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SAE H-13 STEEL REPLACEMENT BY SAE 4340 IN THE SHRINK TOOL HOLDER

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Abstract. *The metalworking industry has been increasingly manufacturing parts with high complexity, requiring greater precision in machining processes. More efficient process management results in increased productivity, reduced machine setup time and, especially manufacturing cost. The present study aims to change the raw material to reduce the cost of the tool holder known as shrink mandrel, whose principle is the adjustment by thermal contraction with fixation between the radial interfaces of the tool holder and the tool. The methodology used is based on the concept of maintaining mechanical properties in cold conditions and the application in high rotation, using computer simulations by finite element method using the SOLIDWORKS® software. To know the facts of these premises, it can be concluded based on the raw materials literature and computer simulation, it is possible to change the SAE H-13 steel by AISI 4340 steel.*

Keywords: *Shrink chucks, Tool Steel, Computational simulation.*

1. INTRODUCTION

With the rapid development of the metal mechanic industry over the last decades, the necessity of high degree material to attempt the complexity and development. Currently, the economic scenario requires companies to provide customer service with greater agility and flexibility in addition to reduced costs, being more competitive in the global market. In this context, the efficient management of the best machine tools, CAD / CAM software and cutting tools becomes important elements to reduce costs (FAVARETO; VALLE; JUNIOR, 2009).

In this context, the industry, due to the increasing complexity and technological development of this processes and products who need low costs and flexibility to maintain themselves. This has been causing frequent inconveniences involving cutting tools with directly affecting the cost of the finished product. These cutting tools have a significant share in the costs, in addition to the acquisition cost, the cutting tools impact on the final cost of the product in several ways such as improper uses and operation causing breakage and waste; waste in the process due to defective tools and longtime of setup (GOLDONI, 2003).

Goldoni (2003) also explain about some disorders resulting from premature wear of tools, unexpected breaks and low quality of parts in the production line. The tool management is used as the main method to increase productivity, eliminate waste and improve product quality by reducing interruptions in the normal production flow.

1.1 Tools holder - what is a cost shrink chucks

Shrink chucks uses the shrinkage principle. According to Booker et al. (2004) "A shrink fit is a semi-permanent assembly system that can resist relative movement or transmit torque between two components by creating high radial pressures at the interface of their constituent faces". This process offers a low cost of fixation between the parts, considering that the process does not require the use of other fixing elements, such as screws and rivets, which results in reducing the complexity of the assembly and reducing the setup time within the industry. (Figure 1).

The concept of shrink fit consists in the pressure between the internal diameter of the mandrel and the external diameter of the stem (cutting tool), through the interference in the dimensions of the radial interface. This process consists of heating the tool holder to a specific temperature. In such a way that the tool holding channel expands sufficiently for the tool to fit snugly. Then the shrink fit is cooled by liquid or gas, returning to operating temperature (BOOKER et al., 2004).

The biggest uses of shrink chucks are on the mold and die industry. Generally use them to fix cutting tools such as endmills, drills and reamers. Currently on the market there are several styles of chucks such as hydraulics, collet holders and weldons, each containing its particularities. What differs shrink fit from collet and weldon doors is the fact that they have some characteristics such as: machining precision, availability of different profiles, tightening torque, consistency of setup, balance repeatability, cleaning of the tool holder and availability of variable fixings. When compared with hydraulic chucks, what differs both is the fact that the shrink tool holder has the same characteristics as the hydraulic one, with the difference that they have a lower cost and do not require maintenance.

Figure 1: Shrink tool holder with various fixings.

1.2 Steels for Tool holder

Shrink fit are tool holders that require care when choosing raw materials for project design. The working conditions of these tool holders are extremely severe, due to some factors such as: cyclical exposures at high temperatures, their sudden cooling in most situations, their corrosive means, and their normal operating conditions (vibration, effort of machining and etc.). In order to meet the requirements of these tool carriers, alloyed steels are used, as they have better properties when compared to carbon steels (SCHEID, 2010).

Generally, the raw material of shrink fit is used in design, comes from high alloy steel with medium or high carbon content and alloys to obtain the desired characteristics, such as:

1.3 Tribology

The science that studies friction and wear, that is, the relationship between moving surfaces is called tribology (HECK, 2010). Tier (1998) show, that wear can be described as the damage produced on a surface caused by the contact between two surfaces resulting in the gradual loss of material. The behavior of the material under wear conditions depends on some variables, such as: type of contact, stress level and resulting temperature.
According to Díaz (2018) components of machines, vehicles and structures are subject to constant repetitive loads, where these efforts when cyclical cause failures in the materials involved, even if these stresses are below the flow limit of the material. In the other hand the hardness of both materials are almost the same.

The main mechanisms undergo wear and tear efforts, which may be: abrasive, adhesive, erosion, cavitation and fretting. Shrink chucks are exposed to the phenomenon of fretting in the region of attachment between the chuck and the machine shaft, which can considerably reduce the tool holder life.

The fretting phenomenon occurs in machines or components that have elements in mutual contact and in repetitive movements, where they are subject to the relative displacements between surfaces during the contact zones, being associated in parallel to the occurrence of wear, corrosion and damage by fatigue. (DÍAZ, 2018).

According to Ashiuchi (2009) fretting wear is characterized by the contact between two surfaces, through a forced contact, resulting in surface wear caused by the formation of dust oxides that are harder than the base material accelerating the surface abrasion. Ashiuchi (2009) also says that in cyclical loads the fretting phenomenon can form cracks that can be increased by fatigue, even with the end of fretting wear.

1.4 Machinability

We can define machinability as the performance of a material when machining. Machinability is not an attribute that depends on the material, but rather on the relationship between the machined material and the operation used (BAPTISTA, 2002). The scope of the process comes after the cutting tool penetrates the material, where it ends up deforming elastically and after plastically, due to the flow of the material, which is generated by exceeding its maximum stress. Other variables found in the context of the process are: cutting speed, feed, depth of cut, types of tools, types of machine tools and types of cutting fluids (BAPTISTA, 2002).

Baptista (2002) also tells us that the economic advantages of choosing the right material to be machined associated with the set of machining properties result in notable gains, where energy consumption, production times and costs can be significantly reduced.

1.5 Chemical composition

According to Chiaverinni (2005), there are currently several types of steel on the market, which can be offered with different heat treatments, microstructures, conformation conditions, geometries, surface finishes and chemical compositions, all of which are registered and defined by standards. Steels can be classified according to their chemical composition: carbon steels, low and high alloy steels. The alloying elements most found in steel alloys are carbon, silicon, manganese, chromium, vanadium, tungsten, molybdenum,and cobalt. And their respective behaviors are:

Carbon – is the essential element, help in the formation of carbides responsible for wear resistance and hardness to steel (CHIAVERINNI, 2005).

Silicon - at low levels it is used to reduce the rust, silicon stabilizing elements added, such as molybdenum and chromium (CHIAVERINNI, 2005).

Manganese – at high levels it increases the hardenability. The addition of percentages of manganese increases the oil temperability (CHIAVERINNI, 2005).

Chromium – is added to increase the temperability, wear resistance and corrosion. An alloy with certain percentages of chromium and molybdenum has characteristics of temperability and air-hardening. At high levels next to carbon, it results in an alloy with high mechanical resistance and temperable in oil or air (CHIAVERINNI, 2005).

Vanadium – has the characteristic of reduce the rusting and harmonize the size of the grains. This refinement or impediment of grain growth results in stable carbides even at elevated temperatures, increasing the hardness. (CHIAVERINNI, 2005).

Molybdenum – it works as a substitute for tungsten, where half the amount of molybdenum compared to tungsten produces close results. Molybdenum increases ductility and contributes beneficially to the hot hardness of steel. (CHIAVERINNI, 2005).

Phosphorus and Sulfur – They are residual elements and must present minimum values, as they are fragilizing. (ASM HANDBOOK, 1996).

Nickel – Dissolved in the ferritic matrix reduces the grain size, decreases the transformation temperature and increases the material mechanical strength. (ASM HANDBOOK, 1996).

Table 1 shows the composition of H-13 steels according to ASTM A681 and SAE4340 according to SAE J404.

Table 1 – Chemical composition of H-13 and SAE4340 steels, values in %.

Steel	C	Mn	P_{max}	S_{max}	Si	Cr	Ni	Mo	V
H-13	0,32 – 0,45	0,20 – 0,60	0,03	0,03	0,80 – 1,25	4,75 – 5,50	-	1,10 – 1,75	0,80 – 1,20
4340	0,38 – 0,43	0,60 – 0,80	0,03	0,04	0,15 – 0,35	0,70 – 0,90	1,65 – 2,00	0,20 – 0,30	-

1.6 Temperability

According to Chiaverini (1998) the thermal treatments aim to change the pre-existing properties of the steels, subjecting them to a sequence of heating and cooling by controlled means such as: temperature, atmosphere and cooling rate.

The mechanical properties can be acquired by means of thermal treatments, by transforming the austenitic regions into martensitic ones through the tempering process by means of water, oil or air (CALLISTER, 2002).In the tempering process, the steel is heated until it enters the austenitization phase and after cooling quickly, which results in an increase in the hardness and transformation of the steel phase into martensitic. As this tempering process is usually very abrupt when cooled by means of water or oil, it is necessary to perform another heat treatment called annealing, in order to relieve the stresses resulting from the process and minimize possible cracks or failures. (CHIAVERINI, 2005).

According to the ASM Handbook (1990), the hardness of SAE H-13 and AISI 4340 steels presented in this research, are very similar close to 54 HRC through the quenching process.

This hardness is not relevant to the analysis, since this information is negligible for the execution of the computer simulations. For a better understanding of the concepts that define heat treatments it is essential to understand some terms that will be used during the work, more specifically phase and microstructure. The microstructure of the alloys according to Callister (2002) can be described by the number of existing phases, proportions and the way they are distributed or arranged. In alloys, some variables such as alloying elements, the concentration of these allied to the thermal treatment used can determine how the microstructure will be, and in some situations even determine the physical properties and the mechanical behavior of this material. The phase diagram is used to assist in the control of the phase structures of a system, with which it is possible to perform, in equilibrium, based on the phases present, the compositions of these phases and the phase percentage.

1.7 Thermal properties

In the words of Chiaverini (1986), the increase in temperature in metals generates an increase in the vibration of atoms, resulting in the thermal expansion of the grains, which translates into practice with dimensional change. In the manufacture of shrink, the thermal properties found in the raw material are very important, facilitating the absorption of energy in the form of heat and transforming it into an increase in temperature and dimensional. The heat capacity, specific heat and thermal conductivity are properties normally analyzed for this application, based on this assumption it is understood that:

Heat capacity is a physical quantity that measures the amount of heat supplied to produce an increase in body temperature (CALLISTER, 1998).

In order to better understand the definition of specific heat, it is of utmost importance to understand some other definitions. In which heat is the energy in transit from a body with a higher temperature to a body with a lower temperature, resulting in a change in its dimensional state. Mass can be described as the amount of matter present in a body, while temperature is a measurable physical quantity described as the amount of heat in a given environment or body (CONCEITO DE, 2019). If we take these precepts we can then say that the specific heat is described as the portion of heat required to increase the temperature in a unit of mass (CHIAVERINI, 1986).

Another important property is thermal conductivity, which can be expressed as the ability of an element to conduct heat (CHIAVERINI, 1986). Table 2 shows the thermal properties provided by Villares Metals, for SAE H-13 and AISI 4340 steel.

Table 2 – Thermal properties of SAE H-13 and SAE4340 steels.

Material	**Properties**			
	Thermal conductivity (W/mk)	Thermal expansion coefficient (m/mk)		Specific heat (J/Kg.K)
H13	42	11,1	293,15K°- 373,15K°	460
		12,1	293,15K°- 473,15K°	
		12,9	293,15K°- 573,15K°	
		13,5	293,15K°- 673,15K°	
		13,9	293,15K°- 773,15K°	
4340	44,5	11,5	293,15K°- 373,15K°	475
		12,0	293,15K°- 473,15K°	
		12,2	293,15K°- 573,15K°	
		12,5	293,15K°- 673,15K°	
		12,9	293,15K°- 773,15K°	

1.8 Computational Simulation

In the words of Ernani (2006), computer simulation is acquired through mathematical models performed on a computer, in order to replicate or copy aspects of a real system to one that is being developed. The simulation allows us to carry out the modeling of a project, imputing data from its real work situation, and through experiments to predict how the system will behave, this help in decision making.

Currently, there are several commercial software that use mathematical models for modeling and simulating the efforts present in their components. The industry increasingly seeks the use of CAD / CAE technologies to reduce costs, continuously improve the process and increase the quality of its products. The software used in this paper is SOLIDWORKS, which consists in a 3D graphical interface, 2D detailing, in addition to the motion studies module, which is both static and dynamic, which allows the user to quickly and efficiently define the geometry of the problem, allocation of raw materials, application of loads according to conditions, generation of mesh and finally the simulation of the analyzed project.

2. OBJECTIVE

The objective of the present study is the replacement of SAE H-13 alloy steel, raw material currently used in the manufacture of shrink chucks in metal mechanic sector, whose area of expertise is in the manufacture of clamping tools for machine tools. This steel has some characteristics such as high mechanical resistance, resistance to thermal fatigue and thermal shock, however, on the other hand, it counts on the high price of raw material, representing a high manufacturing cost.

In this way, the research is limited to identifying and presenting a material with a lower cost as a new proposal for the material already used in the making of this type of mandrel, in such a way that it matches or approaches the characteristics of the steel used currently.

3. MATERIALS AND METHODS

This section describes the analytical means used to define the possible substitute raw material for the currently used alloy SAE H13. The analysis started with the study of the chemical and thermal compositions of several alloys of steels, in order to determine if the necessary mechanical properties will be met. In order to emulate the real working conditions, the data were obtained through literature and others provided by Villares Metals, thus meeting the reliability requirements of this research.

For the computational analysis tests, the SOLIDWORKS software was used, creating a 3D model with an external and dimensional profile starting from the norm, as shown in Figure 2. The mechanical properties of the steels used in the tests were acquired and imputed in the software and through the analysis by finite elements, allowed us to verify if there was any type of degradation.

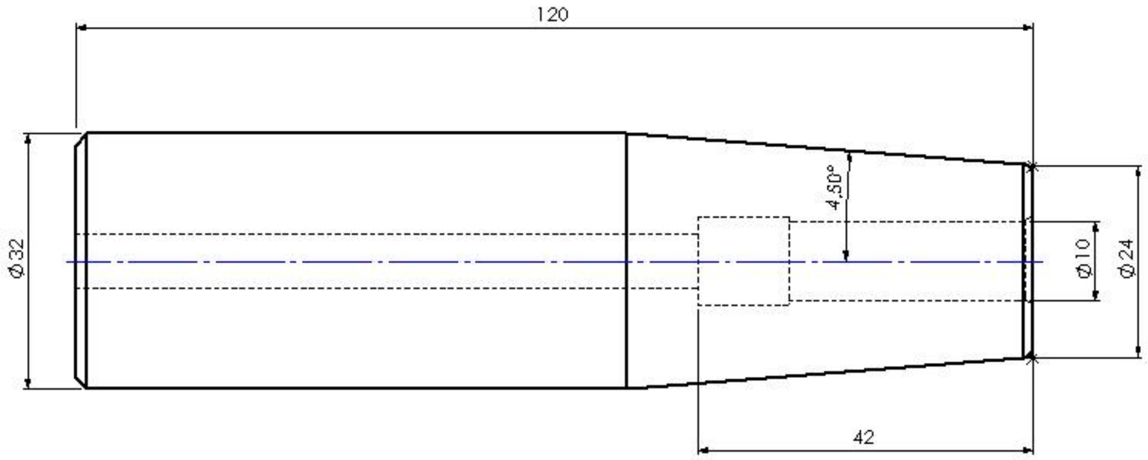

Figure 2: Sketch of the 3D model used for analysis.

4. RESULTS AND DISCUSSIONS

The setup process, that is, the process of preparing and assembling the cutting tool in the shrink mandrel, requires the mandrel to be very efficient in terms of its thermal properties. In this context, a material was chosen that maintained or approached the mechanical and thermal characteristics of the steel currently used. As shown in Table 1, it can be seen that AISI 4340 steel differs considerably in some percentages of alloying elements such as: Silicon, Chromium, Nickel, Molybdenum and Vanadium.

Figure 3 shows the results presented in the computational analysis according to data present in Table 2 the interaction was insert in the SOLIDWORKS software to perform the analysis, note that in the image that have two different arrow models, one in green and the other in blue, these represent two types of different phenomena: heat by radiation and by conduction. The blue colored arrows represent the irradiation phenomenon emulating the work situation to which the inductor heats up the entire length of the hole. The green colored arrows represent the conduction phenomenon, emulating the heat transfer between the outer region of higher temperature.

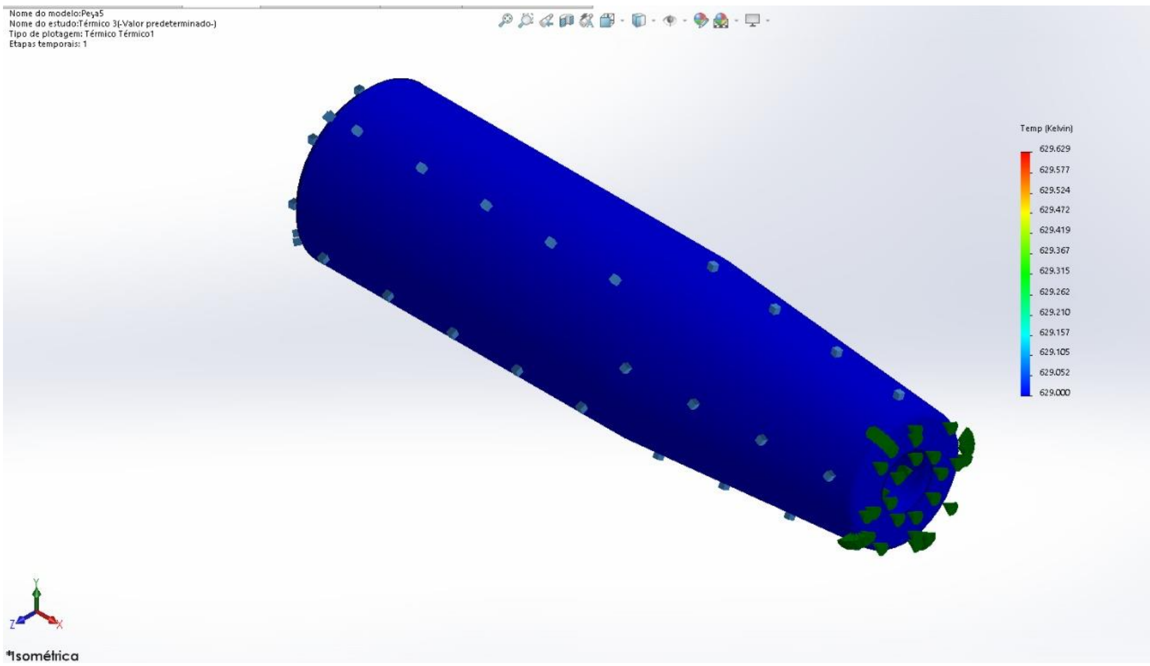

Figure 3: Representation of forces acting in the analysis.

The scale enlargement, in which there is a gradient and beside some temperatures, note that the maximum temperature of the scale is 629.62 ° K, where it is higher than the maximum process temperature. This maximum value of the gradient was defined in order to generate a safety margin, likewise represented by the red coloring, symbolizing that this region is suffering some type of degradation due to the temperature.

Note that in the result presented, the gradient remains blue, in which there is not even any type of marking on the scale, stating that the maximum temperature used in the setup process 623.15 ° K is not sufficient to reach the minimum value start of degradation at 629.05 ° K.

5. CONCLUSION

With the present study, it is noted that although the chemical composition of AISI 4340 steel differs considerably in some percentages of alloying elements such as: Silicon, Chromium, Nickel, Molybdenum and Vanadium but their thermal properties are very similar.

The validation of the proposal shown in this case study was performed through computational simulations with the aid of the SOLIDWORKS software, the analysis found that the mandrel made in the AISI 4340 alloy expands sufficiently when heated between 590.15 ° K to 623.15 ° K, without degradation caused by the temperature used in the study.

The analysis cooperated significantly to reduce the cost of manufacturing shrink mandrels, consequently improving their final cost, without any degradation during the thermal expansion processes. The present study is based on the technical literature, thus reducing the potential errors in the construction of the methodology and results, reducing the cost of preparation and subsequent assembly in industrial processes.

Based on the analysis presented, it is possible to observe that the change in the raw material meets the main operating requirements of the product with regard to thermal expansion, thus making it possible to substitute the SAE H-13 alloy for AISI 4340.

For future studies will be carried out in the sense to analyze the life cycle, fatigue and hardness in the mandrel in order to complement the analysis exposed in this article and will be validated by mechanical tests the properties before and after the thermical cycle.

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