An Analysis of the Thermal Simulation of Parts Processed by Cutting, with Different Geometries

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Abstract. In practice, different cutting processes are encountered, each process having different characteristics. Due to the existing friction forces between the workpiece and the cutting tool, a significant amount of heat is generated. This amount of heat can be determined by experimental measurements. With the help of the SolidWorks program, the geometric element that must be studied can be made, so that later it can be studied from the point of view of the thermal behaviors following the processing. We will take into account the different critical areas that may occur and that may materialize through areas where the final surface is not compliant. This paper aims to study the way in which the temperature is propagated in the workpiece, so that the phenomenon can be understood and determined how this excessive heat can be removed from the cutting area.

1. Introduction

There are many mechanical processing processes that can be considered for different materials and geometric elements to be processed. Mechanical processing generally involves the removal of additional material using various processing tools. During the mechanical processing of cutting, are generated some areas of increased friction between the tool and the workpiece. These frictional forces encountered during processing generate heat, which can be excessive and can damage the cutting process [1].

As we already know, there is an interdependence between the chosen material, the processing regimes and the heat generated by the cutting: the cutting regimes, the tools used, the cutting tools used to make the processing. The shape of the chips is an important indicator of the cutting process; through this we can realize the degree of plastic deformation suffered by the layer of detached material. Thus, following previous studies on different types of processing and different materials, we can distinguish two types of chips: breaking and plastic deformation [2].

In machining, the cutting process is performed by composing two movements: the main movement, the rotation of the tool and the secondary movement, the advance of the part caught in the device on the table of the machine tool. With the help of the milling process, different types of surfaces can be made from simple to complex: flat, conical, bored, wedge or helical channels, gears, etc [3].

Following the study of these heat transfer phenomena that occur in the mass of the workpiece, we can say that we have a conductive heat transfer in the workpiece. Thermal conductivity involves the transmission of heat from close to closer in the particles of the same body, these particles being in contact. As we can easily see, the heat is transmitted in the mass of the material in the cutting area is the highest, practically there must be paid more attention. This heat transfer is due to the difference in heat potential [4].
It is known from the literature that heat transfer between two environments takes place in three ways: convection, conduction and radiation. Conductive heat transfer is characteristic of solid media because it involves an immobility of particles. The convective heat transfer takes place between the fluid and the solid medium (for example, between the workpiece and the atmosphere), sometimes it can be combined with a heat transfer by radiation [5].

Using specialized computer programs by developing and studying the different geometries of the parts, with several types of materials can study various thermal phenomena that occur during the cutting process, thereby being able to achieve their optimization. If we have too high temperatures in some areas during cutting, this will create imperfections in the implementation of the cut surface. To avoid this the temperature can be reduced by choosing an efficient cooling system, so in the processed area the temperatures can be controlled more easily and at the same time established and eliminated the critical areas [6].

2. Simulations setup
As we have established from the introduction, we have a heat dissipation through conduction in the mass of metallic material. In this case if we analyses the Fourier law (equation (1)), then we will know that the heat flux density is proportional to the dropping of the temperature, or inversely proportional to the temperature gradient [7].

\[ q = -\lambda \, \text{grad}\, t \quad [\text{W/m}^2; \text{kcal/m}^2\text{h}\text{grad}] \]  

where \( \lambda \) is the thermal conductivity [W/m\cdot\text{grad}; kcal/m\cdot\text{h}\cdot\text{grad}], \( t \) is the temperature field that is based on the point considered and time.

If we consider and we will focus on case of a homogeneous piece, like the workpiece simulated, the heat conduction is given by (equation (2)):

\[ q = \frac{t_2 - t_1}{R} \quad [\text{W/m}^2] \]  

where \( t_1 \) is the temperature in the processing area, \( t_2 \) is the temperature of the part before machining, and \( R \) is the thermal resistance (equation (3)) and is given by:

\[ R = \frac{\delta}{\lambda} \quad [\text{W/m}^2] \]  

where \( \delta \) is the length of the workpiece and the same \( \lambda \) is the thermal conductivity.

The working piece chosen to be studied and machined by milling has the following geometric elements, as can be seen in figure 1. The geometry is simple but has a different geometry: with a part with chamfer, another part with fillet and a hole [8].

The workpiece is set to be from aluminum alloy, type AA6016-T4, the chemical compositions for this material is presented in table 1. Initially, the piece has a rectangular shape, it will first process the chamfer, then the fillet area, and at the end the hole will be made. From a thermal simulation point of view, the material has the following thermal properties: thermal expansion coefficient 2.4e-005 /K, thermal conductivity 200 W/m\cdot K and specific heat 900 J/kg\cdot K.

| Table 1. Chemical composition (%) of aluminum alloy, type AA6016-T4. |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mg          | 0.25-0.6 | Si  | 1.0-1.5 | Fe  | 0.5  | Cu  | 0.2  | Cr  | 0.10 | Mn  | 0.15 |
| Cr          | 0.15  | Ti  | 0.20  | Zn  | 0.20 | Others | 0.20 | Others | 0.15 | Balanced |
In computer simulations can use lots of geometric elements of different thicknesses and a wide variety of materials, before they are physically made. For this case, different thicknesses $h = 1, 2, 3$ and $4 \text{ mm}$ were chosen for the study. Each will be studied and simulated and the corresponding conclusions will be drawn.

### 3. Results and discussion

In order to perform these simulations, a simple geometric element was chosen, these elements being common to most of the machined parts. The way of working is the following: the CAD model was realized and then the SolidWorks 3D model of the chosen element was subjected for analysis. Within the program there is a simulation module of different practical situations, it was chosen to study the thermal load of that element [9].

In figure 2(a) composition of these two processing was analyzed, if they were carried out, some influence on the temperature distribution was observed. In this case, practically there are no almost no part in the piece isn’t uninfluenced by thermal machining.

![Figure 1. The reference geometry of simulated workpiece.](image1)

![Figure 2. Temperature distribution for simultaneous plane and hole processing.](image2)
In the initial part of the computer simulation, the material was chosen, namely aluminum alloy, type AA6016-T4, with its own characteristics. When using other metallic materials, of course there will be differences in the temperature value of the simulations. Figure 3 captures the temperature distribution over a length of 15 mm, in the transfer section, starting with the thermally influenced area.

**Figure 3.** Temperature distribution in selected plane near influenced zone.

In figure 4 an export of a data for a long-term temperature distribution was performed for the main surface of the analyzed element. When these temperatures can be critical to the integrity of the material or other phenomena that are not welcome, it is possible to intervene in the critical areas by adopting efficient cooling systems, so that the temperature reaches normal values. This general temperature graph shows exactly where to optimize.

**Figure 4.** The temperature distribution on the main surface of the workpiece. (a) sheet thickness 1 mm; (b) sheet thickness 2 mm; (c) sheet thickness 3 mm; (d) sheet thickness 4 mm.
As can be seen from the previous graphs, the temperature distributions on the entire surface of the part also differ depending on its thickness. In the processed areas the temperature values could be higher as expected.

The areas where deformations or other imperfections may occur in the material are at the contact between the workpiece and the cutting tool. A temperature control in this area is given by the proper choice of material, cutting tool as well as the chosen work regimes.

4. Conclusions
A better knowledge of the phenomena that occur in the case of chip cutting helps to achieve the best processed elements. Excessive heat from the cutting process can only be harmful. This has important repercussions on the newly created surface, as well as residual stresses are generated in the material that cannot be accepted.

In many cases, in the cutting process it is desired to remove this excessive temperature from the cutting area, this is done through complex cooling systems that use simple air-water cooling systems, up to complex emulsions. Particular care should be taken in the choice of materials to be processed and in the processing regimes chosen.

By computer simulation, the cutting parameters can be selected from the beginning, the geometry of the finished part can be studied without having the real element. With this method you can find out what problems can arise by making these surfaces and what would be the cutting temperatures and their propagation pattern.

Choosing a complex cooling system must be done carefully because it may incur additional charges quite high given the cooling system itself but must monitor their environmental impact. When the agent is released into the cooling zone, a quantity of aerosols is released on contact with the processing surface, which can be harmful to the operator's health.

5. References
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