds up to 220m / min, but as technologies have become better and production processes increasingly competitive, the objective of this research was precisely to identify the limits and how far the chip would remain within the ideal formation and what this could generate to the logo of the tool life. During all the laboratory tests, it was observed that even the tool suffering from wear and tear, the chip did not change its physical appearance or its flow behavior, proving that, even when putting the tool to a severe condition and above that it is recommended to him , the chip remains within the expected, this is also due to the fact that we keep the other factors fixed, favoring the process.

Fig – Wear of Cutting Edge 300m/min, 400m/min and 500m/min (Costa, 2016)

Throughout the wear and tear of each tool, it was not only the wear but also the vibration that was generated along the wear of the tool, up to its own limit of 0.3mm. As increasing the cutting speed the contact time tends to be lower, the vibration also tendentiously increased, however, the parameters of 300m/min and 400m/min maintained an increase of the vibration in relation to constant and increasing wear, different from the 500m/min parameters, which only have a tendentiously shorter contact time, also has a natural increase in temperature since the rotation has become larger and the scrubbing also, generating not only premature wear of the tool but also a vibration totally uncontrolled and without a definite increase or decrease pattern.

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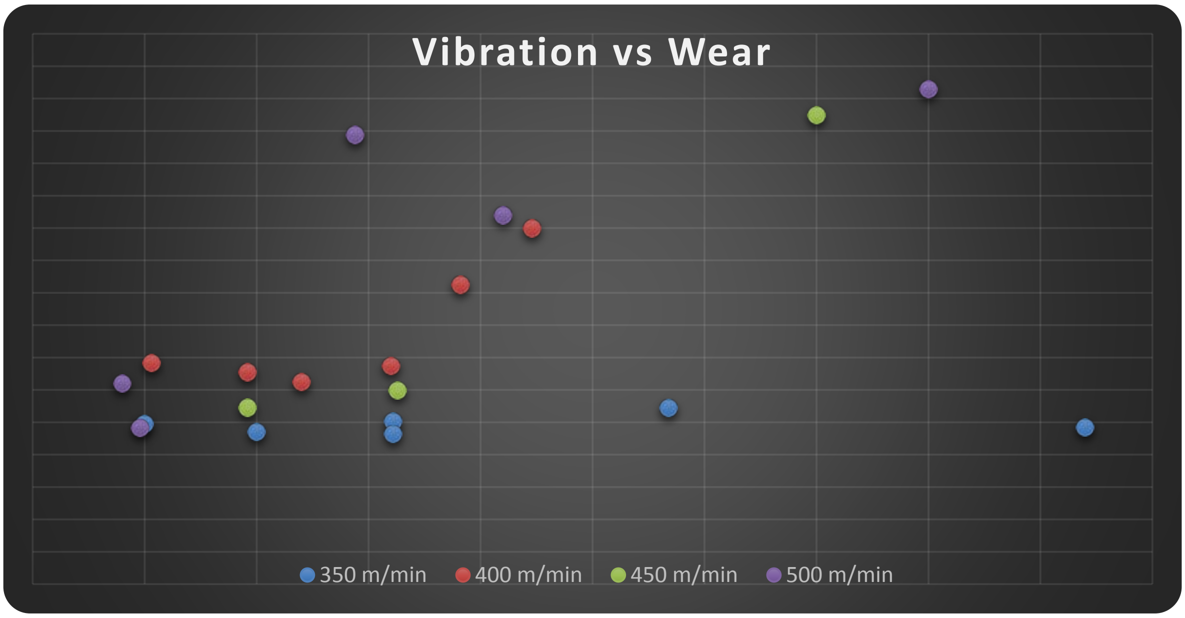

Fig –Vibration and Wear (Costa, 2016)

In order to verify if the same abnormality occurred, the cutting speed was reduced from 500m/min to 450m/min only to carry out this verification, but it was noticed that, even when suffering from the heating of the process was the largest parameter, this new proposal pointed a gradual increase and similar to the other parameters, thus indicating that in fact the limiting working limit or the working limit parameter of the tool should be lower than the cutting speed of 500m/min.

4. Conclusion

This research was very important and worth, given the relevance of the subject, the actuality treated and the own involvement with the machining area. Based on the objective of analyzing the formation of chips in the process of steel machining without refrigeration, one can see the importance of the study carried out to contribute to cost reduction, better understanding of the processes and materials and better final quality of the parts generated in the industry . It was observed that, although the shear rate has increased considerably, the formation of the AISI 8620 steel chip remained the same and there was no abnormal formation during the process. In addition, from this research there is a cut-off speed limit for PVD-coated inserts for the turning process and their due behavior regarding wear and vibration.

This process can be applied in several segments of industry, however, due to the high heating during chip formation and its dissipation, it is recommended that the technique analyzed in this research be implemented only in closed machines and / or equipment due to safety.

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