IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Effect of Machining On Stainless Steel: A Review

To cite this article: R R Elewa *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1107** 012084

Effect of Machining On Stainless Steel: A Review

R R Elewa[1]*, A O Araoyinbo[1], O S I Fayomi[1,] A U Samuel[1], M B Biodun[1] and N E Udoye[1]

[1]Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria
E-mail address: remilekunelijah@gmail.com Tel.: +2348037944686

Abstract. Machining takes place when a part of undesirable material ranging from metals, polymer, and wood to ceramic or even composite is removed from a part to give a better shape and design. The parts that are machined are called workpiece and undesirable materials are called the chips. The machining process is in three forms which are the conventional (traditional) process, abrasive process and non-traditional processes. This review paper focused on the various forms of machining in stainless steel, based on the machine able family. Stainless found the way into various applications resulting in their wide usage which include equipment in the industries, equipment's in beverage and food, automotive trim and cookware. This paper aims at opening more light on the importance of stainless steel during machining operations.

Keywords: Chips, corrosion, machining, stainless steel, tools.

1. Introduction

Machining takes place when a part of undesirable material ranging from metals, polymer, and wood to ceramic or even composite is removed from a part to give a better shape and design. The parts that are machined are called workpiece and undesirable materials are called the chips. The machining process is in three forms which are the conventional (traditional) process, abrasive process and nontraditional processes [1]. During the process of machining ablation and evaporation mostly takes place leading to the wearing out of the work piece [2].

Machining operations take place using the conventional (traditional) processes, this operation comprises of milling, drilling, boring, turning and much more. In the contemporary industry, abrasive processes are very important cutting processes, such as grinding, lapping and polishing [3]. Other forms of cutting processes involve the use of chemical energy to remove material from workpiece thereby avoiding physical contact between the workpiece and the tools, this form of processes are called nontraditional machining operation and they consist of machining f electro discharge or, machining for electrochemical, water machining for water jet, ultrasonic machining and laser machining [4].

Machining is utilized in the treatment of various modern areas; it is the treatment of workpieces into perfect surface finish characterized by roughness, texture, residual stresses and microstructure using dimensional measurement [5] Performance and yield of a metal in an assembling industry relies greatly on the metal cutting processes which can only be achieved through perfect machining process [6]. These processes have been used over the years and improvements are taking place from time to time, metals like aluminium, carbon steel, stainless steel and much more, has been worked on and stainless steels are preferred than other metals due to their characteristics[7].

IOP Conf. Series: Materials Science and Engineering 1107 (2021) 012084 doi:10.1088/1757-899X/1107/1/012084

Stainless steel is more preferred because it rewards both producer and client with benefits like Heat and Corrosion Resistance, Durability, Appearance, Strength, Fabrication Flexibility, Low Maintenance [8]. Examples of iron-based composites are Stainless steels which consist of 10.5 per cent chromium or more. some Extra alloying components will also be included for the duration of liquefying, the example of some metals are used to improve some properties and also qualities, these metals are columbium, nickel, titanium and molybdenum, [9]. Stainless steels serve as significant application ranging from machinery and equipment for tough industrial environments to brightly polished consumer products to machine [10]. According to metallurgical structure, there are several types of stainless steel, of stainless steel are categories into five (5) parts; they are austenitic, ferritic, martensitic, precipitation and duplex. Which has nowadays offers genuine forms of material goods ranging from an extensive choice of types preferably right for machining or extra fabrication processes to particularly formulated alloys capable of being developed in the most challenging surroundings [11]. Stainless steels can be machined utilizing properties fit for meeting a wide scope of assembling and end-user necessities which are, cold shaped, forged, expelled, or welded by contemporary manufacturing instruments and procedures [12]. Stainless steel is selected based on their Mechanical Properties, Total Cost, corrosion or Heat Resistance, Fabrication Operations, Availability.

2. **Corrosion Resistance**

The impact of chromium as an element of the alloy has contributed to the corrosion resistance quality of stainless steel. Thin, transparent chromium oxides are formed when it is combined with oxygen to protect the metal surface [13]. To improve chromium oxide film molybdenum, nickel and chromium and some important alloying elements must be improved so that it can be protective and stable in a mild aqueous environment and the normal atmosphere [14]. Resistance penetration of chloride can be achieved by adding molybdenum and chromium thereby improve the film stability, and in a strong acid environments nickel improves film resistance. With the help of oxygen in the environment, the protective film will reform itself in the case of disturbance or destruction and still continue to give maximum protection [15].

2.1 High-Temperature Corrosion Resistance

In elevated-temperature service stainless steel has been widely used, concerning their resistance to corrosion some changes do occur in chromium oxide film protection. For instance, a protective oxide film is formed when an oxidizing gas is slightly increased in temperature. The film will be in the form of sulfide serving as protection in in an environment containing sulfur-bearing gases. Depending on the alloy content in an environment, In more aggressive environments the sudden increase in scaling may occur due to surface film breakdown under a temperature above 1600ºF, At a point of limit where the film can no longer heal itself, the film breaks down and loses it protective strength due to high temperature and corrosion [16].

2.2 **Thermal Stability**

Evaluation of changes in metallurgical structure was carried out by because of the period in use and rate of temperature on any type of steel or alloy can be expected. Precipitations of carbide embrittlement or softening are examples of changes that take place. Softening occurs at the point where the exposure of martensitic stainless steel to temperature is approaching or exceeding the original hardening temperature. In other not to lose the high hardness of Type 440C the temperature is held at 900ºF for a short period [17].

2.3 Embrittlement
Changes in metallurgical structure of any steel and alloy can occur due to the effect of time and temperature; these changes can be softening, embrittlement or carbide precipitation. When martensitic steel is exposed to the temperature approaching or exceeding the original hardening temperature then softening will occur [18]. To retain the high hardness of Type 440C the temperature has to be held at 900ºF for a little time [14]. At elevated temperature, austenitic stainless steel which is cold worked can be softened. Delicate equipment needs to be handled with care during maintenance so as not to be affected by embrittlement which is caused by loss of toughness at room temperature. High-temperature properties, thermal stability, hot strength and Physical properties are very important during the analysis of stainless steel [19].

2.4 Advantages of Stainless Steel in a Corrosive Environment
There are various types of corrosive environments and they are characterized by the rate of temperature, chemicals and their concentration, flow rate, time and atmospheric conditions [20]. To avoid using the wrong tool for the right process of machining the relationship between the stainless steel and it environment will be considered. However, the most readily, available and Types 304, 430, or 410 are the most widely used stainless steels [21].Type 304 can be applied in different applications, in the food processing environment it is a strong resistance in architectural construction it withstands rust, it can withstand various types of inorganic materials, it opposes dyestuffs and organic chemicals. However, at high chloride, high acid and high-temperature condition, the protective rate will be reduced [22].

At moderate temperature and concentrations, Type 304 withstands sulfuric acid and nitric acid, equipment such as liquefied gases, consumer product, wastewater treatment transportation, equipment used in the kitchen and many more are low-temperature equipment and it is used to store them [23]. In an environment that tends to cause pitting Type 316 is better than Type 304 in such corrosion resistance, due to the presence of more nickel and 2-3 per cent of molybdenum. Type 304 has been used widely in process industries because it develops high resistance against sulfuric acid [24].

Type 317 prevent pitting and it is better than Type 316 due to the presence of molybdenum having 3-4 per cent and much more chromium, also Type 430 is used in nitric acid and also for polishing trim applications in the mild atmosphere because it has lower alloy contents [25]. Type 410 is used for the combination of corrosion resistance of highly stressed parts such as fasteners due to its very low alloy content for general purpose stainless steel. It also prevents corrosion in mild chemical environments, mild atmosphere and steam environments [18].

3. The Machinable Family of Stainless Steels
The misconception on machinability by Machine shop operators are diverse, however surface finish, cutting speed, and tool life are the important one to the other in metal machinability [22]. The Machinability of stainless steels is unique and is different from other metals, and carbon or alloy steels. Stainless steel poses a significant challenge for micro-manufacturing technologies, for the reason that it is hard to machine, however it is being used progressively to make micro-components. In other to improve the machinability of stainless steel the composition most be altered and the addition of nonmetallic in other increase the nature of the structure of austenitic

stainless steel. Material such as selenium, tellurium, lead and sulfur is introduced into the metals due to the difficulty in machining. This addition gives rise to form free machining elements [26].

3.1 Free-machining Stainless Steels

Machining characteristics of stainless steels can be achieved through alloying elements such as selenium, copper, sulphur, lead, phosphorus or aluminium during melting point can be adjusted or added [10]. To reduce the possibility of chips to weld the tool, by introducing alloy elements the friction between the tool and the workpiece can be reduced. Also when sulphur is added to the workpiece it reduces transverse ductility and the friction force of the chips causing do to break off more easily. Machinable & Stainless, (Improvement has been made in the machinability of stainless steels thereby introducing the free machining stainless steel of types 303, 303 Se, 430F, 416, and 420F.

3.2 The Machinability of often Utilized Stainless Steels and There Free-Machining

The adverse effects of the free machine are weldability, transverse ductility, corrosion resistance and more. The grades of Free-machining is mostly use based on the environment they are suitable for them to achieve a higher productivity rate if the right grade tool is used for the right machining processes[25]. Type 303 and 303Se of free machine stainless steel was evaluated by Zhu, Chen, Xu, Gu and Zhao 2016 [26], they discovered the one which has higher cutting speeds and is well suited for screw machining operations resulting in longer tool life and higher productivity, in comparison to Type 304 (austenitic-l8Cr-8Ni). Scratching are prevented in the moving parts of Type 303 because of their no galling properties thereby making disassembly of past easily. They are much applicable in valves fitting valve bodies, shafting, valve trim, etc. while Type 303 Se are applicable in hot and cold working operations with better formability and corrosion resistance compared with type303 however they are similar in applications [2].

3.2.1 Machining Characteristics

Investigation on Types 303 and 303 Se stainless plates of steel was carried out by Sullivan and Cotterell 2002 [27] and discovered the speeds to be used should be between 102-130 surface feet per minute in turning operations, due to cold working the machinability of the machine increases resulting in satisfactorily performed polishing and grinding operations which produces brittle chips and are easily machined. The machinability rating of Types 303 and 303 Se is an average of 75 per cent when compared to Type 416. type 303 and type 304 was compared by irapattarasilp and Kuptanawin 2012 [28] and discovered the best possible machining rate should be considered first, knowing fully well that type 304 has corrosion resistance and strength but lacks speed and accuracy which makes Type 303 a modifier of Type 304 with chromium, nickel, and sulphur contents and 25-30 per cent faster than Type 304.

Type 303Se, is the variation of free machine Type 304, the sulphur content is replaced with selenium when cold working is to occur, Type 303 Se is better than 303 in machined surface finish, the cold working involves swinging, severe thread rolling and staking. The 400 series stainless sheets of steel were examined by [29], there are also free-machining alternatives to consider. During machining Type 430F is preferred to type 430 because type 430F is adjusted to enhance the machining characteristics by preserving the workpiece for a long time. Free machining variation of Type 420 is Type 420F and that of Type 410 is Type 416.

3.2.2 Machinability of 303, 303se and Its Disadvantages

The principle support for utilizing austenitic hardened steel in the business is because of their consumption obstruction. The wide modern utilization of austenitic tempered steels is defended by their erosion opposition. These materials are non-attractive, which makes them valuable in clinical, pharmaceutical and nourishment handling zones. 303 and 303Se speak to 65-70% of the tempered steel grades. Tempered steel SS303 is an assessment of material by and large used in the creation of prohibitive enhancements for the equipment and the vehicle business; these materials are typically powerless to the surface harm, stage changes during assembling, and high work solidifying in spite of the advantages in regards to erosion opposition [30].

In the present high volume creation condition, Users have frequently announced machining troubles with this material Optimum setting of machining parameters, for example, cutting velocities and feed rates and Problems, for example, poor surface completion and high apparatus wear are regular this material because of work solidifying of the material during machining operations.it likewise has the issue of a component of developed edge arrangement during cutting which causes cement wear of apparatuses. These issues have been ascribed to the work solidifying of the material during the machining operation, because of martensite arrangement, work solidifying of hardened steels happens, because of temperature impacts (warm) and plastic distortion from working (mechanical) martensite may be shaped in austenitic steels.

Investigation of the scraped spot instruments in AISI 303 austenitic solidified steel models were evaluated by Jashari, S, Atapek, Polat, & Çelik, 2018 [30], strategies for scratch tests at the scaled downscale and Examination has relied upon the obvious coefficient of crushing and surface depiction: from 5 to 40 mN, littler scope wrinkling and wedge game plan occurred; and from 50 to 100 mN, small scale cutting was viewed. The numerical results asserted that the manganese sulphide has improved the cutting strategy. The strain-set surface extended the material quality, which occurred on less mass cleared during the scratch test. [31].

type 430F treated steel is proposed for snappier cutting and lessened costs when making machined parts from a 16.00/18.00 per cent straight-chromium stainless steel Type 430F doesn't solidify by heat treatment, It machines in turning tasks at paces of 124-155 surface feet for each moment, It is utilized for parts requiring great erosion obstruction like apparatuses, aeroplane parts just as solenoid valves anyway it isn't normally prescribed for vessels containing gases or fluids under high pressure [32]. Type 430F hardened steel is used to fight consumption from climate, freshwater, nitric corrosive, dairy things, etc. Parts must be liberated from scale and outside particles, as the last treatment, after the scale has been cleared or consequent to machining, all parts should be passivated.

Type 416 is the quickest machine capable of every stainless steel, and it is particularly suitable for good productivity on customized screw machining undertakings because of the more drawn out gadget life outcomes The usages for Type 416 are expansive and consolidate fittings, gears, lodgings, lead screws, shafts, valve bodies, valve stems, and valve trim. Believe it or not, this sort is ideal for parts requiring great machining work. Its low frictional properties limit troubling in an organization. Hung territories work straightforwardly without seizing, and destroying is particularly basic. Siphon shafts and valve stems work even more effectively in squeezing, and many metal-to-metal contacts withstand more weight because of their adversary of clutching qualities [33].

4. Conclusion

In this review, the characteristics of stainless steel as metal and its alloy was examined, their differences and their applications in various aspects of manufacturing sectors was also evaluated. The availability of stainless steel from different grade becomes essential due to the constant improvement in their alloys over corrosion resistance, machinability and welder ability, which makes stainless steel one of the most used metal, however stainless steel in its grade are applicable to different industrial purposes that means a particular grade cannot be use for multipurpose as compared to other metallic alloys.

Acknowledgements

The authors are grateful to Covenant University for its financial support.

References

[1] Benardos, P. G., & Vosniakos, G. C. (2003). Predicting surface roughness in machining a review International Journal of Machine Tools and Manufacture, 43(8) 833-844.
[2] O'Sullivan, D., & Cotterell, M. (2002). Machinability of austenitic stainless steel SS303. Journal of Materials Processing Technology, 124(1-2), 153-159.
[3] Won, C. H., Jang, J. H., Kim, S. D., Moon, J., Ha, H. Y., Kang, J. Y., ... & Kang, N. (2019). Effect of annealing on mechanical properties and microstructure evolution of borated stainless steels. Journal of Nuclear Materials, 515, 206-214.
[4] Krall, S., Reiter, M., & Bleicher, F. (2018). Influence of the machine hammer peening technology on the surface near material structure of stainless steel X_5CrNi18-10. Materials Today: Proceedings, 5(13), 26603-26608.
[5] Bissey-Breton, S., Vignal, V., Herbst, F., & Coudert, J. B. (2016). Influence of machining on the microstructure, mechanical properties and corrosion behaviour of a low carbon martensitic stainless steel. Procedia Cirp, 46(1), 331-335.
[6] Hoier, P., Malakizadi, A., Friebe, S., Klement, U., & Krajnik, P. (2019). Microstructural variations in 316L austenitic stainless steel and their influence on tool wear in machining. *Wear*, *428*, 315-327.
[7 Ravitej, S. V., Murthy, M., & Krishnappa, M. (2018). Review paper on optimization of process parameters in turning Custom 465® precipitation hardened stainless steel. Materials Today: Proceedings, 5(1), 2787-2794.
[8] Laleh, M., Hughes, A. E., Xu, W., Haghdadi, N., Wang, K., Cizek, P., & Tan, M. Y. (2019). On the unusual intergranular corrosion resistance of 316L stainless steel additively manufactured by selective laser melting. Corrosion Science, 161, 108189.
[9] Novovic, D., Dewes, R. C., Aspinwall, D. K., Voice, W., & Bowen, P. (2004). The effect of machined topography and integrity on fatigue life. International Journal of Machine Tools and Manufacture, 44(2-3), 125-134.
[10] Bagaber, S. A., & Yusoff, A. R. (2018). Sustainable Optimization of Dry Turning of Stainless Steel based on Energy Consumption and Machining Cost. Procedia CIRP, 77, 397-400.

[11] Sivaiah, P., & Chakradhar, D. (2019). Modeling and optimization of sustainable manufacturing process in machining of 17-4 PH stainless steel. Measurement, 134, 142-152.

[12] Jebaraj, A. V., Ajaykumar, L., Deepak, C. R., & Aditya, K. V. V. (2017). Weldability, machinability and surfacing of commercial duplex stainless steel AISI2205 for marine applications–A recent review. Journal of advanced research, 8(3), 183-199.

[13] Fomin, A., Fomina, M., Koshuro, V., & Rodionov, I. (2019). Composite metal oxide coatings on chromium-nickel stainless steel produced by induction heat treatment. Composite Structures, 229, 111451.

[14] Sanni, O., Popoola, A. P. I., & Fayomi, O. S. I. (2019). Electrochemical analysis of austenitic stainless steel (Type 904) corrosion using egg shell powder in sulphuric acid solution. *Energy Procedia*, *157*(August), 619–625. https://doi.org/10.1016/j.egypro.2018.11.22

[15] Samuel, K. G., Mannan, S. L., & Radhakrishnan, V. M. (1992). The influence of temperature and prior cold work on the strain-hardening parameters of a type 316 LN stainless steel. *International journal of pressure vessels and piping*, *52*(2), 151-157.

[16] Rasouli, D., Kermanpur, A., & Najafizadeh, A. (2019). Developing high-strength, ductile Ni-free Fe–Cr–Mn–C–N stainless steels by interstitial-alloying and thermomechanical processing. Journal of Materials Research and Technology, 8(3), 2846-2853.

[17] He, Q., Paiva, J. M., Kohlscheen, J., Beake, B. D., & Veldhuis, S. C. (2020). An integrative approach to coating/carbide substrate design of CVD and PVD coated cutting tools during the machining of austenitic stainless steel. Ceramics International, 46(4), 5149-5158.

[18] McGuire, M. F. (2008). McGuire, M. F. (2008). *Stainless steels for design engineers*. ASM International.Stainless steels for design engineering. Materials Park, Ohio.

[19] Dalmau, A., Richard, C., & Igual–Muñoz, A. (2018). Degradation mechanisms in martensitic stainless steels: Wear, corrosion and tribocorrosion appraisal. Tribology International, 121, 167-179.

[20] Ravitej, S. V., Murthy, M., & Krishnappa, M. (2018). Review paper on optimization of process parameters in turning Custom 465® precipitation hardened stainless steel. Materials Today: Proceedings, 5(1), 2787-2794.

[21] Loto, R. T., & Loto, C. A. (2017). Potentiodynamic Polarization Behavior and Pitting Corrosion Analysis of 2101 Duplex and 301 Austenitic Stainless Steel in Sulfuric Acid Concentrations. *Journal of Failure Analysis and Prevention*, *17*(4), 672–679. https://doi.org/10.1007/s11668-017-0291-6

[22] Geng, P., Qin, G., & Zhou, J. (2019). Numerical and experimental investigation on friction welding of austenite stainless steel and middle carbon steel. Journal of Manufacturing Processes, 47, 83-97.

[23] Wang, S., Hu, Y., Fang, K., Zhang, W., & Wang, X. (2017) Effect of surface machining on the corrosion behaviour of 316 austenitic stainless steel in simulated PWR

IOP Conf. Series: Materials Science and Engineering 1107 (2021) 012084 doi:10.1088/1757-899X/1107/1/012084

[24] Kaladhar, M., Subbaiah, K. V., & Rao, C. S. (2012). Machining of austenitic stainless steels–a review. International Journal of Machining and Machinability of Materials, 12(1-2), 178-192.
[25] Reddy, K. K. M., Reddy, K. S., Reddy, V. V., & Krishna, M. G. (2019). Comparison of Taguchi based Utility and Grey Relational Approaches to OptimizeBi-objective Machining of AISI 202 Austenitic Stainless Steel. Materials Today: Proceedings, 18, 310-319.
[26] Shen, C., Wang, C., Wei, X., Li, Y., van der Zwaag, S., & Xu, W. (2019). Physical metallurgy-guided machine learning and artificial intelligent design of ultrahigh-strength stainless steel. Acta Materialia, 179, 201-214.
[27] Zhu, Y., Chen, J., Xu, H., Gu, L., & Zhao, W. (2016). Research on the surface quality of the blasting erosion arc machined stainless steel. Procedia CIRP, 42(1), 252-256.
[28] Jirapattarasilp, K., & Kuptanawin, C. (2012). Effect of turning parameters on roundness and hardness of stainless steel: SUS 303. AASRI Procedia, 3, 160-165.
[29] Seriacopi, V., Fukumasu, N. K., Souza, R. M., & Machado, I. F. (2016). Analysis of abrasion mechanisms in the AISI 303 stainless steel: effect of deformed layer. Procedia CIRP, 45, 187-190.
[30] Jashari, N., Atapek, H., Polat, Ş., & Çelik, G. A. (2018). Ion plasma nitriding of ferritic steel AISI 430 f. Materials Science. Non-Equilibrium Phase Transformations., 4(4), 138-141.

[31] Alphonsa, J., Mukherjee, S., & Raja, V. S. (2018). Study of plasma nitriding and nitrocarburising of AISI 430F stainless steel for high hardness and corrosion resistance. Corrosion Engineering, Science and Technology, 53(sup1), 51-58.

[32] Dalmau, A., Richard, C., & Igual–Muñoz, A. (2018). Degradation mechanisms in martensitic stainless steels: Wear, corrosion and tribocorrosion appraisal. *Tribology International*, *121*, 167-179.

[33] Davis, J. R. (Ed.). (1994). Stainless steels. ASM international.