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STUDY OF THE SUSTAINABILITY PROCESSES DURING DRY MACHINING INJECTION MOLD COMPONENTS

BY

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Abstract. The paper presents the advantages of the dry milling against conventional coolant milling of injection molds components, towards a sustainable strategy of machining. This sustainable process targets directly the energy consumption in machining, energy which is crucial in nowadays for a secure and linear growth in production. Finally the research targets the process of dry milling of several injection mold components and present it in a clear and understandable way the differences of tool wear and the influence on the machined surface.

Keywords: sustainable machining; dry machining; injection mold; energy consumption.

1. Introduction

Sustainability is a well-defined concept in numerous scientific articles, publications and conferences and is defined as a healthy development growth which cannot alter the future generations of humanity (Hegab *et al.*, 2018). The sustainable development targets specific economic and social aspects without damaging the eco-system of our planet. Sustainable manufacturing aims to

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produce adequate processes in order to transform raw materials to finished parts by reducing environmental emissions and contamination and also reducing consumption on earth's natural resources (Zhao *et al*., 2017). A sustainable production can be achieved by the application of sustainable principles to manufacturing, such as green supply chain, life-cycle assessments methods: accordingly, designers, manufacturers and process engineers must go through specific strategies depending on the products to develop and produce. From this point of view we can conclude that the manufacturing process of the injection mold components has a lot of stages along their production cycle that have to be investigated to improve the sustainability of the entire process (Bordin *et al*., 2017). As stated in other research, this concept concludes that influence of energy due to material consumption on machining sustainability is significant. In opposition with conventional milling which uses cooling liquid, dry machining has a bigger potential in sustainability, due to the fact that the machine pump is not active, which means that some part of the energy is saved and the tool wear has also a smaller value (Bordin *et al*., 2017).

It is known that machining is an important manufacturing cluster. The reduction of energy consumption is of great importance in order to achieve sustainable manufacturing. As stated is some paper, the energy efficiency is often very low which can underline that the non-cutting stages in a CNC machine, usually dominates the energy requirements. There are many components that consume a lot of energy in machine tools, such as spindle motors or other hydraulic pumps (Rakesh Kumar Gundaa *et al*., 2016). The CNC machines not only process raw materials, but also produce waste and heat. Only threw a proper classification, the energy consumption could be measured, predicted and reduced. Therefore, improving energy efficiency in machining processes is of high value for the future of process development (Goindi and Sarkar, 2017).

Moreover, the cooling liquid fluid that runs during milling process significantly affects the sustainability of machining processes, being considered one of the main environmental hazards in the context of manufacturing. As was stated in other papers, the conventional semi-synthetic cooling liquids are not biodegradable, being as such they may contain components such as heavy metals (lead, chromium, nickel), which are extremely dangerous for the human health. Furthermore such liquids can damage water and also soil resources when wrongly handled, imposing rigid and expensive disposal procedures to the manufacturing companies. In addition, a long exposure of the operators to standard cooling liquids is scientifically proved to cause skin and breathe illnesses (Bordin *et al*., 2017). According to the latest researches dry, near dry and cryogenic cooling strategies are emerging as efficient alternatives to standard flood cooling in machining. With this idea taken into account, it can be stated that dry machining of the injection mold parts, having no cooling liquid during the process imposes no problems of any kind of contamination, disposal and pollution of water and air that can be potentially encountered.

On the basis of these considerations, dry machining can be implemented as clean strategies to the finishing milling of the injection mold components. Since no works are present in literature about this topic, the presented research is aimed at proving the feasibility of applying dry cooling strategies when milling to proposed components. A comparison with a standard flood cooling is given, focusing the investigation on the tool wear and machined surface integrity.

2. Experimental Work

2.1. Workpiece Material

The alloy tested in the presented work is the X37CrMoV5-1 manufactured by Dorrenberg Edestahl. The material was supplied in 4 plates with measurements of 350mmx350mmx22mm. The chemical composition and the mechanical proprieties of the X37CrMoV5-1 (Dorrenberg Official Website) are summarised in Table 1.

Table 1
Chemical and Mechanical Proprieties of X37CrMoV5-1 (Dorrenberg Official Website)

Chemical Composition: (Typical analysis in %)					
C	Si	Cr	Mo	V	
0.37	1.00	5.30	1.30	0.40	
Mechanical Proprieties of					
Hardness, Rockwell C	Modulus of Elasticity	Charpy Impact	Poisson ratio	Machinability	
52.5	207GPa	13.6 j	0.27-0.30	75%-80%	

During dry machining the metal chips from the ferrous alloys have the tendency to glue themself on the tool edge and also on the cutter face, causing the forming of tensions and above normal forces, surface chattering, vibrations, excessive tool wear and also increase friction which gives us a big temperature raise. The generated high temperature coupled with a low thermic conductivity give us an increase on the tool temperature which causes a premature rupture as it is shown in Fig. 1.

Fig. 1 – Tool failure.

Many researchers have tried different ways, which are necessary to overcome some of the above mentioned problems that have been associated with dry milling. Although dry milling has not highlighted satisfactory result in terms of geometrical precision, milled surface quality, tool life, metal chips evacuation and production rate. Taken all this into consideration the research has to answer to some of this problems and propose a different radical approach. In every milling operation of the injection mold components, the raw material that has to be milled and also the machining process represent together the input conditions.

The success machining strategies adopted by some of the researchers in the case of dry milling are defined by a hybrid machining process which includes tool with different coatings, which are resistant at high temperatures.

The properties of the raw material have a great influence on the machining parameters and also on the future milling strategies applied during a dry environment. The material proposed above X37CrMoV5-1 has good machinability properties which can result into a better removal rate of the metal chips, better milling forces, better surface and a longer tool life. The final idea is to obtain the desired part with the imposed geometrical and surface precision by decreasing the forces and machining temperature and increasing the tool life and production rate.

2.2. Tool Materials Used in Dry Machining

Dry machining is accomplished in conditions of high tool temperature compared to the traditional machining. So the main idea is to find a suitable tool for dry milling that has the ability of having a high rigidity and withstand high temperatures. Furthermore the tool has to withstand high stresses and forces which are present during dry machining. The tool coating plays an important role in this particular matter and therefore the literature underlines some of the most used coatings for this procedure (Yip and To, 2017):

- Titanium Aluminum Nitride (TiAlN or AlTiN)
- Titanium Carbo-Nitride (TiCN)
- Ceramics
- Chromium Nitride (CrN)
- Diamond

Fig. 2 – Yonnex 8mm Carbide End Mill with 4 flutes used in the research (Yonnex Official Website).

In our research we will use an end mill with Cemented tungsten carbide coating. This type of coating shows an increase resistance and rigidity, making it possible to manufacture tools with a positive cutting angle which decrease the cutting forces and also the energy consumption. Successful dry machining of the X37CrMoV5-1 was carried out by a carbide tool from Yonnex which has micro-grain cutter structure and Titanium Aluminium Nitride (TiAlN) coating with a total exterior diameter of 8 mm, shown in Fig. 2. The higher hot hardness and strength of the tool resulted in only a small amount of flank wear and no crack formations were observed.

As can be observed in Fig. 2 the tool geometry differs from conventional end mills. It somehow copies the geometry of some of the modular heads used in roughed milling, by having an involute type radius which provides a small depth of cutting but in the same time it increases significantly the feed and speed in opposition with conventional end mills. Also in order to provide a longer tool life the carbide end mill is designed with a positive rake angle and keeping the cutting edge very sharp. In dry machining, normally the tool temperature is high which helps in increasing the toughness, so that tool chipping is not likely to be the main cause of tool failure. Hence, it is possible to use high rake angles, small wedge angles and sharp cutting edges.

2.3. Experimental Dry Milling Procedure

A Doosan DNM 5700 was used to perform this proposed test. The cooling system provided with the machine tool was to fulfil standard flooding (wet milling), and air threw the spindle head (dry machining). A semi-finishing Yoonex End Mill, presented above is used in order to solve the proposed test.

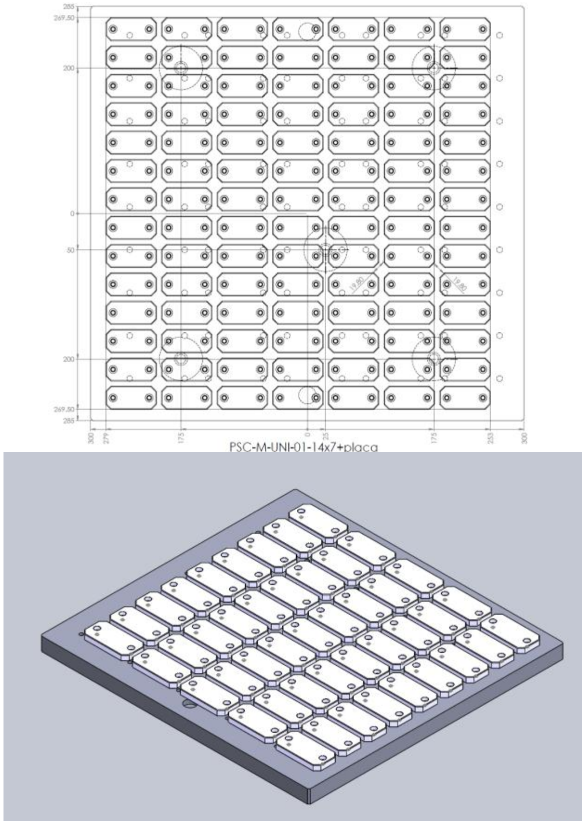

Fig. 3 – The arrangement of the test parts.

First of all the test is conducted on the X37CrMoV5-1 material delivered in 4 plates with equal dimensions of 350mmx350mmx22mm. The aim is to mill 45 grouped parts from each plate, components of an injection mold. The strategies used in the case are similar on each part and are defined in Table 2.

Table 2
Parametrical Conditions Input Into the System

Tool	Feed [mm/min]	Speed [rot/min]	Condition of milling	Lateral Step % of initial diameter	Stepdown [mm]	Time of milling [minutes]
YONNEX End Mill Φ8R0.5	9360	5200	DRY	100%	0.25	138’
	4860	3200	DRY	100%	0.25	189’
	9360	5200	COOLANT	100%	0.25	138’
	4860	3200	COOLANT	100%	0.25	189’

The grouping of the parts was designed in Solidworks in such a way that there is a constant distance between parts equal to 9 mm on each side. This is necessary so that the 8 mm end mill to pass between them. The dimensions of standard part is 100mmx70mmx14.5mm. On this basis the final arrangement is done in order to fill the entire ordered plate, defined above. This resulted in 5 columns and 9 rows, summing a total amount of 45 parts (Fig. 3), which make the final plate with the dimensions of 350mmx350mmx22mm. The required strategy for milling was designed in PowerMill, by using a conventional strategy (Fig. 5). The entire process it is done in only one stage with a constant step-down, due to the fact that the final part is to be inserted in a cavity were the tolerances in length and width is approximately of 1 mm (Fig. 4).

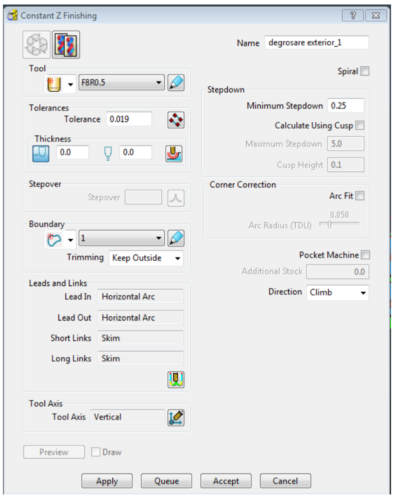

Fig. 4 – Constant Z finishing strategy used in milling the proposed project.

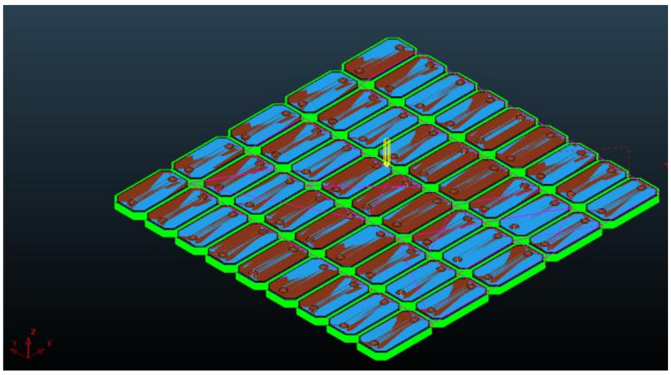

Fig. 5 – The simulation of the toolpath in PowerMill.

The results of the test shown an increased productivity for the dry machining strategy, due to the fact that during the test were the mill was flooded in coolant, in both case did not finish the program in one piece so it had to be reset and start from the breakage point. This particular phenomenon appeared due to the chips gathering inside the mill channels. To the tremendous forces involved the end mill shattered. For the second case of test involving dry machining the tool path reached the end of the program in one piece with no above normal wear (Fig. 6). On the other side, once the mill passed the 11.5 mm depth some of the metal chips glued themselves to the wall of the parts resulting in above normal roughness (Fig. 7). The roughness was elevated by using a CMM device with high capability of measure up to 0.5Ra, using a flexible tip sensing probe, necessary for high accuracy measurement.

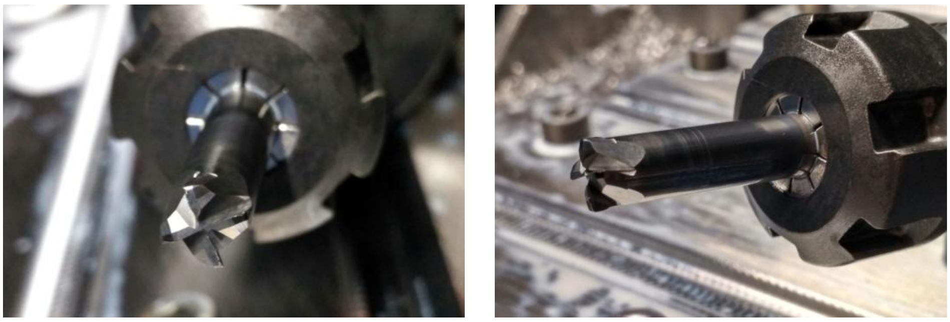

Fig. 6 – Visual identification of the tool wear after process completion.

Fig. 7 – The final processed parts during the first fixture.

3. Conclusions

The proposed paper demonstrated the stated hypothesis from which we started, namely the replacement of the conventional machining procedure which uses cooling liquid with dry milling procedure is a sustainable alternative. The effects of the proposed strategy, reinforced with the specialty literature and machining parameters give a positive line towards reducing the tool wear. Simultaneously it is stated that dry machining reduces the negative aspects produced by the conventional cooling method through the positive results concerning the environment and also the health of the operator, both important criteria in this industry branch. However some consequences appeared regarding the quality and precision of the machined surface and therefore this particular reason limits the efficient implementation of dry machining. With this stated a hybrid method of cooling, between dry machining and cooling liquid, has to be taken into consideration and future study it.

REFERENCES

Bordin A., Sartori S., Bruschi S., Ghiotti A., *Experimental Investigation on the Feasibility of Dry and Cryogenic Machining as Sustainable Strategies when Turning Ti6Al4V Produced by Additive Manufacturing*, Journal of Cleaner Production, **142**, 4142-4151 (2017).

Goindi G.S., Sarkar P., *Dry Machining: A Step Towards Sustainable Machining e Challenges*, Journal of Cleaner Production, **165**, 1557-1571 (2017).

Hegab H.A., Darras B., Kishawy H.A., *Towards Sustainability Assessment of Machining Processes*, Journal of Cleaner Production, **170**,694-703 (2018).

Rakesh Kumar Gundaa, Narala Suresh Kumar Reddya, Kishawyb H.A., *A Novel Technique to Achieve Sustainable Machining System*, Procedia CIRP, **40**, 30-34 (2016).

Yip W.S., To S., *Tool Life Enhancement in Dry Diamond Turning of Titanium Alloys Using an Eddy Current Damping and a Magnetic Field for Sustainable Manufacturing*, Journal of Cleaner Production, **168**, 929-939 (2017).

Zhao G.Y., Liu Z.Y., He Y., Cao H.J., Guo Y.B., *Energy Consumption in Machining: Classification, Prediction, and Reduction Strategy*, Energy, **133**, 142-157 (2017).

*** www.dorenberg.de

*** www.itt.it

STUDIU PRIVIND SUSTENABILITATEA PROCESULUI DE PRELUCRARE USCATĂ EFECTUATĂ ASUPRA PĂRŢILOR COMPONENTE ALE MATRIŢELOR DE INJECŢIE

(Rezumat)

Scopul lucrării a fost să prezinte avantajele prelucrării uscate comparativ cu prelucrarea convenţională ce foloseşte emulsie în vederea răcirii sculei şi piesei în timpul prelucrărilor. Astfel s-a încercat definirea procedeului de prelucrare uscată ca fiind o metodă sustenabilă prin amplele avantaje ce le oferă. Metoda experimentală propusă a fost realizată pentru a întări ipoteza şi a evidenţia totodată concluziile acesteia. Aşadar s-a putut observa o scădere considerabilă a uzurii frezei în timpul prelucrării uscate. Cu toate acestea un lucru deloc de neglijat a fost apariţia unei valori crescute a rugozităţii suprafeţei ceea ce duce în mod clar la o scădere a preciziei prelucrărilor. Astfel se propune ca o direcţie de cercetare viitoare stabilirea unei metode hibride de prelucrare ce va trebui să răspundă cerinţelor pieţei.