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Machining of stainless steels – a review

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Abstract: *Although stainless are characterized by high ductility, high durability and excellent corrosion resistance, they have certain disadvantages that act as constraints in certain applications. These steels are considered as the most difficult-to-cut materials as compared to the other alloy steels due to their high work hardening, low heat conductivity and high built up edge (BUE) formation. Some important concepts in the metallurgy of stainless steels are briefly introduced in the present paper, and some of the problems associated with the machining of stainless steels are also brought forward. Also a review is made of the various works of researchers in this context. Finally, this paper concludes with a discussion on future research areas.*
Keywords: *stainless steels; difficult-to-cut materials; machining; review*

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I. Introduction

Early uses of stainless steel were limited to a few applications such as cutlery, gun barrels, nitric acid tanks, etc. As various compositions were developed which made it highly corrosion resistant even at elevated temperatures, and gave it high strength, manufacturers started using it for a greater number of applications. Now stainless steels have become more popular and a part of everyone's life and also finds greater use in all kinds of industries. These are found in a number of applications such as, bulk materials handling equipment, building exteriors and roofing, automobile components (exhaust pipes, engine, chassis, fasteners, tubing for fuel lines, etc.), chemical processing plants (scrubbers and heat exchangers), pulp and paper manufacturing industry, petroleum refining, water supply piping, consumer products, shipbuilding and marine industry, pollution control equipment, sporting goods (snow skis), and transportation machinery(rail cars), to name just a few. Utensils and equipment made of stainless steel such as commercial cookers, pasteurizers', transfer bins, process equipment of milk, soft drinks and fruit juice and other specialized equipment plays a crucial role in our daily life. Stainless steel products play a major role in improving the hygienic aspects of service in restaurants, public kitchens, schools, local health centers, etc. (http://corrosionist.com; http://chemistry.about.com). The advantages of stainless steel include easy cleaning with a minimum of maintenance, good corrosion resistance, durability, economy, food flavour protection, and sanitary design. Another important notable advantage of stainless steel is its eco friendliness. It has a very long life when compared to mild steel and it can also be recycled 100% (http://chemistry.about.com;http://azom.com).

Stainless steels are made of some of the basic elements found in the earth's crust, e.g., iron ore, chromium, silicon, nickel, carbon, nitrogen, and manganese. These steels are categorized into five basic types according to their metallurgical structure. They are martensitic SS, precipitation hardening SS, duplex SS, austenitic SS and ferritic SS. Table 1 shows the worldwide market shares of these categories. It is clear from Table 1, austenitic stainless steel grades are used in the largest volumes (72%) as compared to other grades. This is due to its ability to be fabricated by all standard fabrication techniques and its very high ductility (ASDA, 2006). The common austenitic grades can be folded, bent, cold and hot forged, deep drawn, spun and roll formed.

Table 1 Worldwide market shares of stainless steel categories

Stainless steel categories	*Market share*
Martensitic	2%
Precipitation hardening	1%
Duplex	0.6%
Austenitic	72%
Ferritic	24%

Source: ASDA (2006)

But when it comes to machining, generally austenitic stainless steels are considered as more difficult to machine, than other grades due to their nature of high work hardening tendency, low thermal conductivity and high ductility (Akasawa et al., 2006; Rodriguez et al., 2008; Çaydas and Ekici, 2010). Some common problems associated with this grade are, high surface roughness and high tool wear (Kosa, 1989). Many research works contributed their efforts to overcome the problem of poor machinability of austenitic stainless steels. The objective of the present paper is to review the previous works on machining of austenitic stainless steels, and explore the future research areas.

Metallurgy of austenitic stainless steel

Austenite also called gamma phase iron is a metallic non-magnetic allotrope of iron with an alloying. When alpha iron (ferrite) undergoes a change in temperature from 912°C to 1,394°C, a phase transition from a body-centered cubic to the face-centered cubic configuration occurs, known as gamma iron, also called austenite. The most commonly used of this gamma form of iron is stainless steel. Austenitic stainless steels contain chromium and nickel (and sometimes in addition manganese and nitrogen) to stabilize the austenitic microstructure. Austenitic stainless steels have certain characteristics due to the stable austenitic microstructure, such as good formability, weldability, ductility, excellent toughness even at cryogenic temperatures, and a non-magnetic characteristic (http://chemistry.about.com). It is also the most rusty resistant of all grades due to the presence of a high percentage of chromium and nickel content. That is why austenitic stainless steels have become the most popular and largest used of all the groups of stainless steels used today. The 300 series grades of austenitic stainless steel is based on the 200 and 300 series (Kalpakjian,2006).

300 series grades of austenitic stainless steels

The 300 series is based upon the classic 18% chromium and 8% nickel stainless steel. It is the most commonly used grade worldwide. Here nickel is used to make the austenite structure and is responsible for its great toughness (impact strength), and strength at both high and low temperatures. Nickel also greatly improves resistance to oxidationandcorrosion.The300seriesgradesalsohave‘L’typeand‘H’type sub-grades. The L-type grades are intended for extra corrosion resistance. The letter L indicates low carbon (as in 304L, 316L) which is around 0.03%. It is used exclusively for welding. The ‘H’ grade contain minimum of 0.04% carbon and maximum of 0.10% carbon. This is recommended when using the material at extreme temperatures. The most commonly used grade is 304. It consists of 18% Cr and 8% Ni. Type 316 is the most common grade after 304. It consists 16% to 18% Cr and 11% to 14% Ni. From the application point of view 300 series grades cover various sector such as chemical processing industry, food and dairy industry, beverage industries, aircraft industry, construction nuclear reprocessing plants,home appliances, etc. The 300 series is commercially available for around 34. Some of them are namely 301, 302, 303, 304, 308, 309, 316, 304L, 316L, 317, 321, 347(http://spiusa.com).

200 series grades of austenitic stainless steel

The development of the 200 series of austenitic stainless steel (also called as Chrome-Manganese steels) is nothing new . This concept was developed in the early 1930s. Its use increased due to the rise in nickel prices during the 1950s. The late 1980s saw an interesting development in India .India was dependent on imported nickel which was costly. In the 1980s, the price of imported nickel rows sharply causing a crisis. Due to this, the Indian government decided to reduce the nickel imports. It was in the backdrop of this scenario that Indian producers like Jindal Stainless Steels Ltd. (JSL), started a drive to develop Cr-Mn grades like J1 and J4 which were introduced in the stainless steel market. Although the ferritic grades such as 430 were an option to avoid the high cost of nickel, the 200 series was chosenbecause of their non-magnetic property. Hence it was the increase in nickel price that led to significant increase in the use of 200 series. This series has much lower nickel content than 300 series. Recent years have shown a considerable increase in the amount of market share of 200 series which has been doubled from 5% to 10% during the last decade (ASDA, 2006, ISSF,2005).

Table 2 Registered grades of 200 series grades

Grade		*Chemical composition (wt %)*			
AISI	*UNS*	*Cr*	*Ni*	*Mn*	*N*
304	S30400	18.0–20.0	8.0–10.5	2.0 max	0.10 max
201	S20100	16.0–18.0	3.5–5.5	5.5–7.5	0.25 max
202	S20200	17.0–19.0	4.0–6.0	7.5–10.0	0.25 max
205	S20500	16.5–18.0	1.0–1.75	14.0–15.5	0.32–0.40

Notes: AISI – American Iron and Steel Institute, UNS – unified numbering system

Source: ASDA (2006)

Nickel is the element that turns ferrite into austenite, which is actually in 300 series. But nickel is not the only element to make the austenite structure. Manganese (Mn) and Nitrogen do the same, and together with austenite can act as former. When excess amounts of Mn and nitrogen are used to replace some of the nickel, the resulting stainless steel is known as the 200 series. The 200 series is commercially available in various grades such as 201, 202, 205. The most durable of these grades are 201 and 202, which contain 3.5% to 6.0% nickel, while type 304 contains 8.0% to 10.5% nickel, which is the most widely used grade of the 300 series (from Table2). Other grades of 200-series, such as Type 205, use at least 1% to 1.75% nickel. Features of 200 series are:

- lower material cost than 300series
- offers good formability(ductility)
- stronger and harder due to the higher nitrogen,manganese
- offers about 30% higher yield strength than 304grade
- non-magnetic.

The 200 series grades are popular in China and South East Asia. These are found in applications such as deep drawn kitchen equipment, liquid gas storage vessels, trailer frames, industrial strapping, railway rolling stock, furniture, bins, coal handling equipment, etc. Although the 200 series is covered by international coding and specifications, it has its limitations. The lack of chromium makes it less corrosion resistant and narrows the range of applications. From Figure 1, it is observed that Pitting corrosion resistance is highly influenced by the chromium and Sulphur content. It is also observed that the poorly produced 200 series grade have high levels of Sulphur, which causes pitting. It can be stated that in comparison with 300 series grades,

200 series grades are more economical and suitable, where less severe corrosion conditions exist. International Stainless Steel Forum (ISSF) strongly advised the users of these grades that they must compare the nature and in-service conditions of the intended application with the properties of these grades (ASDA, 2006; ISSF, 2005; http://sssheet.com).

Figure 1 Pitting corrosion resistance comparison (see online version for colours)

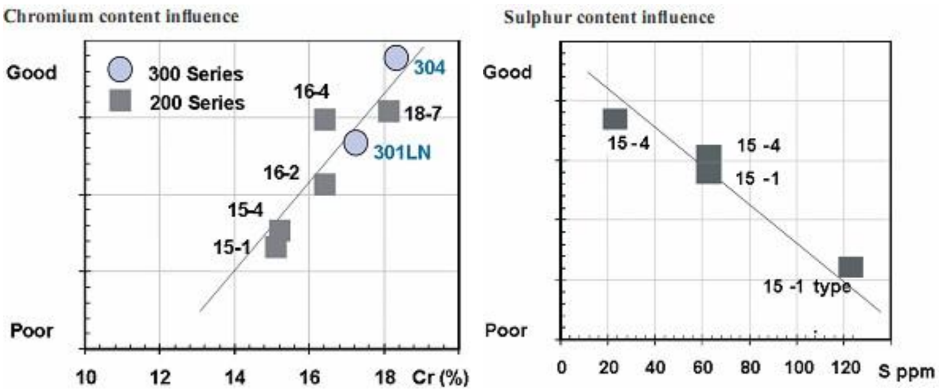

Figure 2 shows the estimation of the market shares of three categories of stainless steel globally from 2001–2009 by ISSF. It is observed that there is a consistent increase in the use of 200 series right from the year 2001 to the end of the year 2009. By comparison the share of 300 series has decreased considerably. The share of 300 series steels which accounted for 72.2% in 2001 was down to around 60.5% in the year 2009 (ISSF, 2010; Metal World Research Team, 2007).

Free-machining steels

In order to improve the machinability of austenitic stainless steels, free machining elements such as Sulphur, lead, selenium, tellurium, copper, aluminum, phosphorous need to be added. These elements help to reduce the friction between the work piece and the tool. More attention has been paid to the development of copper and Sulphur added free-machining steels as their addition improves machine ability without affecting corrosion resistance . although additive elements such as lead, selenium, and tellurium improve machinability, some of these are not recommended for use from a health point of view. The free-machining grades of austenitic stainless steels are namely 303, 303 Se, 203, 303 Cu (Akasawa et al., 2003; Kosa, 1989).

3 Machining of austenitic stainless-steel

Machine shop operators may have different views and opinions about the definitions of machinability.

Some of them are interested in the cutting speed at which a material is cut; others may consider tool life and the surface finish produced. But it is worth nothing that, all factors should consider the rate to define the machinability of a metal (Gandarias et al., 2008). Machinability refers to the degree of difficulty in machining under specified conditions. It is expressed in percentages. Austenitic stainless steels are considered the hardest to machine material due their high work hardenability, high ductility and hardness, low thermal conductivity, gumminess. Apart from these, some other factors that affect machining difficulty are hardness level, carbon content and nickel content. While machining austenitic stainless steel, several factors must be taken in to account, such as selection of the insert geometry and machining with coated ceramets grades to avoid formation of built up edge (BUE), chip breaker geometry and high feed rate are recommended for the purpose of chip disposal, and adequate rigidity of tool is also to be ensured to overcome chatter (Specialty Steel Industry of North America, 1995; Trent and Wright, 1989).

II. Literature review on machining of austenitic stainless-steel

Kuram et al. (2010) conducted an experimental studies to determine the effect of vegetable-based cutting fluids on thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel. In this study they used three different vegetable-based cutting fluids. Taguchi method was used for experimentation and mathematical models were developed from regression analysis (RA) to predict values of tool wear and forces. The lowest surface roughness and the lowest thrust force values were observed at the spindle speed of 720 rpm using commercial sunflower cutting fluid and at feed rate of

0.08 mm/rev. It was observed that sunflower cutting fluid and canola cutting fluid were more effective on the reduction of tool wear and force than commercial semi-synthetic cutting fluid. Çaydas and Ekici (2010) used support vector machines (SVM) tools namely least square-SVM, spider SVM and an artificial neural networks (ANN) model to assess the developed surface roughness values of AISI 304 austenitic stainless steel. It was shown that the all SVM developed models performed better than the ANN models. Statistical paired *t*-test was conducted to validate the results of SVM and ANN models. The *t*-test results of the experimental findings showed the spider SVM as most correlated pair. Jang et al. (1996) found the residual stresses in the AISI 304 grade work piece when turning. The shear stresses and the axial components of the stresses in the direction of feed were compressive and insensitive to the cutting conditions. It was found that the hoop stresses were tensile, increase with cutting speed, feed and decrease with depth of cut. It was also observed that tool sharpness was the influencing factor to the residual stresses. Tekıner and Yesılyurt (2004) investigated the values of flank wear, BUE, power consumption, surface roughness, and chip by considering acoustic emission (AE) during machining of AISI 304 grade. Results obtained from process sound were compared with classical methods. The work revealed that the change of cutting parameters also led to change of sound pressure levels. And there was sudden increase or decrease in sound pressure level, when there was occurrence of a negative event in cutting process. Xavior and Adithan (2009) experimentally determined the influence of three types of cutting fluids namely coconut oil, emulsions and neat cutting oil on surface roughness and flank wear during turning of AISI 304 SS with carbide tools. They concluded that the feed rate for surface roughness and cutting speed for tool wear were the most influential factors. Further, it was concluded that coconut oil was a better choice in reducing tool wear and surface roughness than the conventional mineral oils.

M'Saoubi et al. (1999) analysed residual stresses induced in turning of AISI 316L standards and also resulfurised steel which has improved machinability. Here coated and uncoated cemented tungsten carbide tools were used. When standard stainless steel was turned with coated and uncoated tools, the highest temperature point at tool and work piece interface were 900°C and 780°C. It was observed that the residual stresses induced in resulferised AISI 316L grade were lower than the steel of grade AISI 316L standard austenitic stainless steel. The shape of residual stress profile was highly influenced by feed rate. Muñoz-Sánchez et al. (2009) also chose the AISI 316L grade for machining with a view to analysing the influence of tool wear in surface integrity. It was found that the residual stresses were affected significantly due to the change in tool wear. Further numerical analysis was also carried out, by Lin (2008) who went for high speed machining of different grades of austenitic stainless steels SUS 303, SUS 303 Cu and SUS 304 by fixing the depth of cut as 0.1 mm to evaluate the surface roughness variation andmachiningstability.Inalltheexperimentaltestsgoodsurfacefinishwasobtainedat lower values of feed rate. It was also observed that the critical feed rate (0.02 mm/rev) caused the chatter on work piece. O'Sullivan and Cotterell (2002) used an online AE analysis technique to detect the work hardening of austenitic stainless steel 303. This technique can also be adopted for drilling and turning operations . They found that the Bankhansen noise measurement could be effectively used to Characterize the amount of α'-martensite phase in austenitic stainless-steel.

Endrino et al. (2006) conducted experiments to investigate the effect of physical vapor deposition (PVD) coating of AlCrN, AlCrNbN, fg-AlTiN and nc-AlTiN coating, on tool wear and tool life of finishing carbide end mills when machining AISI 316L.In conclusion results showed that the nc-AlTiN coated tool had shown a better performance than all the others within post running in (stable) stage of the wear. Abbot-Firestone curves were used to analyze the coating surface texture before and after post deposition treatment. Korkut et al. (2004) determined the optimum cutting conditions during machining of AISI 304 austenitic stainless steel. Probably this was the first attempt to determine the optimum cutting conditions during machining of AISI 304 austenitic stainless steel. Turning tests were carried out with a multi layer coated cemented carbide tool under dry environment. The researchers investigated the effect of speed on tool wear and surface roughness. Finally, they create a correlation between tool wear, surface roughness and chips obtained at the selected speed. Al-Ahmari (2007) developed models to predict the machinability of material, tool life, cutting force and surface roughness using RA, response surface methodology (RSM) and computational neural networks (CNN) to compare and determine with the experimental data obtained when turning austenitic AISI 302 grade. In order to determine the best predicting machinability model, the relative error in percentage was computed. Also, *t*-test, *f*-test, and Levene's test were conducted to compare the goodness of fit of models. It was concluded that CNN is better than the RA and RSM method in predicting machinability models. Reddy et al. (2010) used electrical discharge machining (EDM) method to machine AISI 302 grade to explore the influence of the current, open-circuit voltage, servo and duty cycle on the responses: material removal rate (MRR), tool wear rate (TWR), surface roughness (Ra) and hardness (HRB). The second order regression models were developed study the responses. Further Pareto chart and normal probability plots were used to analyze the significant and interaction effects of theinputs.

Klocke et al. (2010) focused on the effect of macro and micro geometry on the delamination behavior of PVD coating. Secondly, a FEM simulation model was developed for chip formulation to interrupt the coating's failure. It was observed that the high contact pressure at the rake face leads to the partial removal of coating and recommended a positive rake angles to reduce the coating delamination. Muhammad Jahan et al. (2010) made an attempt to machine deep micro holes in two difficult to machine materials: WC-CO and austenitic stainless steel SUS 304 with the micro-EDM drilling. They aimed to assess the performance of the two materials in terms of micro holes, machining stability, MRR and electrode wear ratio. The research revealed that the WC-Co showed better performance than the SUS304 in all aspects that they investigated. In case of machining stability and MRR also WC-CO had shown better performance. And the thermal and electrical properties of work piece materials were influenced by the performance parameters. Li and Wu (2010) chose conventional austenitic stainless steel and free cutting austenitic stainless steel work piece materials. These two types of alloy ingotsweremelted, castandforgedintobars. Further, machinability tests were conducted to determine the effect of free cutting additives. The end results showed that the addition of free cutting additives improved the machinability of austenitic stainless steel and also the ultimate tensile strength, yield strength and total elongation values of material with free cutting additives.

Ozek et al. (2006) conducted experimental investigation of the machining characteristics of AISI 304 grade by changing the cutting parameters in order to explore the effect on the tool-chip interface, surface roughness and flank wear. The depth of cut and feed rate proportionately influenced the surface roughness while the cutting speed had an inverse influence. The flank wear values were observes to have decreased with increase in cutting speed. It was also observed that there was a decrease in interface temperature with the increase in the cutting speed. Akasawa et al. (2003) conducted experiments to determine the effect of variations of the contents of additives S, Ca, Cu and Bi on the machinability of various grades of 300 series of austenitic stainless steel. The steels were melted and bars were prepared for turning at the required specifications using various processes such as hot-forging, cold-drawing, annealing and pickling. It was found that the desulfurized austenitic stainless steel had greater surface roughness than the desulfurized steels. The turning of calcium treated and bismuth addition steels showed better surface finish and the lower cutting force. The progression speed of tool wear was low when turning desulfurized austenitic stainless steel at higher speeds.

Jiang et al. (1997) used a hot forged bar and a quenched bar of AISI 304L and turned them at high speeds of 200 m/min. The influence of austenitic grain size on tool life and its distribution on chip deformation were investigated. The machining results showed that lower tool life was observed when machining the hot forged bar. There was also a slight decrease in tool life as the grain size increased in the quenched bars. It was also noticed that the segment height ratio of chip was higher in case of the hot forged bars due to uneven distribution of grain size. Galanis and Manolakos (2010) developed a surface roughness model using RSM when carrying out high speed machining of AISI 316L, for shaping femoral heads with multilayer coated carbide tool. The end results revealed that the depth of cut was the most significant factor and feed rate was inconsequential. The work of Bonnet et al. (2008) developed a friction model when turning AISI 316L SS using TiN coated carbide tool to describe the friction coefficient occurring at the tool-chip interface. In order to find out the friction coefficient a new experimental set up was presented, and the local sliding velocity at the tool-chip inter face was the key factor in the developedmodel.

Ciftci (2006) conducted experiments under dry environment to investigate the surface roughness and cutting forces during turning of two grades of austenitic stainless steels, AISI 304 and 316 with chemical vapors deposition (CVD) multi layer cemented carbide tools. It was concluded that the cutting speed was showing the most significant effect on surface roughness and lower cutting forces were obtained by TiC/TiCN/TiN coated tool as compared to TiCN/TiC/Al_2O_3 coated tool. Also, higher forces were developed in AISI 316 than for AISI 304 at all selected cutting speeds. Paro et al. (2001) selected to turn X5 CrMnN18 18 stainless steel material to investigate its machinability with TiN and Al_2O_3 coated carbide inserts. From the results it was found that catastrophic failure of tool nose was taking place due to high cutting forces and sharp edge chipping and the machinability was reduced due to the presence of BUE. Regarding tool wear, maximum flank wear (VB) value was reached after ten minutes turning time. Sen Sussi (2007) were concerned with the chip micro hardness behavior at diameters of work pieces for 30,40and 50mm when turning AISI304 grade. The RSMwasapplied to develop statistical models to predict accurate chip micro hardness. The experimental results obtained showed that increase in chip micro hardness was taking place at low level cutting speed, high level feed rate and depth of cut. Rodriguez et al. (2008) machined different compositions of austenitic stainless steels in order to analyze the effect of additives, in the mechanical properties and machinability of the material. The ultimate goal of this work was to obtain optimal cutting conditions for any type of austenitic stainless steels. Hong and Brooker (2000) suggested an economical cryogenic cooling approach to machine AISI 304SS. They proved that this approach was more profitable than emulsion cooling system. A small amount of liquid nitrogen was injected at the tool- chip interface and not to the work piece. This approach provided 67% tool life improvement and 43% improvement at moderate speed when compared to the emulsion cooling.

Abou-El-Hosseir and Yahya (2005) studied the tool wear and failure models and effect of cutting speed, feed rate on tool life of multi layer carbide tools during the end milling operation. It was found that tool life was reduced due to the increase in cutting speed. It was also found that the feed variations had not much effect on tool life. Gandarias et al. (2008) characterized the performance of AISI 303, 304, 316 grades by using both turning and drilling operations with high speed steel (HSS) and coated carbide tools. The experiments were conducted under two coolant techniques, minimum quantity lubricant (MQL) and cryogenic treatment. The turning results showed that the machinability of AISI 303 was better than the remaining two grades. Also, the cryogenic treatment had given better results than MQL. Nordin et al. (2000) presented a report on wear and failure mechanisms of multi layered PVD coated tools during milling of austenitic stainless steels. The tool life was influenced by chipping of the cutting edge. It was proved that the machining of austenitic stainless steels with multi layered PVD coated tools result in the formation of less comb cracks due to its lower tool-chip interaction. Khan and Hajjaj (2006) determined the performance of cermet tools for high speed machining of AISI 304 SS. It was found that these tools were suitable only for finishing operations in between feed rate 0.1 and 0.2 mm/rev. The cutting speed was also restricted to below 600 m/min. exceeding this limit led to catastrophic failure of cutting edge. Machinability of AISI 304 was satisfactory at a low cutting speed, feed and depth of cut. The maximum limit of depth of cut was also restricted to 0.3mm.

Valiorgue et al. (2008) proposed a novel approach to develop a finite-element model to predict the residual stresses profile that was induced when turning AISI 316L. This model simulated the movements of the thermo mechanical load on the machined surface. Many researchers conducted experimental investigations regarding the influence of machining parameters on the distribution of residual stresses, but without developing any simulation model. The work of Maranhão and Davim (2010) was also concerned with Finite element modelling of thermo mechanical behavior of AISI 316. In addition to that, friction coefficient influence on cutting and feed forces, cutting temperature, plastic strain, plastic strain rate, maximum shear stress and residual stresses were also determined. The simulated results were compared with experimental values and it was concluded that friction coefficient had a strong effect on the cutting process.

Kaladhar et al. (2010) determined the optimum process parameters when turning AISI 202 austenitic stainless steel samples. It was found that the feed was the most significant factor that influenced the surface roughness followed by nose radius.

Kaladhar et al. (2011) conducted experimental investigations to explore the performance of PVD (TiAlN-TiN) and CVD (TiCN-Al_2O_3-TiN) coated tools on the surface quality of work piece, when turning AISI 304 austenitic stainless steel work pieces. It was observed that the best surface finish for all samples was obtained while using a PVD coated tool. The ANOVA analysis revealed that the nose radius is the most significant factor when turning is carried out by a PVD coated tool. Whereas cutting speed is the most significant factor when the material is turned by CVD insert. Further, the optimum values of process parameters were determined to obtain optimal value of surface finish.

4 Some machining problems observed from experimental findings

The problems often reported by users regarding the machining of austenitic stainless steel have been discussed by various publications. Because of the severity of these problems which lead to poor machinability, these steels are classified as difficult-to-machine materials. In addition, many researchers claim to have observed certain phenomena which they encountered during their experimentation which they regard as reasons for poor machinability of austenitic stainless-steel.

1 The presence of macro particles on the coating of tool surface makes it difficult to carry out machining operations with these tools (Endrino et al.,2006).
2 Non-homogeneous distribution of chip thickness is responsible for poor surface finish (Korkut et al.,2006).
3 Whenresulfurisedsteelsareusedformachining,greatersurfaceroughnessis obtained. Further BUEs are also generated (Akasawa et al.,2003).
4 Chipping of the cutting edge, decrease in cutting speed, increase in depth of cut, and increase in feed rate are found to cause poor surface finish on machined surfaces. And it is also found that at lower cutting speeds, the tool performance is very poor (Ciftci, 2006; Korkut et al., 2006; Nordin et al., 2000; Li and Wu,2010).
5 Increase in grain size of austenite is responsible for the deterioration of machinability (Lin,2008)
6 Tool life is shortened due to the increase in quenching temperature of the material during machining of quenched bars (Lin,2008).
7 The variations of different grades of austenitic stainless steels properties (due to variations in their chemical compositions) have an influence on their machinability (Ciftci,2006).
8 Uncoated and single coated cutting tools cause tool failure due to high cutting forces and leads to poor machinability (Rodriguez et al.,2008).
9 The chatter takes place at the feed rate of 0.02 mm/rev during high speed machining (Maranhão and Davim,2010).
10 Tool wear is adversely affected due to the liquid nitrogen which reduces the work piece temperature (Akasawa et al.,2003).

III. Discussions

The applications and benefits of austenitic stainless steels are being increased in various fields of manufacturing because of their properties high ductility, high durability and excellent corrosion resistance. Though it is a widely used material, users have often reported machining difficulties which they faced during machining. As a consequence of this; many researchers have been making attempts to overcome these difficulties. In this section, future research areas of austenitic stainless steel machining are summarized. It is observed that publications of most of the research papers are concerned with machining of 300 series grade of austenitic stainless steel only, and not much attention has been given to machining of 200 series grade of austenitic stainless steel by researchers. This is, in spite of the fact that the use of 200 series grade has doubled during the last decade. It has been emerging (to some extent) as an alternative to 300 series grade which is costlier due to the high nickel prices. It is covered by international codes and specifications, and the ISSF has also recommended it, albeit by giving certain instruction to the users.

So, there is a big void in the research work on different aspects of machining of 200 series grade. A lot of process variables are involved during the machining process. Under such circumstances it is difficult to standardise machinability of steels. Working conditions can be very different in an industrial scenario. So, in view of the technological and industrial validity required of a research work, it is worthwhile to set the maximum performance conditions in austenitic stainless steels machining. Optimization of machining variables can be developed by fuzzy logic, genetic algorithm, Taguchi method, RSM, neural networks, etc. These are involved in the studies of maximum tool life, minimum cost, best surface finish and dimensional accuracy. But little work has been carried out on this aspect of machining. Many researchers have not dealt with AE technique to know the effects of machining coolant when machining austenitic stainless steels; hence the results are considered to be inconclusive. The influence of tool coatings on work piece can also be studied, because multi layer coated tools improve machinability of these steels significantly. It is also observed that the discussing the behaviour of austenitic stainless steels during high speed machining is rare.

IV. Conclusions

The present paper has reviewed and finds that-

- Austenitic stainless steels are used more than any other grades; these are considered as difficult-to-machine material.
- The 200 series grades of austenitic stainless steels are becoming a viable alternative to 300 series due to the rise in price of nickel which is one of the chief constituents of 300 grades.
- In the 200 series, some of the nickel in the basic composition 18/8 is replaced by manganese and nitrogen. It has its own limitations in applications.
- The literature review revealed that most of the research work is carried out on 300 series grade of austenitic stainless steels.

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