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APPLICATION OF LINEAR CUTTING EDGE TECHNOLOGY FOR MACHINING NICRBSI THERMAL SPRAY

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Abstract

New trends in the field of mechanical engineering place ever greater demands on the properties of machine components, especially in the field of material engineering. With this fact, the application of special types of applications, such as thermal spraying, which increases resistance to mechanical wear, corrosion and oxidation, is growing. The functionality of the sprayed surface is not suitable due to the high roughness of the surface, so subsequent machining is needed. For very hard coatings such as NiCrBSi, grinding technology is used to reduce the roughness. This article deals with the idea of machining this unique material using turning technology. The machining process uses a linear cutting edge under specified cutting conditions as analysis. Square KC20 carbide inserts and special tools were used for machining. The result of the experiment was the knowledge of the non-standard machining process depending on the roughness of the surface and the amount of insert wear.

Keywords: Machining; Thermal Spray; NiCrBSi; Linear Cutting Edge; HVOF

1. Introduction

The uniqueness of thermal spraying technology lies in the ability to apply coatings to all structural materials and thus increase the functional properties of the coated parts, in the order of hundreds of percent compared to classic surface treatment technologies. There is a continuous expansion of the possibilities of technology applications in the entire range of engineering production. In many cases, it is the only technology for producing, repairing or renovating special parts. Increasing work productivity in this area is of indisputable economic importance, as it is mainly about applications for expensive machine parts with a high added value. This can be achieved by reducing the thickness of the coating, while guaranteeing the properties of the functional surfaces of the parts and/or by more efficiently machining the coatings to final dimensions with defined surface quality. [3] [6] [10]

Applied highly resistant coatings are generally very difficult to machine, as a rule only grinding with special discs is used. Machining productivity is therefore low and, on the contrary, production costs are high. Therefore, it is necessary to investigate the possibilities of their machinability and to increase the cutting capacity of tools, especially with more productive approaches and technologies. This also requires optimizing the preparation parameters of these coatings, considering the increased homogeneity of the coating structure and thereby achieving higher integrity of the machined surface and reliability of the cutting process. [3] [6] [10]

Thermal spraying technology is, from today's point of view, a very important technology affecting several industries. Thermal sprays are most often divided according to the heat energy source used. From this point of view, today there are many variants that create specific coatings with regard to the required functionality and the difficulty of production. From a historical point of view, thermal spraying technology cannot be considered a novelty. The first to come up with this technology was Dr. Ing. Max Ulrich Schoop as early as 1909. The idea itself arose quite by accident that same year when looking at a lead shot that had been fired against a wall. The lead shot flattened not only due to the high kinetic energy when it hit the wall, but also stuck to the mentioned wall due to plastic deformation. In the same year, the first experiment in the form of this technology was tried, simply by pouring melt from a casting pan in front of a nozzle generating compressed air. After filing a patent for the newly discovered technology, Dr. Schoop didn't get much credit and the whole process was likened to applying melted chocolate. [1] [3] [6]

The very principle of creating a thermal spray is described in a simplified manner in the previous text. It can be understood as the application of a continuous layer of additional material on the pre-prepared surface of the sprayed part. In the first point, it is necessary to have a suitable additive material with a certain chemical composition. This material is fed into a special device, where the individual particles of the additive material are melted. The melted particles are subsequently accelerated by the air stream and directed toward the surface by the exit nozzle. After the impact on the base material, due to the high kinetic energy, the grains are deformed and create a continuous surface with a typical lamellar structure. [1] [3] [4]

The structure of the created thermal spray is very specific in terms of construction and appearance. It follows from the very principle of the technology that the melted grains of the new material are significantly deformed into individual disk-shaped lamellae after impacting the base material. Grains deformed in this way are called "splats" in the field of thermal spraying. Due to the wide range of process parameters and the many methods of thermal spraying, it is logical that the resulting structure will not always be the same in terms of appearance and quality. The graphic appearance of the structure of the thermal spray can be seen in Figure 1. In addition to the fused disc-shaped grains, there are also grains in the structure that were not completely fused. These grains are only partially deformed after hitting the surface and are therefore more globular in nature. Due to the purity of the additive material and the application process, there are also various inclusions and impurities in the structure. Due to the technology, the coating also contains a certain percentage of porosity. All these imperfections have a major impact on the quality of the coating. [3] [4] [7] [9]

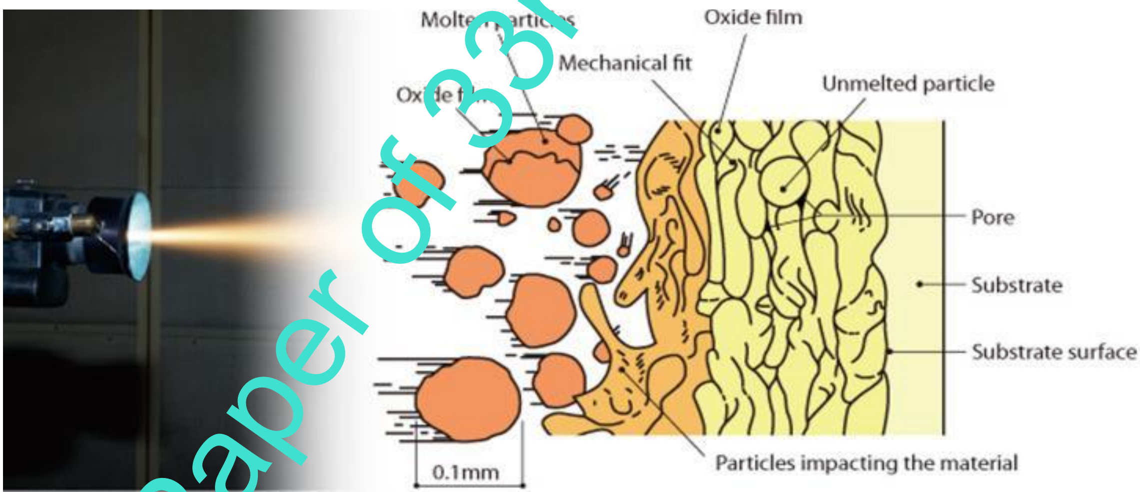

Fig. 1. Description of the HVOF spray application principle [9]

The technology of this coating is referred to in the English literature as HVOF (High-Velocity Oxygen Fuel). This method can be described as the most modern way of creating thermal spray. HVOF technology follows on from the detonation method of spraying, with the difference that the HVOF process takes place continuously. In the combustion chamber, a mixture of fuel and oxygen is burned, which is supplied continuously, and this ratio has a major influence on the melting temperature, which ranges from 2800 to 5000 °C. The most commonly used burning fuel is kerosene, but propylene, acetylene or hydrogen are also used to a lesser extent. [3] [4] [7]

In the combustion chamber, after the fuel is mixed with oxygen, ignition occurs with the help of a candle. During combustion, the additional material is melted in the form of a powder, which is brought to the combustion chamber by a carrier gas, usually nitrogen. The molten particles are subsequently accelerated in a special nozzle, which is convergent-divergent in shape. The molten particles are accelerated up to supersonic values reaching over 1000 m/s. To ensure a stable application process, the temperature and pressure in the combustion chamber are monitored on the one hand, and the entire structure is also equipped with internal cooling for better process regulation, see Figure 2. [3] [4] [7]

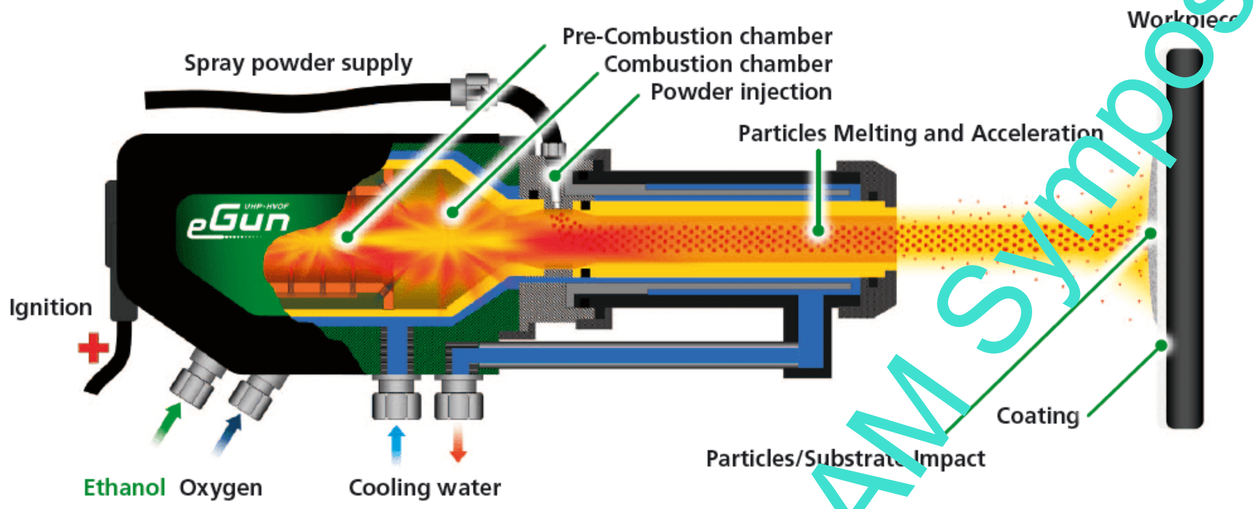

Fig. 2. Scheme of equipment for creating a coating by HVOF technology [4]

Compared to other thermal spraying technologies, HVOF achieves the highest speed of molten parts. Mainly for this reason, a very high-quality coating with adhesion reaching up to 90 MPa is created. Also, in terms of structure, the created coating is of very high quality with a low oxide content and a small porosity of up to 0.5%. However, when compared to spraying using plasma, the HVOF method has a lower melting temperature, therefore it is more suitable for materials with a medium and low melting temperature, such as nickel, chromium, cobalt, tungsten carbide, etc. The advantage of a low melting temperature is, on the contrary, the preservation of the original properties of the additive material, as there are no significant phase changes here. The HVOF method is mainly used in conjunction with the Stellite material (an alloy based on Co and Cr) and the NiCrBSi thermal spray we investigated. [2] [7] [10]

2. Materials used and methodology of the experiment

Additive material NiCrBSi in the form of powder belongs to the cheaper group of metal additive powder materials. Equipment from the American company was used to optimize the spraying process. Praxair. This device belongs to the systems in which the range of setting individual technological parameters is very detailed, therefore the implementation of complex optimization is very important. The only parameter on the burner is the possibility of using barrels of different lengths for different additional materials. The selected technological parameters were: the amount of oxygen, the amount of kerosene, the flow of transport gas, the amount of additional material, the peripheral and transverse speed of the substrate and the distance of spraying. The results achieved in the individual stages confirmed the predicted properties, and by combining the results achieved in the individual stages, coatings were created with properties meeting the standards stated in the foreign professional literature. The coating created from this additive material is significantly more homogeneous in terms of structure and exhibits significantly better structural characteristics and mechanical, physical and chemical properties compared to coatings of the same chemical composition created by all remaining methods. Significantly better mechanical properties were achieved by optimizing technological and movement parameters, see Table 1. [2] [5] [8]

Structural cracks	0
Delamination of the structure	0
Deadhesion	0
Contamination of the interfacial interface	0,50 %
Measurement of the thickness of the functional coating / interlayer	540 µm
Porosity measurement	do 0,25 %
Hardness measurement	$HV_{0,3}$ 641,4
Adhesion measurement	53,65 MPa

Process efficiency	57,80 %

Table 1. Measured properties of HVOF sprayed NiCrBSi coating [11]

The NiCrBSi thermal spray machining test was carried out on the CTX Beta 1250 TC machine, which is located in the laboratories of the Regional Institute of Technology in Pilsen. The first experiment was carried out in order to know the machining process with a linear cutting edge. In particular, the correct position of the exchangeable insert in the section, the correct orientation of the tool and the testing of the program were investigated. The first (trial) experiment was followed by a series of several experiments, which are mainly devoted to learning the NiCrBSi thermal spray machining process. Finally, the best cutting conditions are selected, with which long-term cutting tests are carried out. From long-term tests, the durability value for selected cutting conditions and types of inserts is determined. Durability is determined based on the results of edge wear and surface quality achieved.

For the first pre-experiment, an IC20 uncoated cemented carbide insert was selected for the purpose of stopping in the cut and monitoring the correct position of the cutting edge. The first idea is to find the correct position of the cutting edge and use the entire length of the cutting edge. The Y axis is used to set the displacement value at the first contact of the plate with the workpiece and at the same time the change of the Y axis after the given distance has been moved. The insert is not focused on the tip of the cutting edge as with conventional tools but on the centre of the cutting edge. The movement of the y-axis during machining is therefore set from a positive value to a negative value (y = -3; y = +3). When setting a positive y-axis correction, the tool moves relative to the workpiece axis more to the tip of the insert, on the contrary, with a negative value, towards the bottom of the insert. With this setting, it is possible to use the entire length of the cutting edge in one pass with uniform wear on the cutting edge. Figure 3 shows the position of the y-axis during initial contact with the workpiece and the position of the cutting edge after a defined distance of 100 mm.

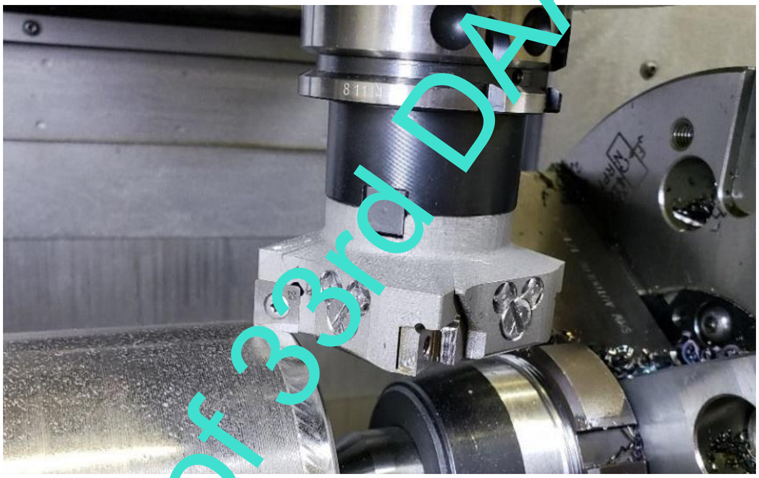

Fig. 3. Test machining of special tool with IC20 insert

3. Evaluation and result of the experiment

According to the previous pre-experiment, the cutting conditions for machining an uncoated carbide insert with the designation SCMW 120408 were selected. The material to be machined, with its composition and properties, is classified as a difficult-to-machine material, therefore worse wear and surface quality results can be expected. The aim of this experiment is to test the fundamental behaviour of the tool with different variants of cooling and movement of the Y axis at a defined distance of 100 mm see Figure 4. Cutting speed, feed, depth of cut and blade angle settings are constant. From the conducted experiment, a table was created with a description of the cutting conditions, the achieved surface roughness, the resulting wear on the VBD edge and the overall appearance of the machined surface. A Keyence VHX 6000 optical microscope was used to measure and evaluate the resulting wear. The wear of the inserts was measured on the face (KB value) and the back (V_{Bmax} value). A Marsurf M300 roughness meter was used to measure the roughness.

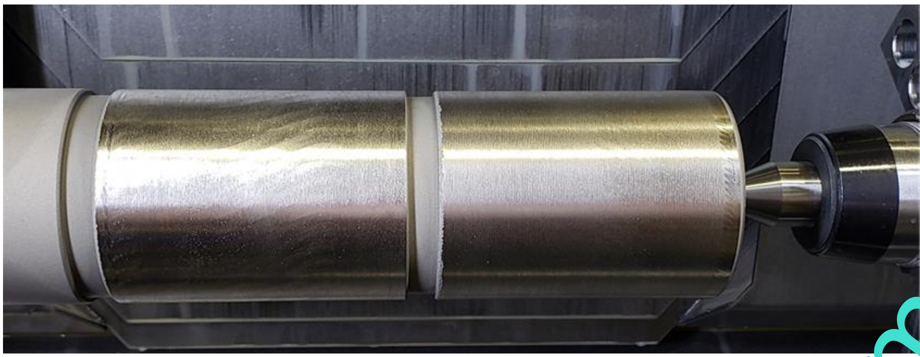

Fig. 4. Workpiece with a machined layer of NiCrBSi coating

From the results achieved (Table 2) when machining with a cemented carbide insert, it appears at first glance that machining with this material clearly does not meet the defined requirements for the machined surface. During the experiment, the effect of stiffness during machining and the effect of cooling on the resulting machined surface was investigated. From the experiment, some basic information about this method of machining was found. It can be seen from the table that the inclusion of the movement of the Y axis during machining has a negative effect on the appearance of the machined surface due to large vibrations. During machining, vibrations did not occur along the entire machined length, but only in approximately 1/3 of the surface. When machining sample 2.1 the appearance of the surface was unified without audible vibrations, but at the same time, the roughness of the machined surface Ra and Rz turned out to be significantly worse than in the other variants. Of course, worse roughness Ra and Rz were also found in samples with Y-axis movement. On the other hand, the uniform appearance of the surface came out well when machining with a constant value of Y. The best-achieved roughness Ra = 1.97 μm was obtained for sample 7.1 on surface number 1 using cooling. However, when comparing sample number 1 and 5, it follows that the inclusion of liquid during machining does not have a significant effect on the roughness or appearance of the surface.

Insert	No.	Roughness	Ra [μm]	Edge wear [mm]		Cutting conditions						Surface appearance
						Vc [m/min]	f [mm/ot]	ap[mm]	λ_s	Y axis	Fluid	
SK IC20	1.1	Ra [μm]	2,34	VBmax	0,27	80	0,6	0,15	70°	cons.	no	Homogeneous
		Rz [μm]	12,80	KB	0,24							Without vibration
SK IC20	2.1	Ra [μm]	**2,94**	VBmax	0,26	80	0,6	0,15	70°	move	yes	Homogeneous
		Rz [μm]	**16,63**	KB	0,26							Without vibration
SK IC20	3.1	Ra [μm]	2,48	VBmax	0,28	80	0,6	0,15	70°	move	no	**Heterogeneous**
		Rz [μm]	13,66	KB	0,25							**Vibration**
SK IC20	4.1	Ra [μm]	**3,00**	VBmax	0,[illegible]6	80	0,6	0,15	70°	move	air	**Heterogeneous**
		Rz [μm]	**15,41**	KB	0,23							**Vibration**
SK IC20	5.1	Ra [μm]	2,32	VBmax	0,29	80	0,6	0,15	70°	cons.	yes	Homogeneous
		Rz [μm]	14,29	KB	0,22							Without vibration
SK IC20	6.1	Ra [μm]	2,26	VBmax	0,29	80	0,6	0,15	70°	cons.	yes	Homogeneous
		Rz [μm]	13,00	KB	0,24							Without vibration
SK IC20	7.1	Ra [μm]	**1,97**	VBmax	0,11	80	0,6	0,15	70°	cons.	yes	Homogeneous
		Rz [μm]	**11,41**	KB	0,25							Without vibration

Table 2. Summary and measured results during spray machining with the IC20 insert

4. Conclusion

From today's point of view, technology using thermal spraying is a very important technology affecting many important industries. Thermal sprays are basically divided according to the selected heat energy source. The technology referred to as HVOF (High-Velocity Oxygen Fuel) can be described as the most modern way of creating coating. The applied structure of the thermal spray is very specific in terms of construction and appearance. It follows from the principle of creation that the molten grains of the sprayed material are significantly deformed into specific disk-shaped lamellae after hitting the base material.

The NiCrBSi thermal spray machining test was carried out on the CTX Beta 1250 TC machine, which is located in the indoor laboratories of RTI at the University of West Bohemia. The trial experiment was conducted to obtain basic information about the linear cutting-edge machining process. The correct position of the exchangeable insert in the section, the correct orientation of the tool and the testing of the program were examined. According to this experiment, the cutting conditions were selected for machining an uncoated cemented carbide insert marked SCMW 120408.

The aim of the main experiment was to test the basic behaviour of the tool during the variation of cutting conditions, cooling and movement of the Y axis when crossing a surface with a length of 100 mm. The achieved surface roughness, the occurrence and extent of wear on the cutting edge and the resulting appearance of the machined surface were monitored. The cutting speed, feed, depth of cut and blade angle setting were set constant. A table 2 was created from the experiment with a description of the cutting conditions and the results achieved.

The best-measured surface roughness Ra = 1.97 µm was achieved for sample 7.1 on surface number 1 using cooling. However, when comparing sample number 1 and 5, it follows that the use of process fluid during machining does not have a significant effect on the quality or appearance of the surface. From the measured wear results, a strong abrasion on the edge was found in a very short time. The results revealed basic information about the machining process with the conclusion to continue this issue with more progressive types of cutting material and coatings.

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