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A Brief Review on Machinability of Titanium and Its Alloys for Nuclear Application

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Abstract:- There is an instantaneous development of high strength temperature resistant alloys like Titanium-alloys; this material is used for sectors like aerospace, a nuclear, orthopedic, and marine applications. The properties of these titanium materials are very high in hardness, good toughness, impact strength and temperature resistant; so, the machining of these materials by traditionalist method is intricated. For this reason, it is sensible to study the machinability under suitable cutting conditions. This review paper presents the influence of machining parameters like coolant flow rate, cutting speed, application method of cutting fluids and environment of cutting on Tool life, surface quality and cost of cutting during machining of Titanium and its alloys.

Keywords:- *Titanium, Machinability, Titanium Alloys, Tool Life and Surface Quality.*

I. INTRODUCTION

Elevations in the aerospace, nuclear and other niche industries require the superior on-the-job performance of engineering components. These conditions have culminated the large scale progress and use of thermal-resistant and great-strength materials such as Titanium alloys that provides combination of properties like high strength at elevated temperature, resistance to chemical degradation, and wear resistance.

Titanium and its alloys are important engineering materials for industrial applications because of superior strength to weight ratio, high corrosion resistance and good temperature applicability. Titanium alloys have been mostly used in the nuclear industry due to their ability to maintain high strength at elevated temperature, and high resistance for corrosion.

Even though the usage and production of titanium and its alloys are increased, they are expensive when compared with other metals due to the complexity of the extraction process, difficulty of melting, and complications during fabrication and machining.

On the other hand, the long working life and elevated property levels counterbalance the high production cost. Fabrication methods such as castings, isothermal forging, and powder metallurgy have been introduced to reduce the cost of titanium components. However, most titanium parts are still manufactured by machining methods.

Titanium and its alloys are normally possessing deprived machinability, matured to numerous properties of the materials. It is chemically very sensitive and, has a propensity to attach with the cutting tool while machining, thus leading failure of tool with chipping. Again the tool life is shortened by high temperature at the tool-work interface because of poor heat conductivity of titanium, and also, its steep strength at elevated temperature and its low modulus of elasticity further hampers its ability to be machined.

Tool life, surface quality, and cutting power required are three main parameters that define machinability. Titanium is considered as difficult to machine by traditional methods because of its following inherent properties.

- High strength at increased temperature. It dissents the plastic deformation to form a chip.
- Low conductor of heat. Generated heat during cutting does not drive away quickly. That increase temperature at tool tip and reduce tool life.
- Chip formed by Titanium is very thin. It imposes high stresses on rake angle surface of the tool which in turn increase power consumption.
- Tool-tip hot temperatures reaches as high up to 1100°C
- Strong alloying tendency or chemical reactivity with materials in the cutting tools at tool operating temperatures. It adversely affects tool life and caused galling, welding, and smearing of the cutting tool.
- Modulus of elasticity is low. It requires rigidity of the machine tool and machining cost is increased.
- Loss of surface quality and integrity.

II. TITANIUM IN THE NUCLEAR INDUSTRY

Mechanical and chemical properties of titanium make it a good material for nuclear power plant condenser pipes, special valves and nuclear waste storage.

Valves and condenser pipes made up of titanium will be having good strength, less weight, erosion resistant, and thinner.

This advantage makes the components made up of titanium that easy to maintain, functionally more efficient, and have longer service life than parts made from other metals. 20 years is the lifespan of other metals and materials, while titanium last closer to 40 years.

Properties of titanium also make it a suitable metal for nuclear waste storage containers. Low reactivity and high corrosion resistance property of titanium makes it ideal for a nuclear waste storage container, because of which it cannot be easily broken down, which prevents the nuclear waste leaks. It can be also used for building nuclear reactor shields. Titanium helps to increase operational safety as well as life of reactors. Now a days Titanium metal is used in many other applications in nuclear industry due to its very superior properties.

III. TITANIUM MACHINING

Generally most of the conventional and non-conventional machining operations can employ in producing nuclear components. Turning, drilling and Milling are the most used machining operations, The investigations by different researchers on machinability of titanium and its alloys in several cutting conditions is discussed below.

➢ *High Speed Machining*

One of the scholar concluded that the most applicable way to aggregate the removing of metal is to increase the cutting speed, by using tools which can maintain hardness and strength at elevated temperature so as to achieve the high cutting speeds. Increase in cutting forces is observed as the result of higher material removal which may increase cost for cutting.

High speed machining is adopted in industries as it lead to high material removal rate, high productivity, appreciable machine tool hour rate, lesser cutting force, better chip flow, acceptable surface quality and dimensional sustainability.

➢ *High Pressure Cooling*

Immense heat is developed during machining of titanium because of low heat conductivity. The elevated temperature produced at tool work contact resulted in to a low tool life and a bad surface quality. Machining of titanium can be enhanced by lowering tool tip heat by way of pressure jet water cooling in the place of flood cooling. Many researchers have worked in this direction.

M Rehman et al. stated that application of high pressure coolant produces better cooling effect as well as lubrication in the chip tool edge. Cutting force is reduced because of the low coefficient of friction. Welding of the tool and chip is eliminated by effective pressure cooling which improves the tool life and surface finish.

➢ *Dry Machining*

Noxious nature and the harmfulness of the cutting fluids severely degrade the environmental quality of the machine shop. It backs for dry machining which in disagreement with the traditional use of fluids during machining for higher surface quality, productivity and tool life.

Ribeiro et al. conducted turning tests for titanium alloy with uncoated carbides under dry condition, they observed that best conditions of cutting are near to the required conditions for the manufacturer of cutting tool and it is capable to work in more extreme conditions than the usual old-school conditions. They also recorded that it is possible to work with less amount of coolant or preferably in dry condition.

➢ *Minimum Quantity Lubrication*

Cutting fluid not only hazardous to atmosphere but its costs is almost 18%-20% of total machining cost. Several studies proved that dry machining is not suitable for all the conditions. Need of better technic is identified by researchers i.e. method of lubricating cutting area only which is cost effective, as the usage is less harm to the environment is also reduced and superior than dry machining is Minimum Quantity Lubrication (MQL).

Brinksmeier et al., studied MQL method in titanium machining and observed that drop in cutting forces results in higher in surface quality and increase in tool life by 20%. Experimentation is carried out by using different mixture of fluids i. e. MQL (‘Synthetic esters’), MQL (‘Synthetic esters and phosphorus additives’), MQL (‘Synthetic esters high additive’) and overflow (‘emulsion’ 7%) and is concluded that using high ratio of additive products lead to improvement in tool life in comparison with overflow condition of emulsions.

➢ *Recent Trends in Machining Techniques*

Conventional method of lubrication and cooling poses harm to the environment and questioned by many researchers for its usage. So the cryogenic machining was investigated for better cooling at tool-work interface as cost effective and ecofriendly substitute.

Hong et al. used cryogenic cooling method and machined titanium and found that the flooding LN_2 resulted positively than dry cutting; but there was not much increase in tool life compared with flood cooling.

Hong et al. has submitted that new method called cryogenic machining technique lowered the complication of buildup edge, it diminishes the action of chip attaching to the tool material and the intense Liquid Nitrogen (LN_2) jet clean the edge. Authors also have put the light about ways to feed LN_2 with a less flow rate, because for cryogen industry also it is technically challenging.

New delivery line design somewhat achieved to reduce the flow rate. High temperature of working improves the ductility and reduces hardness, this two properties are improves the machinability. As the hardness is reduced by hot machining which results reduction in cutting forces, reduces cost and good surface finish and higher tool life are achieved. Almost same efforts and care one has to be taken while hot machining as in cryogenic machining.

Maity and Swain had carried out some reasearch for hot machining and found that tool life is improved and cutting forces were decreased considerably.

Ginta et al. shown that work-piece preheating increase the tool life of uncoated carbide inserts in end milling of Titanium alloy.

IV. CONCLUSION

Titanium and its alloys are contemplated as hard to machine metal considering the increased temperature for machining and the increased stresses at close to the tip of tool. The temperature of cutting is high because of the heat produced during cutting, the very small chips, a thin partial zone, a little chip-tool contact length and the low thermal-absorption of the material, at the same time due to the small area of contact the stresses induced and the strength of titanium even at high temperature.

Normally, coolant must be applied when cutting titanium alloys. Right utilization of cutting fluids while machining, extraordinarily extends the life as well as durability of the cutting tool. Cutting fluids which are chemically active reduces the force for cutting between the tool and the work. Rapid machining with flood cooling and high pressure coolant methods results better lubrication and better cooling effect in the chip-tool interface. That reduced the cutting force, good surface finish and cost of cutting.

Deliberated few non-usual machining techniques like MQL technique, Cryogenic cooling, Hot machining which also address two major worries of machining, economy and ecology of cutting. But still there is lots of scope available and rigorous research is needed for industrial application of these techniques.

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