Congresso Brasileiro de Engenharia e Ciência dos Materiais
06 a 10 de Novembro de 2022 | Águas de Lindóia – SP – Brasil

ANALYSIS OF METALLURGICAL CONDITIONS FAVORABLE TO MACHINABILITY OF AN A413.0 ALLOY SERIES: CUTTING TEMPERATURE CRITERIA

Fernando S. da Rocha[1*], Suanny Q. Mesquita[1], André C. C. Maciel[1], Tamires I. Botelho[1], Thiago A. P. S. Costa[2], Otávio F. L. da Rocha[2], Maria A. P. S. Silva[1], Antonio L. Seabra[1]

1 - Departamento de Engenharia de Mecânica, Universidade Federal do Pará (UFPA), Avenida Augusto Corrêa, Belém, CEP 66075-970, PA. Nandosrocha12@hotmail.com
2 - Departamento de Engenharia de Materia, Instituto Federal de Educação, Ciência e Tecnologia do Pará (IFPA), Belém, PA.

ABSTRACT

Al-Si alloys are widely used in the industry for manufacturing components that are exposed to critical wear conditions, as they provide better mechanical properties and greater resistance to corrosion and propagation of defects. Machining is one of the most used manufacturing processes in the industry. However, Al-Si alloys are very difficult to machine, especially the ones with over 12.0wt% of solute content. This motivates extremely relevant research that can predict microstructural conditions and solidification parameters that ease the machinability of these materials. Thus, an experimental study was carried out with the eutectic Al-12.6wt.% Si alloy, solidified in a water-cooled vertical directional device to establish correlations between the obtained microstructure and the average cutting temperature by analyzing the heating rate during necking processes on a bench lathe. From the experimental results, a power-type function was obtained which relates the heating rate as a function of the dendrite arm spacing from the base to the top of the ingot, showing a reduction in the average heating rate as one moves away from the metal/mold interface.

Keywords: *Heating rate; Microstructure; Eutectic Al-Si alloy; Necking process.*

INTRODUCTION

The Al-Si system is the most important non-ferrous alloy system because of the attractive combination of some mechanical and manufacturing properties that represent a determining factor for its wide use. For Si contents between 5% and 12.6%, for example, these alloys have good mechanical and corrosion resistance, easy abrasion, and good weldability[(1-4)]. For processing materials through solidification, the gross structure obtained defines the final properties of the product[(1)]. The microstructure, in 12.6% Si, for example, when solidified outside the equilibrium conditions, can reveal multiphase structures, such as Halo-type dendrites (α-Al), massive Si crystals, and the eutectic mixture (α + Si), and this mixture is responsible for the properties of this alloy. Thus, the control of the parameters involved in solidification kinetics is crucial for the industry since the understanding of the mechanisms that control the liquid/solid phase change provides better efficiency and operational performance to the process as the improvement of the desired properties and, therefore, products got[4-6]. On the other hand, most castings, at some point in the manufacturing chain, go through the machining process. Understanding the facility or difficulty in machining a material, defined as machinability, is therefore fundamental to the manufacture of final products[7]. Machinability comprises a comparative analysis, which can be a set of machining properties of a material concerning another taken as standard[8]. Cutting temperature, surface finish, chip control, and cutting force can be considered parameters of machinability[9-11]. Cutting temperature is an important parameter that directly affects tool life, surface quality, and dimensional accuracy[12]. In dry machining processes, very high temperatures are encountered due to the large thermal load generated by friction and increased adhesion of the workpiece to the tool, thus causing greater wear[13-15]. This process in aluminum alloys is very difficult because of the great tendency that these alloys have of adhering to the cutting tools[17]. However, there are many advantages of dry machining such as lower cost, healthier environment, better worker safety, no need for storage, and others[16], but the main advantage is the absence of thermal shocks, which compromise the tool life promoted by temperature gradients induced by the use of cutting fluids[14]. Therefore, to efficiently control the dry machining process, it is essential to analyze the machinability of the material to be used, through the Cutting Temperature criterion. This, therefore, has interrelation with various factors, including the thermal and microstructural parameters[17], such as displacement velocity of the liquidus isotherm, VL and cooling rate, TR and the microstructure, such as dendritic, for example[3,7,18,19]. However, there is a lack of research on the interrelationships of solidification thermal parameters, dendritic spacing, mechanical properties, and machinability of the Al-Si system. In this sense, this work performed an experimental study with a eutectic Al-12.6%Si alloy, directionally solidified through a water-cooled device, to establish correlations between microstructure and cutting temperature (analyzing the heating rate) during necking processes on a bench lathe.

MATERIALS AND METHODS

The investigated alloy was solidified in a vertical upward solidification device. This device promotes only one direction of heat extraction due to the drive of the cooling system located at the base of the ingot, thus providing solidification in the opposite direction of the gravity vector. More details on the preparation method of the studied alloy and the directional solidification device can be found in recently published papers[19,20]. After complete solidification, the resulting ingot was demolded and prepared for metallographic analysis to measure the secondary dendritic spacings (λ_2), according to the technique developed by McCartney and Hunt[21], and to perform the process on a bench lathe. The part of the ingot used for the necking tests had a prismatic geometry, with a cross-sectional area of 144 mm^2. There was no change to a circular section to avoid possible changes in the alloy's structure. Thus, six neckings were performed along and across the length of the ingot, as shown in Figure 1. As a cutting tool, conventional HSS T6 ¾" fast steel chisels coupled to chisel support were used, and the cutting temperature measurement was performed with an infrared pyrometer, coupled to a computer with a data acquisition system. The cutting parameters adopted were: feed of 0.1 mm/rev, the average cutting speed of 35.28 m/min, variable cutting depth, according to the part section, and rotation of 710 rpm. The collected cutting temperatures allowed the calculation of the heating rate, through the derivative of the cutting temperature as a function of time ($\dot{T}$ = dT/dt), but as in the initial and final instants of the process the contacts are irregular, these are disregarded and the derivative is performed only in the linear region of the graph [20] as shown in Figure 1.

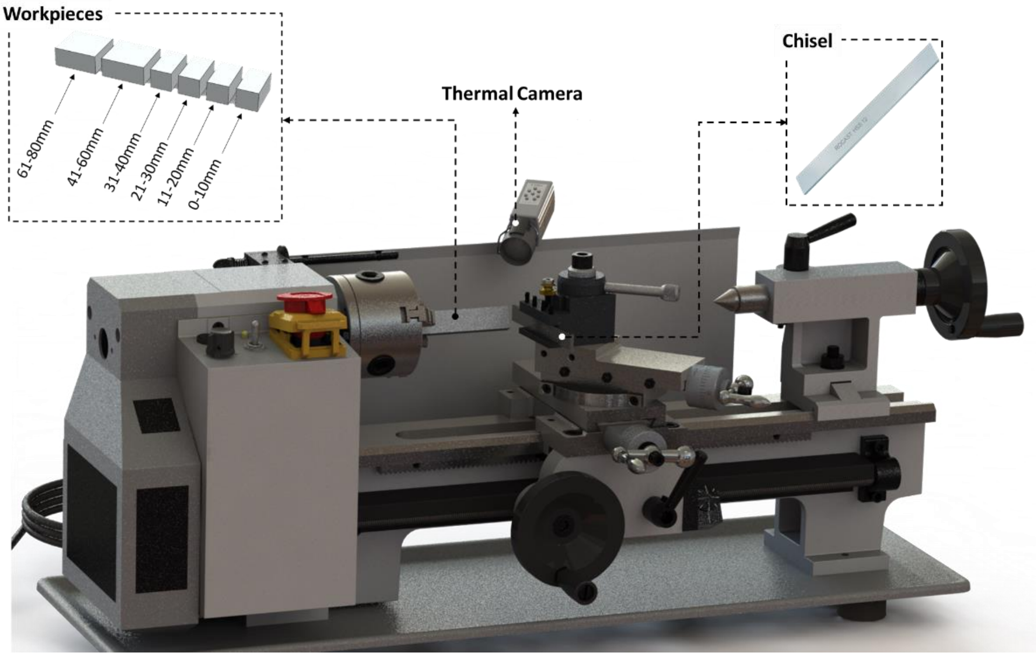

Figure 1. Schematic of the bench lathe showing the necking positions, the thermal chamber, and the high-speed steel chisels.

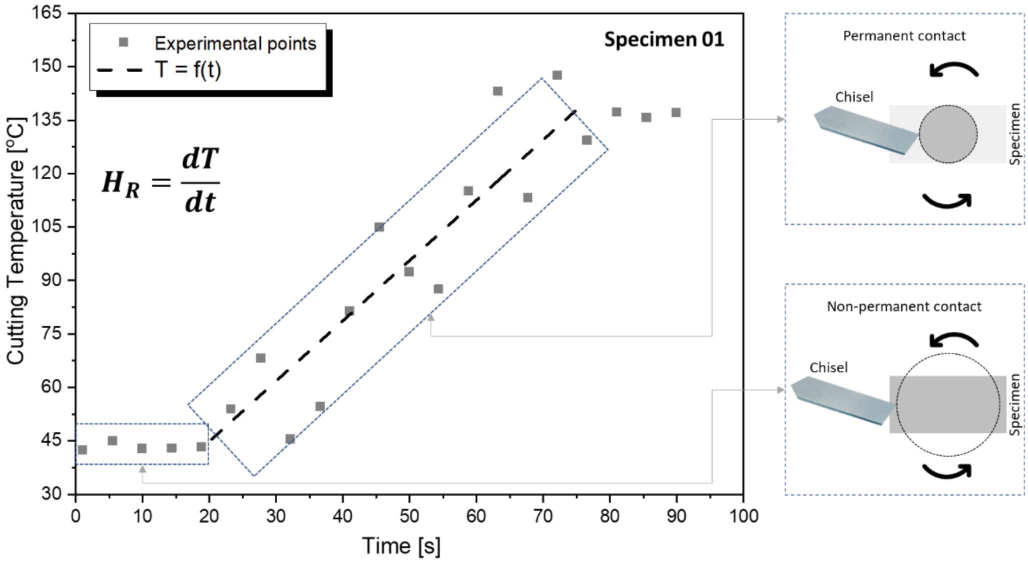

Figure 2. The technique used to calculate the heating rate.

RESULTS AND DISCUSSION

Figure 3 shows the evolution of λ_2 versus position in the solidified ingot, thus confirming the thickening or increase of the secondary dendritic arms for positions further away from the base of the ingot. Figure 4 shows the behavior of the heating rate as a function of position from the metal/mold interface and the secondary dendritic spacing. It can be seen that the multiphase behavior of the alloy directly influences the heat generated during the machining process. The influence of the pro-eutectic phases (Al-α and massive Si crystals) on the cutting temperature behavior was observed, for positions above 10 mm (where halo dendrites and dense primary Si particles coexist), there was a significant reduction of the heating rate from 0.40 °C/s to 0.26

°C/s. In contrast, after 10 mm, with the emergence of this phase and with 2 ranging between 8 and 15.5 µm, there was a significant increase in the rate values from 0.26 °C/s to 0.47 °C/s, which decreases again with the presence of a pro-eutectic soft phase.

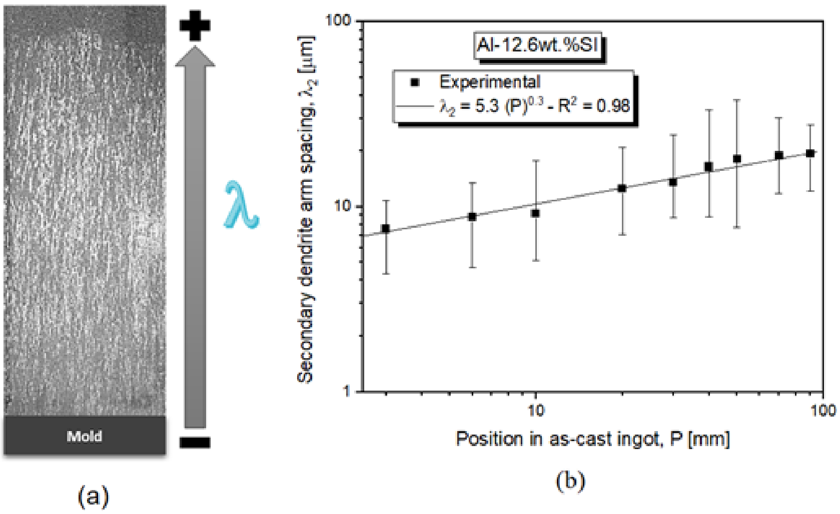

Figure 3. Variation of secondary dendritic arms with position on the ingot: (a) typical solidification macrostructure and (b) $\lambda_2 = f(P)$.

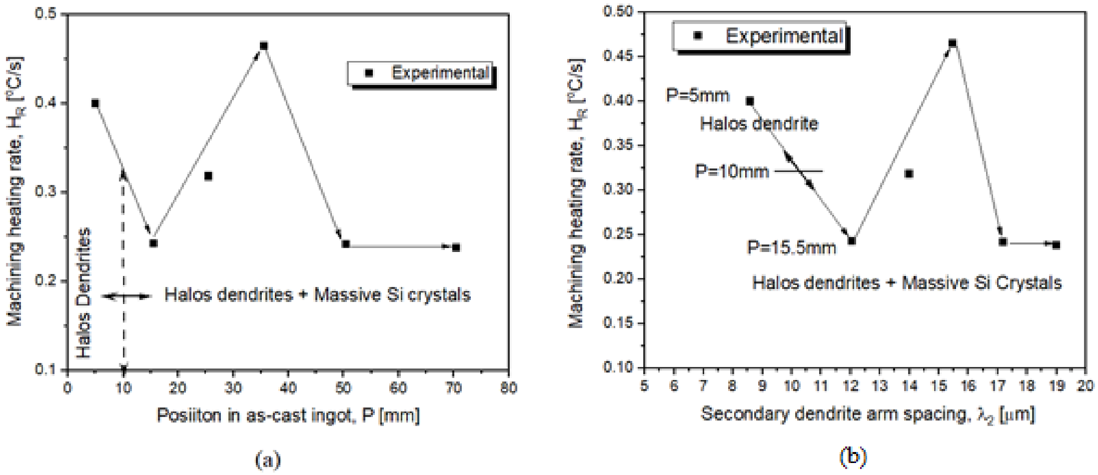

Figure 5. (a) Heating rate in the machining process as a function of position and (b) secondary dendritic spacing.

CONCLUSIONS

The experimental results obtained showed that the Al-12.6wt.% Si alloy, even difficult to machine, still presents relevant aspects of machinability, since the heating rate value varied significantly with both dendritic spacing and phase transition. Rather complex behavior of the machining heat that can be generated in these eutectic alloys was observed, with refined halo dendrites dominating the heat generated in the process until the emergence of the other phases, which vary with the increase or decrease in size or distribution of these phases in the interdendritic regions.

ACKNOWLEDGMENTS

The authors are thankful for the structure and financial support provided by IFPA, UFPA, CAPES, and CNPq for the development of this work.

REFERENCES

1. PERES, M.D. Desenvolvimento da macroestrutura e microestrutura na solidificação unidirecional transitória de ligas Al-Si. 2005. Dissertação (Mestrado em Engenharia Mecânica) - Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, Campinas - São Paulo.
2. MAGNO, I. A. Efeito do tratamento térmico T6 na microestrutura e microdureza de uma liga de alumínio 319.1 solidificada horizontalmente. 2018. Dissertação (Mestrado) - Programa de Pós-graduação em Engenharia Mecânica (PPGEM), Instituto de Tecnologia, Universidade Federal do Pará, Belém – Pará.
3. ULUDAĞ, M.; YAZMAN, Ş.; GEMI, L.; BAKIRCIOĞLU, B.; ERZI, E.; DISPINAR, D. Relationship Between Machinability, Microstructure, and Mechanical Properties of Al-7Si Alloy. J. Test. Eval., v. 46, n. 6, p. 2592–2603, 2018.
4. SPINELLI, J.E.; FERREIRA, I.L.; GARCIA, A. Evaluation of heat transfer coefficients during upward and downward transient directional solidification of Al-Si alloys. Struct. Multidiscipl. Optim., v. 31, n. 3, p. 241–248, 2006.
5. RODRIGUES, J.A.F.; SANTOS JÚNIOR, G.E.; BARROS, A.S.; ROCHA, O.F.L.; MOREIRA, A.S. Liga hipoeutética Al-11%Si: coeficiente de transferência de calor interfacial, variáveis térmicas, parâmetros microestruturais e microdureza. Rev. Mater., v.26, n.4, 2021.
6. ROCHA, O.F.L.; SIQUEIRA, C.A.; GARCIA, A. Cellular Spacings in Unsteady-State Directionally Solidified Sn-Pb Alloys. Mater. Sci. Eng A., v. 361, p. 112-119, 2003.
7. BARZANI, M.M.; NOORDIN, M.Y.; FARAHANY, S.; OURDJINI, A. Effect of machining parameters on cutting force when turning untreated and Sb-treated Al-11%Si-1.8%Cu alloys using PVD coated tools. Trans. Tech., v.234, p.74-77, 2012.
8. FERRARESI, D. Fundamentos da Usinagem dos Metais. São Paulo: Edgard Blucher, 1970.
9. UPADHYAYA, G.S.; TRENT E.M.; WRIGHT P.K. Metal cutting. Boston: Butterworth-Heinemann, 2000.
10. SILVA, S. L.; SILVA DIAS FILHO, J. M.; SANTOS, C. F. dos; COSTA, T. A. P.; ROCHA, O. F. L.; SILVA, M. A. P. de S. Usinabilidade de uma liga Al-6%Cu Solidificada em um Dispositivo Direcional Horizontal, pelo Critério de Temperatura de Corte. Braz. J. Dev., v. 7, n. 6, p. 60959–60971, 2021.
11. DANISH M.; GINTA T.L.; HABIB K.; RANI A.M.A.; SAHA B.B. Effect of cryogenic cooling on the heat transfer during turning of AZ31C magnesium alloy. Heat. Transfer. Eng., v.40, p.1023–1032, 2019.
12. YANG, Y.; CHUANG, M.; LIN, S. Optimization of dry machining parameters for high purity graphite in end milling process via design of experiments methods. J. Mater., n. 209, p. 4395-4400, 2009.
13. CHE HARON, C.H.; GINTING, A.; ARSHAD, H. Performance of alloyed uncoated and CVD-coated carbide tools in dry milling of titanium alloy Ti-6242S. J. Mater., n. 185, p. 77-82, 2007
14. LÓPEZ de LACALLE, L.N.; ANGULO, C.; LAMIKIZ, A.; SÁNCHEZ, J.A. Experimental and numerical investigation of the effect of spray cutting fluids in high speed milling. J. Mater, n. 172, p. 11-15, 2006.
15. NARUTAKI, N.; UAMANE, Y.; TASHIMA, S.; KUROKI, H. New advanced ceramic for dry machining. CIRP Ann. Manuf. Technol., v. 46, n. 1, p. 43-46, 1997.
16. ZEILMANN, R. P.; VACARO, T.; BORDIN, F. M.; SONDA, V. Processos de usinagem e responsabilidade ambiental através da redução da utilização de fluidos de corte. 17 SIMPÓSIO INTERNACIONAL DE ENGENHARIA AUTOMOTIVA, São Paulo, SP, 2009.
17. REYES, R.V.; KAKITANI, R.; COSTA, T.A.; SPINELLI, J.E.; CHEUNG, N.; GARCIA, A. Cooling thermal parameters, microstructural spacing and mechanical properties in a directionally solidified hypereutectic Al-Si alloy, Philos. Mag. Lett., v.96, p. 1-10, 2016.

18. ROCHA, F.S.; COSTA, T.G.; OLIVEIRA, A.G.; COSTA, T.A.; FERREIRA, I.L.; ROCHA, O.L. Transient heat flow parameters, and microstructure of the upward solidified eutectic Al-Si alloy: a theoretical and experimental study. Philos. Mag., v.100, n. 21, p. 2659-2676, 2020.
19. COSTA, T.A.; DIAS, M.; SILVA, C.; FREITAS, E.; SILVA, A.; CHEUNG, N.; GARCIA, A. Measurement and interrelation of length scale of dendritic microstructures, tensile properties, and machinability of Al-9 wt% Si-(1 wt% Bi) alloys. Int. J. Adv. Manuf. Technol., v.105, n.1, p. 1391-1410, 2019.
20. MCCARTNEY, D. G.; HUNT, J. D. Measurements of cell and primary dendrite arm spacings in directionally solidified aluminum alloys. Acta. Metallurgica., v. 29, n. 11, p. 1851–1863,1981.