IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 18, Issue 2 Ser. IV (Mar. – Apr. 2021), PP 01-13
www.iosrjournals.org

Spheroidized Heat Treatment and its Effect on Machinability in Medium Carbon Steels

Víctor Alcántara Alza[1],
[1](*Mechanics Engineering Department, National University of Trujillo, Perú*)

Abstract:
How spheroidization heat treatments influence on machinability and microstructure of AISI / SAE 1040-1050 steels, under cylindrical turning was investigated, in order to find an optimal tool life as a machinability criterion.
Samples were made in the form of bars of 70 and 60 mm in diameter and 125 mm in length. These were subjected to the treatments: T1 = 900 °C / 3 h / oven cooling; T2 = 750 °C / 3 h / - 650 °C / 6h / oven cooling and T3 = 700 °C / 24 h /oven cooling. The cutting parameters were: S = 67m / min and 78m / min; f = 0.1 mm / rev; d = 1 mm. The treatments were carried out in a muffle furnace. Hardness was measured on the Brinell scale (HB). A parallel lathe was used for the machinability tests and the Flank wear was measured using a sterographic microscope. The samples microstructure, were revealed at optical level using a high resolution microscope.
It was found that the tool life (T) increases to the maximum with the treatment (T2). The maximum life tool, were: For SAE 1040 steel: T = 47.8 min, with treatment (T2). For SAE 1050 steel: T = 35.2 min, with treatment (T2). Material machinability is more affected by cutting speed (S) relative to the other variables. The treated samples (T2) show a lamellar pearlite structure with amounts of spheroidite. In the case of samples with subcritical treatments (T3) a totally spheroidized structure is observed.
It is concluded that a combination of laminar pearlite and spheroidite has provided the best life conditions for the tool as a machinability criterion.
***Key Word**: Machinability; Flank wear; Tool life; globular cementite; medium carbon steels*

Date of Submission: 10-04-2021 Date of Acceptance: 26-04-2021

I. Introduction

The importance of medium carbon steels as engineering materials is reflected in the fact, that of the vast majority of ferrous alloys available and used on the market today, a large proportion of them belong to the family of medium carbon steels. These steels are more resistant to cutting, welding and forming compared to low carbon steels. Since the last two decades, various researchers have reported the use of various heat treatments to adapt the properties of medium carbon steels to industrial work. Spheroidization was found to be the new industrial heat treatment used to improve the formability and machinability of low alloy, medium, and high carbon steels [1].

In terms of microstructure, spheroidization treatment is performed on steels to obtain spheroidal carbide particles that are spread uniformly in a ferrite matrix [2, 3]. In technical terms, spheroidization is performed to improve the cold formability of steels and also to improve their machinability. With this treatment, a spheroidized microstructure is obtained that is desirable for cold forming, because it reduces the flow stress of the material, which is determined by the proportion and distribution of ferrite and carbides [4]. The typical spheroidization process is carried out below the Ae1 temperature together with isothermal holding at same temperature. The microstructure obtained with spheroidized or globular carbide particles in the ferrite matrix shows high ductility among the various microstructures of the steels. The high ductility and low hardness of the spheroidized microstructure play an important role in rolling, cold forming, and in the machinability of low and medium carbon steels [5].

The demand for high-quality mechanical components require great accuracy and shorter delivery times. For high-performance systems, this demand has increased considerably in recent years at worldwide. This fact has led to an increase in the efficiency of conventional cutting processes both ferrous and non-ferrous materials, taking into account the factors that improve their machinability [6]. Machinability is the ability or ease of materials to be machined by chip removal. Machinability depends on many factors, their mechanical, physical properties and so on. There are factors that improve the strength of materials, but often degrade their machinability. Therefore, they are faced with the challenge of improving machinability without compromising other properties. [7]. But, while we can identify many factors that affect machinability, up to now there is no unanimous consensus on how to quantify it, we only have machinability criteria. Instead, machinability is often evaluated on a case-by-case and tests are tailored to specific factory needs. The most common measures of quantifying machinability are: through tool life, surface finish, cutting temperature, and energy consumption [7], where the life of the tool is one of the most used criteria.

There are standards that define the tool life as a criterion of machinability. The life or duration of a tool is called to the total cutting time obtained until reaching a predetermined wear (according to ISO 3685, the most common value is to consider a height for the wear zone on flank surface of the tool. VB = 0.3mm). For this reason, the life of the tool is closely related to the wear of the tool one [8]. Wear becomes an indicator to quantify life. Therefore, the wear of the cutting tool becomes an important factor during the machining process. An excessive increase in tool wear is responsible for many alterations on the cutting characteristics, which can lead to a significant increase on system vibration level, increased machining force, damage to the surface finish, difficulty on dimensional control of parts produced, being important variables on the management of tools, as proposed by Boehs and González [9]. Moreover, any wear process on the cutting tool is related in the first instance to the cutting regime which the work material is subjected. Therefore, the ability to predict the useful life of the cutting tool is necessary for the design and the strategy of change of the same one, as well as for the determination of the cutting conditions. The problems that arise are the complexity of the machining process and the lack of appropriate data. The situation is aggravated by the continuous development and introduction of new materials for cutting tools, work materials and by changes in machining conditions; for example: the high speed cutting [10].

Although machinability of a metal is affected, in the first instance, by cutting regime; that is, due to the speed of cut, feed speed and cut depth; machinability is also an inherent property of the workpiece itself. In the case of steels, hardness and microstructure greatly affect the machinability of these materials. In carbon steels, a greater carbon content the higher amount of perlite be present. Perlite is a phase that has low ductility and high resistance; therefore, the greater the amount of pearlite present in the steel, the more difficult it becomes to machine it efficiently. For steels with carbon content greater than about 0.50%, a fully spheroidized structure would be preferable. Therefore, it is desirable to anneal these steels to alter their microstructure which would result in improved machining qualities. Hardened steels and tempered structures are generally not desired for machining [11].

In the literature [12, 13] has been pointed out that in medium carbon steels, the microstructure of coarse pearlite obtained through annealing or the cementite spheroidal that some steels have, would have optimal machinability properties. However, this information is insufficient; as it does not present any restrictive condition in relation to the heat treatments, or the production processes to which the received material has been subjected before being machined. For the same standardized material, any variation in the manufacturing procedures of the received material can change the correlation between the tested treatment (spheroidized) and machinability [14, 15]. On the other hand, there is a considerable effect of the inhomogeneous microscopic distribution of the phases present in the microstructure, especially from the point of view of the tool life on machinability; as well as the effect of the microstructure obtained through heat treatment on machinability [16]. In the specialized literature we observe that another machinability criterion is the material hardness. For example, in some cases it is pointed out that for a steel of 0.45% C, the hardness must be in the range: 180-200 HBN so that this material has an optimal machining [12, 17]. But, for the same material, different hardness values can be obtained through different heat treatments, as indicated in different research works. [18, 19] which indicates that machinability could not be correlated very strongly with hardness. In general, it has been pointed out that the reason for this discrepancy is the banding phenomenon, which means that the difference in the microstructure is found in the lamination direction and the transverse direction of the samples [16, 19, 20]. Ozcatalbas and Ercan [21] conducted studies on the effects of microstructure and mechanical properties on machinability SAE 1050 hot rolled steel, which was annealed and normalized before being machined. Machinability was characterized under the criteria of tool life measurement, chip root morphology, cutting forces, surface finish, and temperature of the cutting tool / chip interface. Optimum machinability, from the tool life view point, was determined for hot rolled steel, which had the minimum impact energy and minimum ductility.

As has already been expressed previously, spheroidized structures are those that provide greater machinability of steels, both medium and high carbon. Although, very varied research works have been addressed regarding the physical and metallurgical principles of spheroidization; still many aspects remain up to date unknown in detail regarding the mechanisms involved and their adequate control [22**].**

The objective of this study is to investigate the conditions of spheroidized heat treatment in such a way that a structure can be obtained that provides optimum machinability under the criterion of tool life for the cylindrical turning of medium carbon steels, taking as a sample two representative types of these Medium Carbon Steels: AISI 1040 and AISI 1050.

II. Material and Methods

2.1. Study materials.

The steels that were used as study material were: AISI / SAE 1040 and AISI / SAE1050. These materials are simple medium carbon steels that were acquired, upon request, from the rolling company Geordau, Chimbote-Peru. Table 1 shows the chemical composition ranges shown by both steels according to the manufacturers' specifications.

Table 1. Chemical composition of study materials

Steel	C%	Mn%	Si%	P%	S%	Al%	Fe%
SAE 1040	0.38-0.40	0.6-0.9	0.20-0.35	Max: 0.03	Max: 0.04	Max: 0.019	Bal.
SAE 1050	0.47-0.50	0.6-0.9	0.25-0.35	Max: 0.03	Max: 0.04	Max: 0.019	Bal.

2.2. Test Specimens.

The specimens will be made from raw bars (state of supply) of dimensions: 3.5 "(89 mm) in diameter and 24" inches (609.6 mm) in length; those that were cut and rolled to form bars close to the measurements of the test specimens whose final measurements are: 125 mm in length and 70 and 60 mm in diameter. For the purposes of the machining experiment, a total of 36 specimens were made: half for machining AISI 1040 steel and the remainder for testing AISI 1050 steel. To define the final dimensions of the specimens, it was taken into account that the length / diameter relationship has a value less than 10, to avoid vibrations that may occur during machining; which is in accordance with the ANSI / ASME standard. B94. 55M [23]. According to the list of tests and having considered (03) repetitions, a total of 36 specimens had to be used.

2.3. Cutting Parameters.

According to the recommendations of the SANDVICK-COROMANT company, expressed in its turning catalogs, two different cutting speeds were used: 67 m/min and 78 m/min; speeds that are within the range of standards used to machine medium carbon steels with spheroidized structures.

Machinability experiments were carried out on a MHASA parallel lathe with 24 rotational speeds. Since the rotational speeds are discrete, a fixed and constant rotational speed was selected in all the tests, and to obtain the two indicated cutting speeds, specimens with two different diameters were used, forming two groups of specimens for each cutting speed. Aplicando la ecuación de la velocidad de corte torneado cilíndrico:

$$S = \pi d n / 1000 \tag{1}$$

Where: S = cutting speed (m/min); n = rotation speed (rpm); d = diameter (mm)

The diameters had to be adjusted to be able to use the same rotation speed n = 355 rpm
The cutting parameters shown in tables 2 and 3.

Table 2. Cutting parameters used in machinability tests

Rotation speed(n) (rpm)	Feed (f) (mm/rev)	Cutting depth(d) (mm)	Workpiece diameter (mm)	Tool edge radius (mm)
355	0,1	1	70 y 60	0,4

Table 3. Cutting speeds (S) and diameters of the samples for a constant rotation speed of 355 rpm, used in the machining of both types of steels

Cutting speed (S) (m/min)	Workpiece diameter (mm)
78 m/min	70
67 m/min	60

According to the ASTM Handbook [24]. Steels can be spheroidized if they are heated and cooled to produce a globular carbide structure in a ferritic matrix, by the following methods:

- For prolonged holding at a temperature just below Ae1
- Heating and cooling alternately at temperatures that are just above AC1 and below Ar1
- Heating to a temperature above Ac1, and then giving a very slow cooling in the oven or holding it at a temperature just below Ar1.

- Cooling at a suitable rate from the minimum temperature at which all carbides dissolve.

Following these recommendations, the following treatment program has been proposed for both steels, as specified in Table 5 and outlined in Figure 1.

2.4. Cutting Tools: Specifications

For turning essays: SANDVIK tool holder code: SCLCR / L 2020K 12 was used, and the cutting tool was a high speed steel tool: HSS-M2 C66, acquired by BOHLERIT company, whose specifications of cutting geometry is shown in table 4.

The cutting geometry for this type of test is found in the standard: ISO 3685: 1993 (E), which typifies the geometric standards for the tests that have the purpose of determining the tool life. The specifications can be seen in table 4.

Table 4. Cutting angles for standard tool life tests, using cutting tool HSS-M2 C66 Source: [25]

Rake angle (γ)	**Clearance angle (α)**	**cutting inclination angle (λs)**	**Cutting edge angle (K_R)**
25°	8°	0°	75°

2.5. Spheroidized heat treatment.

The spheroidized treatment cycles are shown in table 5 and their schematic representation or heat treatment program can be seen in Figure 1

Table 5. Parameters used for each spheroidized heat treatment

item	**Spheroidized heat Treatment**
T_0	No heat treatment
T_1	900°/3hr- cooling in oven
T_2	750°C/3hr - 650°C/6hr – cooling in oven
T_3	700°C/24hr- cooling in oven

$\mathbf{T_0}$ treatment corresponds to the state of supply, used for comparison. The program of treatments carried out consists of the treatments $\mathbf{T_1}$, $\mathbf{T_2}$ and $\mathbf{T_3}$.

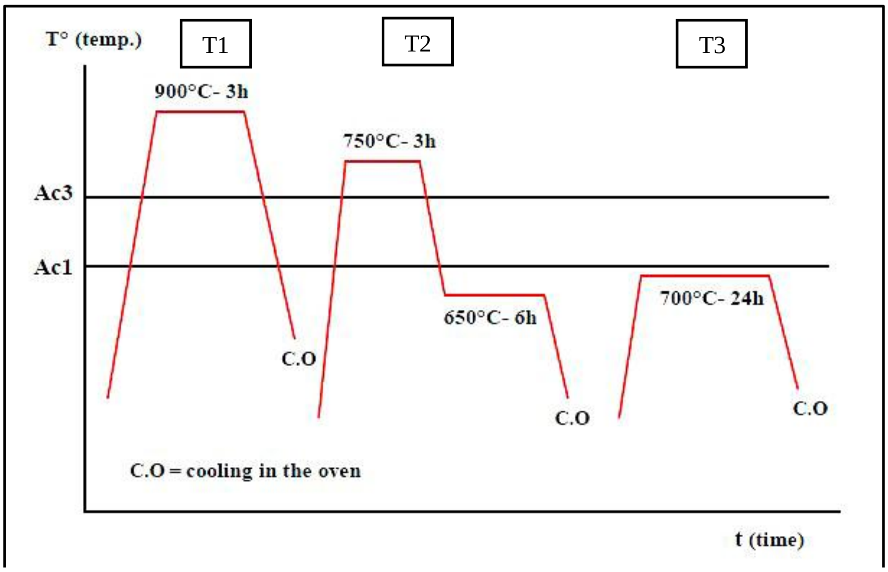


Figure 1. Spheroidizing heat treatment program carried out on the two types of steels used in the research

In Figure 1, it can be seen that the first treatment is a fully austenitized supercritical anneal. The second is made up of two stages; the first is supercritical and the second is subcritical. The third is a subcritical spheroidized treatment, slightly below the critical line Ae1, with long duration. All treatments ended with a cooling in the oven.

2.6. Hardness Tests.

Hardness is not a variable that has been taken into consideration, but its evaluation is very important to interpret the experiment results. Most mechanical properties are related in some way to hardness, just as its microstructure.

The tests were carried out on the ZAMTSU-TH722 universal Durometer, using a 100Kg preload and spherical indector. The readings were made on Brinell scale (HB), due to the smoothness of all spheroidized structures. The specimens for this test were prismatic samples of 12x12 mm in section x 20 mm in length. The hardness in the samples was measured for each spheroidizing treatment before any tests were carried out.

Before the hardness tests, the specimens had to be rectified on their faces, then polished with sandpaper: 400, 800 and alumina cloth, to obtain a good parallelism that guarantees the measurements.

2.7. Machinability Tests.

The tests were carried out using a parallel lathe MHASA of 4 Kw power, applying a cylindrical turning to all rod-shaped specimens.

In this study, the useful tool life as a function of its wear, has been taken as machinability criterion.

It is generally known, that there is no uniform criterion in the scientific community which indicates the exact way to measure the useful tool life as an index of machinability for variety of cutting processes. The useful life of the cutting tool, in most cases, has been defined as the machining time before it fails due to established wear.

Taking into account the results of the review of the scientific literature and being a finish turning operation with intermediate cutting speed, it was taken as a criterion of useful tool life: "The time that tool taken until the flank wear reaches a maximum of 300 μm" It is a very general standard criterion for machining steels [26].

2.8. Tool Wear Measurement.

Depending on the cutting conditions and wear rate, the machining had to stop the test every 2 and 4 minutes to record the wear of the tool. Tool wear standards are related to flank wear, which requires a sterographic microscope. incorporated into the equipment for this purpose

The methodology proposed for wear measurement, is justified by the studies carried out by the North American researcher I.S. Jawahir [27], where in the reference article he reaches the following conclusion: "In general, to estimate tool life, limit values are taken for flank wear or crater wear. However, in the most cases it is observed that the failure of the tool, is largely the result of a number of different types of progressive wear that occur simultaneously; in addition to the crater wear and flank wear, we have the wear of the nose, wear of the notch, and chipped edge "

2.9 Tool life Measurement.

The measurement of tool life was obtained from the wear curves, using a maximum wear criterion of 300 μm according the standard already mentioned**.** In figure 2, the explanatory graph of the way in which the tool life has been obtained from each of the wear curves elaborated is shown**.**

From the intersection point of the wear curve with the horizontal (which defines the life criterion) we lower a vertical, and the time indicated on horizontal axis provides the tool life for machining under certain cutting conditions which represents each curves. In the scheme of figure 2 there are 3 curves with T1, T2 and T3 lives.

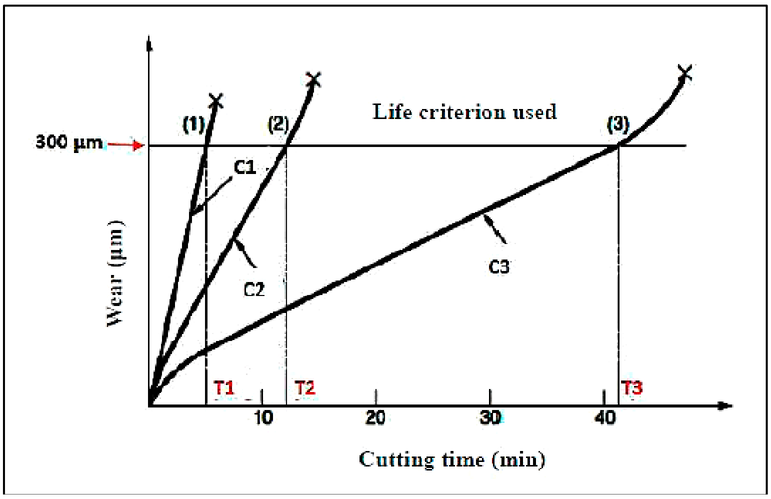


Figure 2. Illustrative graph, that explains, how the tool life has been obtained. Each curve represents a wear curve in machining under a preset condition.

2.10. Microscopy Tests.

The microstructure analysis was carried out at optical level, for which a high resolution Microscope, ZEISS - 1000X, was available. The specimens were small samples taken from the specimens before and after being spheroidized. In order to reveal the microstructure of the samples, the specimens were encapsulated with polyester resin using metal molds. Then we proceeded to roughing, polishing and chemical attack of the polished surfaces. The specimens were roughened with sandpaper from grade 220 to 1000, with plenty of water. then they were polished on a corduroy cloth with alumina from grade 5 µ, 3 µ, 1 µ, to 0.3 µ and water, for 30 sec. It was first attacked with 3% Nital reagent for 60 seconds, and then it was polished again on a cloth in order to eliminate the deformed layer due to roughing. Then the microstructure was observed and the respective photomicrographs were taken.

III. Results

3.1. Hardness Results.

The results for each treatment type are shown in Table 6, and the comparative graphs in Figure 3**.**

Table 6. Hardness results for the two carbon steel samples, according to the type of spheroidized treatment to which they were subjected.

Treatment		AISI 1040				AISI 1050			
Item	Spheroidized treatment	Hardness measurements (HB)			Hardness average (HB)	Hardness measurements (HB)			Hardness average (HB)
		HB_1	HB_2	HB_3		HB_1	HB_2	HB_3	
T_0	No heat treatment	179	180	178	**179**	200	195	194	**196**
T_1	900°/3hr- cooling in oven	150	145	140	**145**	170	164	164	**166**
T_2	750°C/3hr-650°C/6hr – cooling in oven	155	158	155	**156**	177	172	170	**173**
T_3	700°C/24hr- cooling in oven	127	124	124	**125**	144	141	136	**140**

SAE 1040: Hardness maximum = 179 HB Treatment: T0 Hardness minimum = 125 HB Treatment: T3	**SAE 1050**: Hardness maximum = 196 HB Treatment: T0 Hardness mínimum = 140 HB Treatment: T3

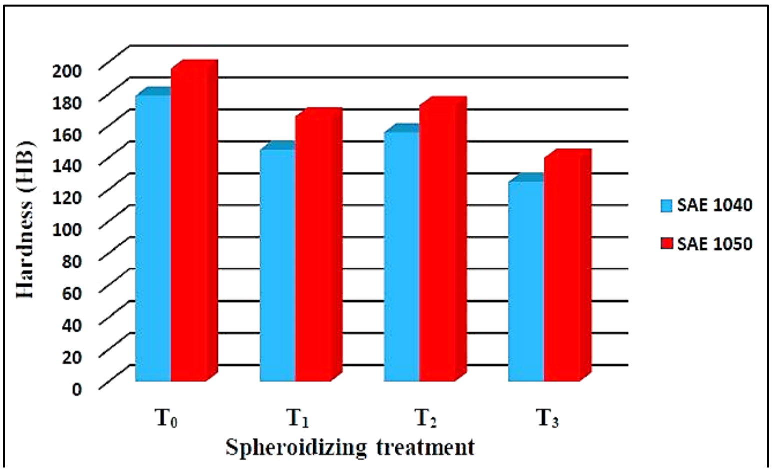


Figure 3. Comparative graph showing the variation in hardness of the two types of steel: SAE 1040 and SAE 1050 subjected to different types of spheroidized heat treatments.
T_0 = Delivery status

3.2. Wear Results.

Table 7. Tool flank wear results on SAE 1040 steel samples subjected to different spheroidizing heat treatments and different cutting speeds.

SAE 1040 Cutting speed = 67m/min					**SAE 1040 Cutting speed = 78m/min**				
Cutting time (min)	**Flank wear (mm)**				**Cutting time (min)**	**Flank wear (mm)**			
	T_0	**T_1**	**T_2**	**T_3**		**T_0**	**T_1**	**T_2**	**T_3**
4	0,111	0,085	0,067	0,091	2	0,195	0,152	0,149	0,161
8	0,151	0,128	0,101	0,122	4	0,223	0,181	0,174	0,189
12	0,167	0,149	0,118	0,140	6	0,239	0,194	0,189	0,201
16	0,181	0,164	0,129	0,157	8	0,254	0,205	0,201	0,213
20	0,193	0,178	0,137	0,169	10	0,308	0,218	0,214	0,225
24	0,212	0,191	0,150	0,183	12		0,232	0,227	0,241
28	0,258	0,207	0,162	0,198	14		0,244	0,239	0,259
32	0,309	0,220	0,184	0,211	16		0,275	0,251	0,308
36		0,242	0,196	0,245	18		0,309	0,263	
40		0,284	0,215	0,293	20			0,305	
44		0,335	0,255	0,318	22				
48			0,305		24				

Table 8. Tool flank wear results on SAE 1050 steel samples subjected to different spheroidizing heat treatments and different cutting speeds.

SAE 1050 Cutting speed = 67m/min					**SAE 1050 Cutting speed = 78 m/min**				
Cutting time (min)	**Flank wear (mm)**				**Cutting time (min)**	**Flank wear (mm)**			
	T_0	**T_1**	**T_2**	**T_3**		**T_0**	**T_1**	**T_2**	**T_3**
4	0,175	0,147	0,137	0,148	2	0,234	0,182	0,173	0,177
8	0,209	0,182	0,175	0,177	4	0,254	0,215	0,204	0,209
12	0,222	0,197	0,191	0,195	6	0,293	0,231	0,219	0,226
16	0,243	0,203	0,204	0,202	8	0,324	0,245	0,233	0,241
20	0,296	0,225	0,218	0,221	10		0,263	0,246	0,255
24	0,326	0,244	0,235	0,242	12		0,304	0,261	0,272

28		0,286	0,249	0,259	14			0,309	0,319
32		0,331	0,278	0,281	16				
36			0,309	0,326	18				

3.2.1. Wear charts

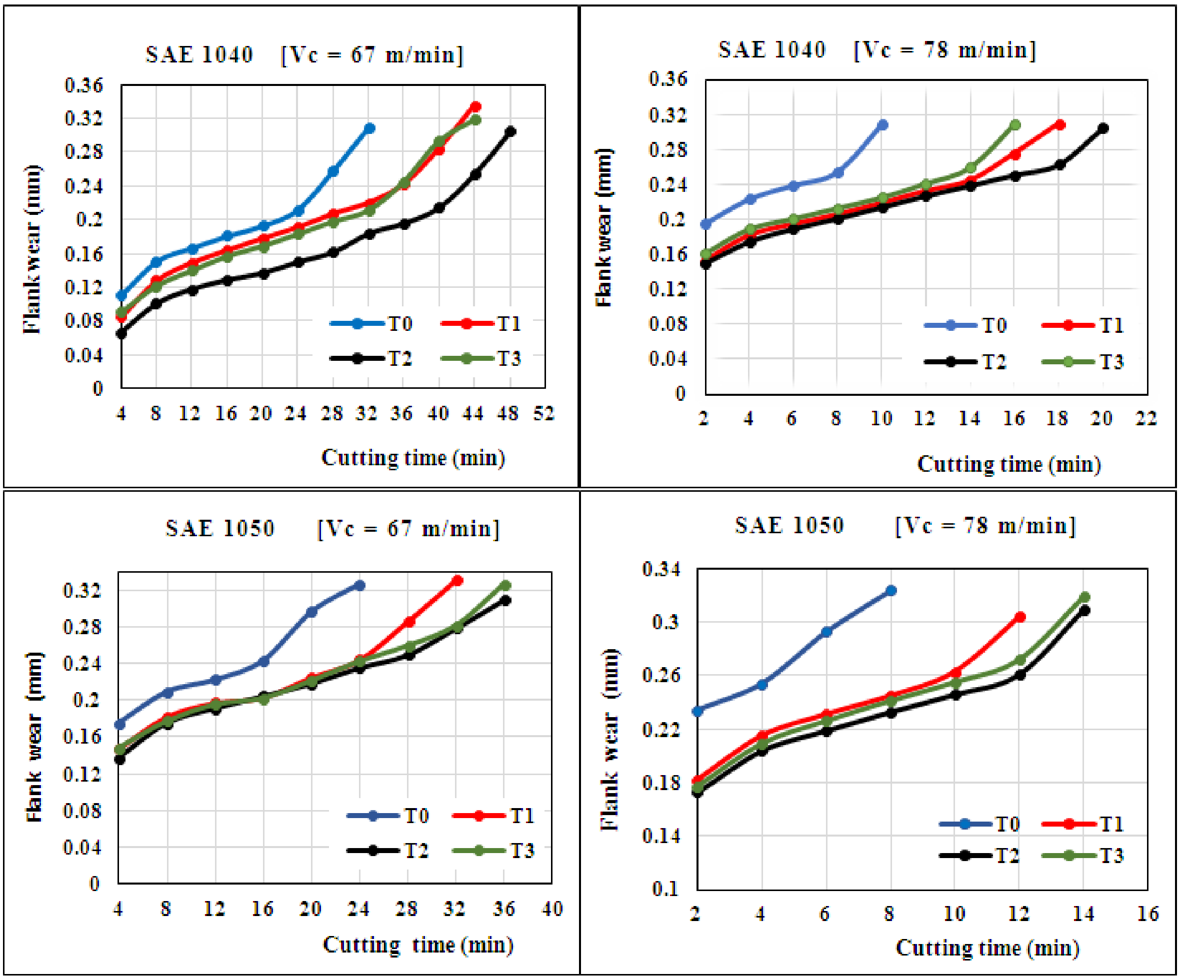


Figure 4. Wear measurement graphs on the flank wear of the HSS cutting tool, when turning SAE 1040 and SAE 1050 steel bars, under spheroidized treatments using cutting speeds: 67m/min, and 78 m/min.

To determine the cutting time for the machining of each specimen, it has been considered that this will be defined, when the flank wear measurement (F.W) slightly exceeds the allowed limit value: F.W. = 300 µm. Tables 7 and 8 have been drawn up with this consideration in mind. Many empty boxes will be seen in these tables, since no more time is needed to reach the limit value of the permitted wear. This can also be observed in all the graphs in Figure 4. In this way, it was easier to determine the tool life as shown in Figure 5 and whose concrete results are shown in Table 9.

It was also necessary to relate the results of Machinability of the cutting process (expressed in tool life) with the other parameters that have intervened in the present study, which resulted in the elaboration of the graphs shown in Figures 6, 7 and 8.

As can be seen: All the parameters taken into account influence on tool life and how will it be observed later, the microstructure of the cutting material plays a very important role, since the material has to have a high degree of ductility to be efficiently machined. This high degree of ductility is provided by the type of heat treatment applied, which has already been determined.

3.3. Tool life Results

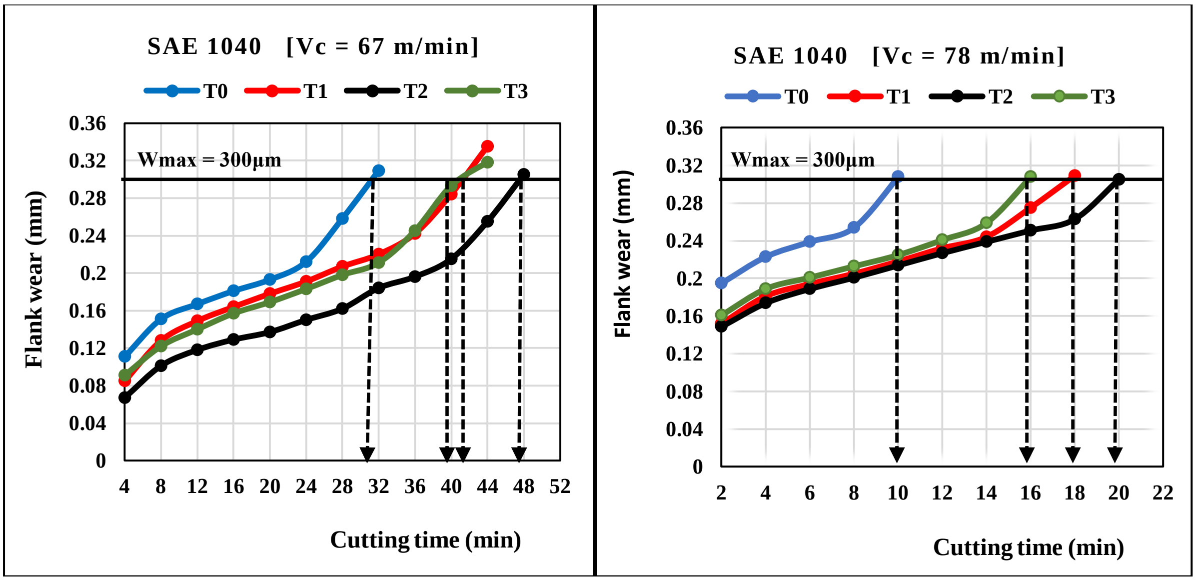


Figure 5. Graphs that indicate the procedure followed to determine tool life of the HSS cutting tool, for turning spheroidized SAE 1040 steel using cutting speeds: 67 and 78 m / min. (S=Vc)

Table 9. Machinability index, taking as a criterion the tool life, defined as the maximum allowable flank wear of 300µm. Samples of SAE 1040 and SAE 1050, subjected to spheroidized treatment were used.

TOOL LIFE FOR TURNING CUTTING (T)								
S = 67 m/min								
Material	**SAE 1040**				**SAE 1050**			
Treatment	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Tool life ”T” (min)	31,5	41,5	47,8	40,8	20,7	29,6	35,2	34,00
S = 78 m/min								
Material	**SAE 1040**				**SAE 1050**			
Treatment	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Tool life “T” (min)	9,8	17,8	20,0	15,8	6,6	12,0	13,8	13,2

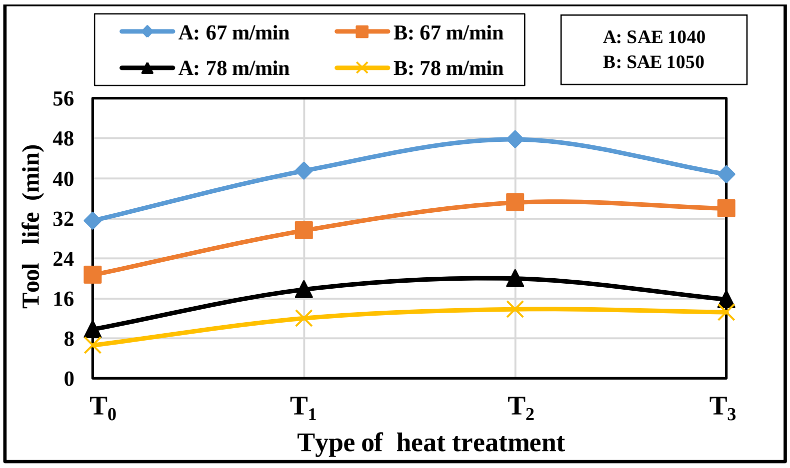


Figure 6. Graphs that indicate variation of tool life with respect the types of spheroidized heat treatment.

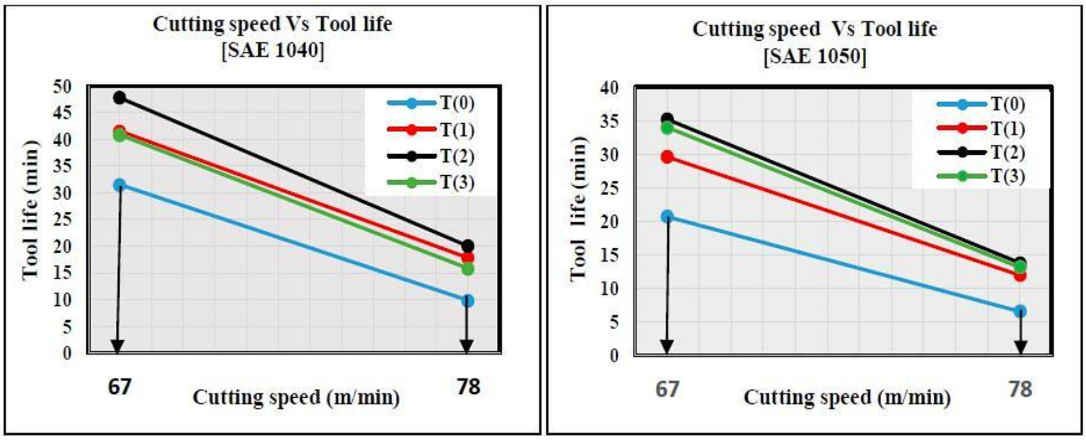


Figure 7. Tool life trend curves as a function of cutting speed for turning SAE 1040 and SAE 1050 steel bars.

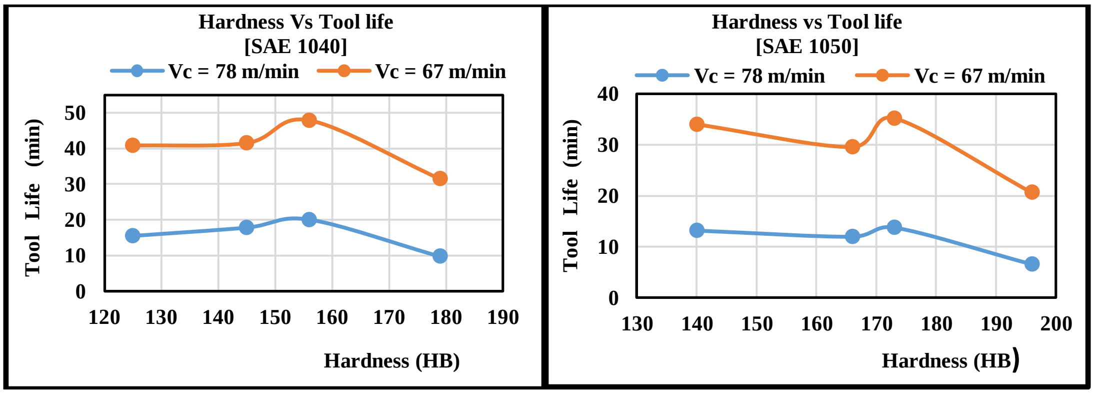
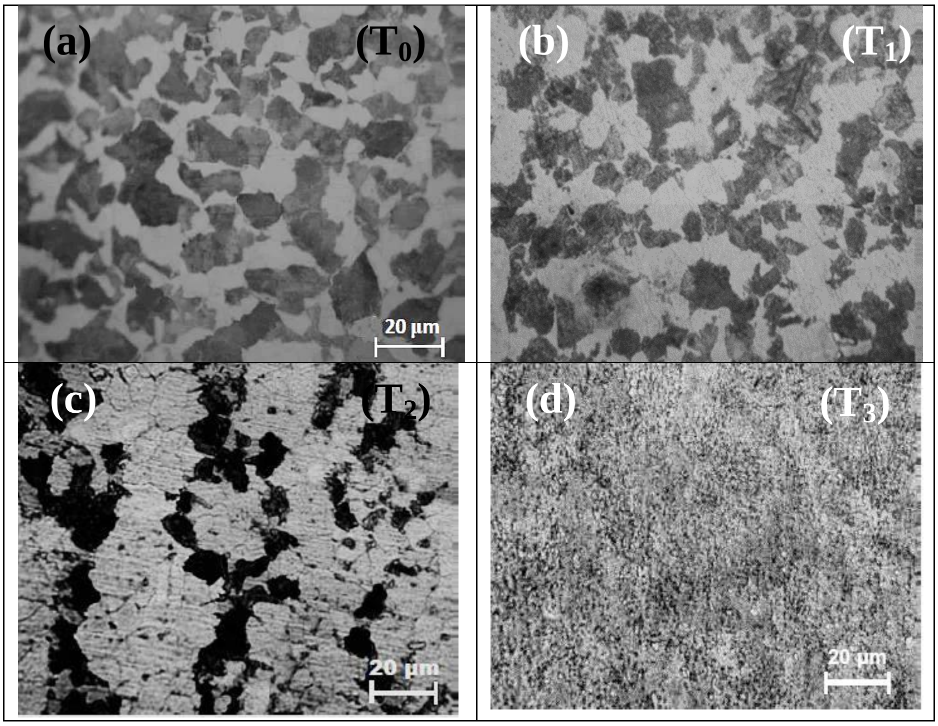


Figure 8. Tool life trend curves as a function of the hardness of the steels: SAE1040 / 1050, and cutting speeds used in machining

3.4. Microstructure



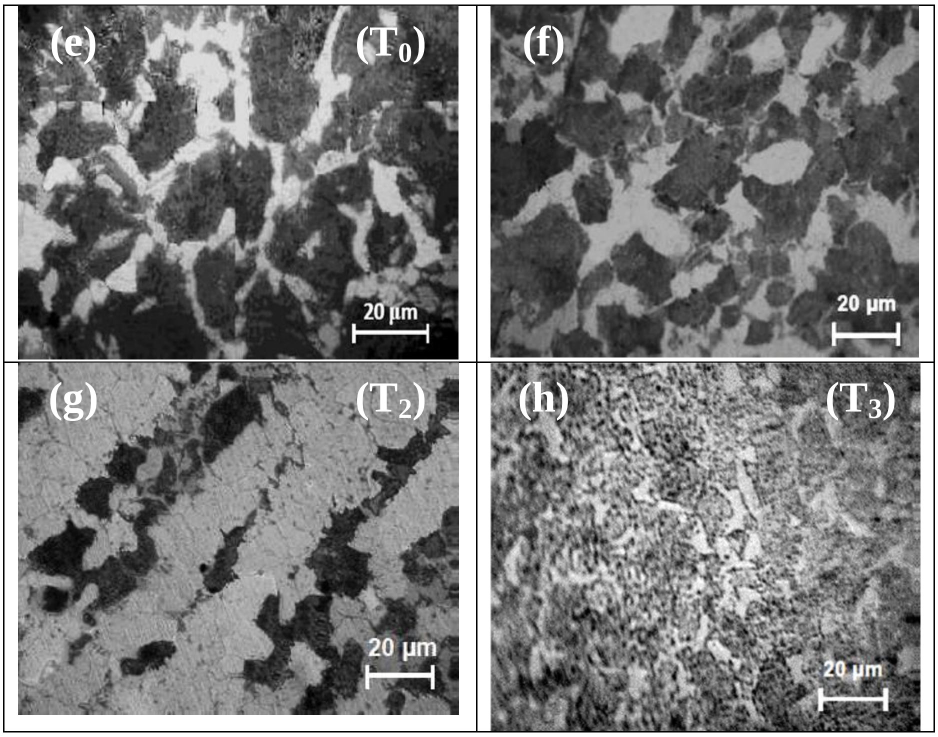


Figure 9. Microstructures at optical level of samples the two types of steels, subjected to different spheroidized conditions; (a), (b), (c), (d): SAE 1040; (e), (f), (g), (h): SAE 1050.

IV. Discussion

For both types of steel: In the state of supply (T0) the specimens show the maximum values of hardness and all the spheroidized heat treatments reduce it. In this state, SAE 1050 steel shows higher hardness than SAE 1040 steel, as expected, due to its higher carbon content. In the various types of spheroidization, the same happens, varying their hardness ranges according to the type of treatment.

Hardness values of spheroidized group (T2 = 750 ° C / 3hr-650 ° C / 6hr - oven cooling), are very close to the group (T1 = 900 ° / 3hr- cooling in the oven) and are greater than the group (T3 = 700 ° C / 24hr- oven cooling). For the spheroidized treatments, the hardness values of group T2 are very close to group T3 in an interval Δ = 7-8 HB. In any case, the hardness of the spheroidized samples has the following relationship: T2> T1> T3.

In strict sense, Treatment T1 is a globular anneal and treatments T2 and T3 are spheroidization anneals with temperatures very close to the critical temperature Ae1. The T2 treatment was carried out slightly below Ae1 and the T3 treatment slightly above Ae1; that is, in the intercritical zone. This fact justifies the relationship of T2 and T3. Furthermore, given that the longest immersion time in the furnace corresponds to group T3, it was expected that the highest volumes of cementite diffusion would have occurred as the structure became spheroidite, which explains the lower hardness value of the group. T3, with T1 in the center. These results can be justified with the microstructure. In Figure. 9 (d) and 9 (h), it can be observed, for both types of steels, the clearly spheroidized structure that is formed with the T3 treatments.

The tool wear results when turning SAE 1040 steel are found in table 7, and its trend graphs can be seen in Figure 4. For SAE 1050 steel, it is found in table 8, and its trend graphs We observe it in the same Figure 4. For all types of samples, the least wear occurs in the samples in the supply state (T0) and for the spheroidized samples they decrease. It is also observed, for all cases, the higher the cutting speed, the wear increases. Additionally, SAE 1050 steel samples cause greater wear than SAE 1040 samples due to hardening for carbon content. For the SAE 1040 steel samples, for both speeds (67 m / min and 78 m / min) it is observed that the least wear is produced by the samples without treatment (T2). Likewise, for a speed of 78 m / min until minute 12, the spheroidized samples T1, T2 and T3 have almost the same wear value. Instead; for a speed of 67 m / min, samples T1 and T3 show very close values throughout in all time range; the other two curves are separated. For SAE 1050 samples, for both speeds the least wear is provided by the treated (T2) specimens. For a speed of 67 m / min, machining the spheroidized samples T1, T2 and T3, for 24 min; these have almost the same wear value. For a speed of 78 m / min, the values are almost constant up to the first 8 minutes. In all cases, it is the T2 samples that show the least wear. If we compare the results of wear with those of hardness, we can infer from the graphs, that the spheroidized treatment has to soften the material to achieve less wear on the tool; that is: In all cases, it is the T2 samples show the least wear. If we compare the results of wear with those of hardness, we can infer from the graphs, that the spheroidized treatment has to soften the material to achieve less wear on the tool; that is: "Hardness is inversely related to wear", as expected. But it should be noted that machining with a soft structure does not always ensure good machinability.

The general results for the tool life are derived from the graphs in Figure 5. Their values are found in table 9 and their comparative graphs are found in the figures 6, 7 and 8 derived from these tables. The results in table 9 indicate:

For SAE 1040 steel:
Maximum Tool Life = 40.8 min, for S = 67 m /min and treatment (T2)
Minimum Tool Life = 9.8 min, for S = 78 m /min and no treatment (T0)

For SAE 1050 steel:
Maximum Tool life = 34 min, for S = 67 m/min and treatment (T2)
Minimum Tool life = 6,6 min, for S = 78 m/min and no treatment (T0)

In Figure 6 it is observed that tool life increases as decreasing cutting speed and also with the type of steel, providing more tool life with the one have lower carbon content (SAE 1040). Heat treatment also influences, having found that treatment (T2) is the one that provides the longest tool life in all cases; thus demonstrating the effectiveness of the spheroidized treatment on the steels machinability. On the other hand, observing the graphs carefully, we can add the following observations: 1) If we parameterize the other factors, the life decreases as the cutting speed increase 2) The spheroidized treatment directly influences the tool life, being the T2 treatment the most suitable for this case; 3) The life of the tool does not necessarily increase with the decrease or increase of hardness. There is no definite relationship between tool life and hardness, as if there is between hardness and spheroidized treatment; making itself felt the effect of other machining factors.

Medium carbon steels, when turned with HSS tools, have more machinability when the carbon content of workpieces is lower, and are further increased if a two-stage spheroid treatment is applied, with temperatures very close to critical points.

From all the analysis carried out in the tables and curves, regarding wear and tool life values, we can affirm: The cutting speed is the parameter that most influences on the tool life, and therefore the machinability of the material under this criterion it is shown that the cutting speed has a significant effect on the tool life of medium carbon steels.

Regarding the microstructure, the following is observed: For the case of the specimens without heat treatment (T0), a ferritic-pearlitic structure is observed in the two steels, where there is a greater amount of pearlite for the SAE 1050 steel samples than for the samples made of SAE 1040 steel. This result was to be expected due to the higher carbon content of hypoeutectoid steels. Having made an approximate calculation with a dot grid in each photomicrograph there is ~ 50% ferrite content and 50% pearlite for SAE 1040 steel and ~ 40% ferrite and 60% pearlite for SAE 1050 steel. In the case of the samples with globular annealing (T1) for the two steels, it can be observed that the grains are larger than for the samples without treatment (T0). This treatment has led to an increase in grain size in both cases. For the samples with treatment (T2) in the two steels a laminar perlite structure can be observed. In SAE 1050 steel it can be seen more clearly. Small amounts of spheroidites are also observed, which has allowed for greater machinability. For the samples with treatment (T3) for the two steels a totally spheroidized structure can be observed. Due to the higher carbon content the spheroidites of SAE 1050 steel are larger than those corresponding to SAE 1040 steel. If we observe the T2 and T3 structures for both types of steels; In Figure 8, it is shown that the T2 treatment has not reached a complete spheroidization, showing a ferrite matrix with spheroidized cementite embryos, while in the T3 treatment the cementite of the pearlite laminar has been totally spheroidized, despite the fact that both treatments have been made close to the critical points Ac3 and Ac1. This can be explained due the spheroidization rate is directly influenced by the diffusion of carbon in the ferrite and gradually decreases as the mean size of the spheroidized particles increases [28]. Knowing by Fick's laws, that the diffusion coefficients depend on temperature and time. This last parameter is the one that has most influenced the formation of spheroidite in treatment T3 considering a much longer time and at a temperature higher and closer to the critical Ae1 than for treatment T2.

Finally, it has been found that the totally spheroidized structure for these steels is achieved with subcritical treatments very close to the Ac1 point and with a high residence time. In this case, it corresponds to the treatment (T3) in both types of steels.

V. Conclusion

After study about spheroidized treatment and its effects on the machinability of medium carbon steels SAE 1040 and SAE 1050, the following conclusions can be drawn:

1. For both steels, the maximum hardness values are obtained with specimens without heat treatment (T0) and the minimum values with the treatment (T3 =700ºC/24 h), which corresponds to a totally spheroidized structure.

2. Tool life to HSS tool, in cylindrical turning is lower in the supply state (T0) and increases reaching an optimum value in both materials, when a spheroidal anneal is applied in two stages using temperatures very close to the critical points: Ae1 and Ar1 (T2 treatment).
3. Maximum tool life of the cutting tool was: T = 40.8 min for SAE 1040 steel, machined at 67 m / min, with T2 treatment and minimum tool life was: T = 6.6 min, for 1050 steel, machined at 78 m / min, without treatment (T0).
4. For both steels, the minimum hardness corresponds to the treatment (T3) whose structure is totally spheroidized. However, the longest life is found with the treatment (T2) whose structure is partially spheroidized; therefore, softer structures do not always produce a longer life of the cutting tool. The other factors that act in the cutting process alter the machinability.
5. An inverse relationship between hardness-wear has been found; but in all cases spheroidizing reduces hardness and increases the tool life. The explanatory mechanism depends on the treatments parameters.
6.Apart from spheroidizing, the parameter that most influences the tool life is the cutting speed; that is, the machinability of the material is more affected by the cutting speed for the same treatment.
7. In this study it has been found that the samples annealed with T2 treatment (laminar pearlite structure with amounts of spheroidite) is the one that has produced the best machinability; in comparison to the samples with T3 treatments (totally spheroidized structure); although their values are very close; which shows that there are multiple factors that affect the machinability of a cutting process.

References

[1]. Harisha S. R., Sathyashankara Sharma1, U. Achutha Kini1 and Gowri Shankar M. C., Study on Spheroidization and Related Heat Treatments of Medium Carbon Alloy Steels. MATEC Web of Conferences 144, 02008 (2018).
[2]. Bhadeshia H:K:D:H: Prog. Mater. Sci. 57(2012) 268–435.
[3]. Krauss G. Steels-Processing, Structure, and Performance, ASM International, Materials Park, OH, 2005, pp. 251-262.
[4]. Heat Treating, ASM International Handbook, 1991, p: 119.
[5]. Lee Y-W., Son Y., Lee S.-J., Microstructure and mechanical properties of spheroidized D6AC steel, Materials Science & Engineering A 585 (2013) 94–99
[6]. Martínez, F., Sánchez, T., *et al*. "Comportamiento del acabado superficial de la pieza y el desgaste de la herramienta al fresar aluminio con altas velocidades de corte en fresadoras CNC convencionales". *Ingeniería Mecánica*. 2006, vol. 9, no 2, p. 7-12.
[7]. Bakerjian, R.; Cubberly, W. H. (1989). *Tool and manufacturing engineers handbook*. Dearborn, Mich: Society of Manufacturing Engineers. pp. 15–3, 15–10, 19–13 to 19–18. ISBN 0-87263-351-9.
[8]. Abate G., Maceira G., Perez G., Martínez G., Rendimiento de insertos de metal duro no recubiertos, en operaciones de torneado y la influencia de la calidad del inserto, SAM /CONAMET, 13er Congreso Internacional en ciencia y tecnología de Metalurgia y Materiales, 2013.
[9]. Boehs L., González I., Uma proposta para um Modelo de Gerenciamento de Ferramentas, Anais do XIII Congresso Brasileiro e II Congreso Ibero Americano de Engenharia Mecanica, Belo Horizonte, 1995.
[10]. Grzesik, W. Advanced Machining Processes of Metallic Materials: Theory, Modelling and Applications. 1° ed. Poland: Elsevier Science, p. 213-226. ISBN 978-0-08-044534-2.
[11]. Papadakis, E.P., "Physical Acoustics and Microstructure of Iron Alloys", International Metals Reviews, Vol.29, No.1, 1984, pp1-23.
[12]. Lane J.D., Stam J.W., General Inroductor Review of the Relationship Between Metallurgy and Machinability, Iron and Steel Inst. (Prod. Confer.) Machinability, 1967, pp. 65–70.
[13]. Tonshoff H.K. Material Aspects in Machining of Forged Parts, High Productivity Machining (Prod. Conf.), 1985, pp. 207–221.
[14]. Araki T., Fukunaga H., Sata T., Some Results of Cooperative Research on the Effect of Heat Treated Structure on the Machinability of a Low Alloy Steel, Influence of Metallurgy on Machinability of Materials (Prod. Conf.), ASM, 1975, p. 381.
[15]. Sadık M.I., Lindstrom B., The role of tool–chip contact length in metal cutting, J. Mater. Process. Technol. 37 (1993) 613–627.
[16]. Dutta J.N., Patki G.S., Influence of banded structure on machinability with reference to case hardening steels, in: Proceedings of the International Conference on Influence of Metallurgy on the Machinability of Engineering Materials, ASM, 1983, p. 413.
[17]. Tonshoff H.K., Machinability of forged steels in interrupted cutting, J. Mater. Process. Technol. 21 (1990) 219–236.
[18]. Vasillko K., Novak S., Sadecky L., Results of research in to the effect isothermal annealing on the machinability of steels, Hutn. Listy. 35 (1980) 14.
[19]. Araki T.,Yamamato S., An Evaluation of Machinability of Low Alloy Steel Material With or Without Heat Treatment, Machinability Testin.
[20]. Okusa K., Kitagawa R., Akasawa T., Method of Testing Steel Machinability by Face—Milling End of Cylindrical Workpiece, Machinability Testing And Utilization of Machining Data (Prod. Conf), ASM, 1979, pp. 36–50, 422.
[21]. Ozcatalbas,Y., Ercan,F., "The effects of heat treatment on the machinability of mild steels", Journal of Material Processing Technology, 2003, vol.136, pp.227- 238
[22]. Zhi-qing LÜ, Hui-fang ZHANG, Qing MENG, ZhenGhua WANG, Wan- tang FU, Effect of Cyclic Annealing on Microstructure and Mechanical Properties of Medium Carbon Steel, Journal of Iron and Steel Research, International. 2016, 23(2): 145-150
[23]. ANSI/ASME. Tool-life testing with single-point turning tools. ANSI/ASME B94.55M. New York, USA: The American Society of Mechanical Engineers, 1985
[24]. ASTM Handbook Heat Treatment Vol 3
[25]. ISO 3685:1993 Standard for Tool Life Testing with Single-Point Turning Tools
[26]. Astakhov V.P .and Davim J.P., Tools (Geometry and Material) and Tool Wear, 2008, XIV, 361p. 222illus. Hardcover.
[27]. Jawahir I.S., Designing for Machining: Machinability and Machining Performance Considerations, in Metrological Design HB, USA, 2004.
[28]. Cree A.M., Faulkner R.G., Lyne A.T., Mater. Sci.Technol,. 11 (1995) 566–571.