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Exploring the capabilities of cryogenic coolants in turning of Hastelloy C276

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Abstract :
Materials which are lighter and stronger have faced increase in demand to fulfil requirements that cannot be done by other materials. Specifically, demands for super alloy are due to their wide range of resistance to chemicals .Despite the increasing demand for Hastelloy (super alloy) products, machining them remains a significant challenge .The conventional cutting fluid is commonly used to control the cutting temperature by isolating the cutting zone which results in further increase in temperature. So the alternative cutting fluids like cryogenic coolants (liquid nitrogen, carbon dioxide) are here to replace conventional fluids. This research investigates the effects of cryogenic cooling on machineability of Hastelloy in turning operation.

Index Term- *Super Alloys, Hastelloy, Carbide Cutting Tools, Cryogenic coolants,* LN_2,CO_2

1. INTRODUCTION

Material cutting is one of the dominant parts of shaping materials into the final product. Machining operations, such as milling, turning and drilling, present a major proportion of material cutting operations. In machining operations, a cutting tool is used to remove material from a workpiece in the form of cutting chips by plastic deformation. This process consists of mechanical and thermal forces being induced into both cutting tool and workpiece. Some of the advanced materials, such as super alloy (Hastelloy), possess high cutting forces and

temperature during machining operations which have resulted in them being generally termed difficult-to-machine materials, as opposed to easy-to-machine materials such as Aluminium alloys and medium carbon steels.

It is well recognized that using cutting fluids is one of the most common methods to regulate the cutting temperature by removing excessive heat generated during machining operations. In addition, cutting fluids can lubricate the cutting zone and reduce friction. As a result, lower mechanical stress will be induced on the cutting tool and the heat generated due to friction will be reduced. However, cutting fluids, also known as metal cutting fluids, are known to be dangerous substances for both the environment and human health. This has resulted in overgrowing concerns and generation of different government rules regulating the use, maintenance and disposal of cutting fluids.

Using liquefied gases (e.g. liquid nitrogen and carbon dioxide) as a coolant is a technique to control the cutting temperature. This technique is termed cryogenic machining and has attracted significant attention from researchers globally (Yildiz and Nalbant, 2008). In this method, a super cold liquid gas is used to freeze the work piece material and/or cutting tool in order to modify their material properties and control the cutting temperature. There are a number of reports on the effects of cryogenic cooling on machinability of different materials (Yildiz and Nalbant, 2008). Since different materials react differently at low temperatures, different approaches are required for different materials and machining operations.

2. Experimental Procedure

Cryogenic Machining

Cryogenic machining presents a method of cooling the cutting tool and/or work piece during material removal processes. The coolant is usually nitrogen fluid(LN) that is liquified by coolingto -196.8 degree Celsius, nitrogen is a safe non corrosive and non-combustable gas. In fact, 78% of the air we breathe is nitrogen. The liquid nitrogen in a cryogenic machining system quickly evaporate sand returns to the atmosphere, leaving no residue to contaminate the work piece, chips, machine tool, or operator, thus eliminating disposal costs. Additionally, cryogenic machining can be used to machine work materials at higher cutting speeds, and to achieve higher surface quality and better surface integrity, with increased machinability and reduced overall costs. Proven benefits of cryogenic machiningare:

- improvedprocesssustainability(cleanerandsafer,environmentally-friendly processes providing no adverse health effects for personnel on the shopfloor)
- increasedmaterialremovalrate(MRR)withnoincreaseintool-wear rates and tool change time, resulting in reduced over all costs via higher productivity.

Hastelloy

Hastelloy C276 is a nickel-molybdenum-chromium super alloy with an addition of tungsten designed to have excellent corrosion resistance in a wide range of severe environments. The high nickel and molybdenum contents make the nickel steel alloy especially resistant to pitting and crevice corrosion in reducing environments while chromium conveys resistance to oxidizing media. The low carbon content minimizes carbide precipitation during welding to maintain corrosion resistance in as-welded structures. This nickel alloy is resistant to the formation of grain boundary precipitates in the weld heat-affected zone, thus making it suitable for most chemical process application in an as welded condition.

Although there are several variations of the Hastelloy, nickel alloy, Hastelloy C-276 is by far the most widely used.

Alloy C-276 is widely used in the most severe environments such as chemical processing, pollution control, pulp and paper production, industrial and municipal waste treatment, and recovery of sour natural gas.

Corrosion Resistant Hastelloy C276

Considered one of the most versatile corrosion resistant alloys available, Hastelloy C-276 exhibits excellent resistance in a wide variety of chemical process environments including those with ferric and cupric chlorides, hot contaminated organic and inorganic media, chlorine, formic and acetic acids, acetic anhydride, seawater, brine and hypochlorite and chlorine dioxide solutions. In addition, alloy C-276 resists formation of grain boundary precipitates in the weld heat affected zone making it useful for most chemical processes in the as-welded condition. This alloy has excellent resistance to pitting and stress corrosion cracking.

3. Experimental Setup

Cryogenic orthogonal cutting tests were conducted on Hastelloy C276usingaMAZAKhighspeedCNCturning center,equippedwithcryogenicfluiddeliverysystem, with cubic boron nitride tools (Secondary grade: CBN 100)

Hastelloy were machined at varying cutting speeds, feed rate, depth of cut. Cryogeniccoolingconditionsthecuttingtimeforeachtestwas18–20stoallowthemachine to reach the mechanical and thermal steady-state conditions. In the machining tests, a very low, flank wear of 0.03–0.05 mm was observedontheutilizedCBNtools,thustheinfluenceoftool-wear was not investigated in thisstudy.The cryogenic coolant was applied by a nozzle to the area of interest as shown in it has been generally known that cryogeniccoolingheavilyinfluencesthemachining processalong the primary, secondary and tertiary shearzones.After machining, samples of 5 mm × 5 mm were sectioned bywire-EDM,thenpolishedandetchedfor5susing5%Nital solution to observe microstructural changes using a light optical micro- scope (1000×) and a scanning electron microscope(SEM).

4. Experimental Results and discussions.

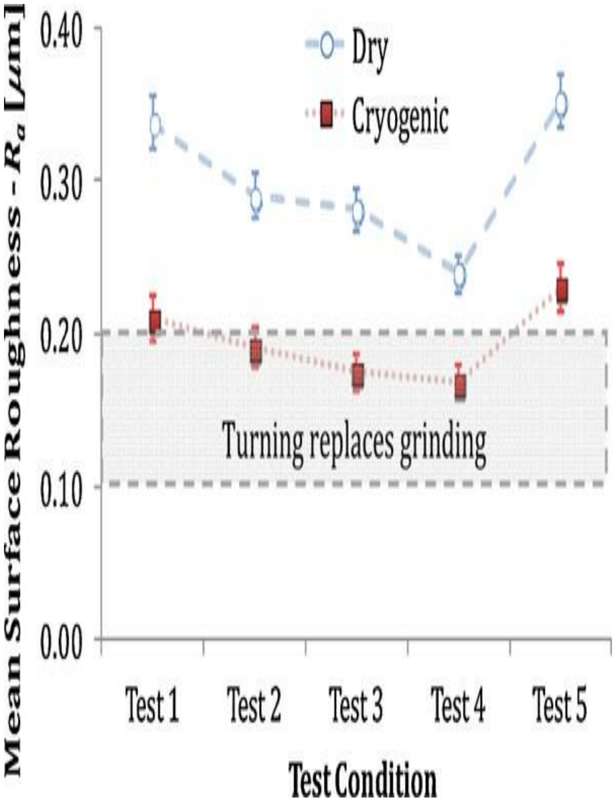
Surface roughness

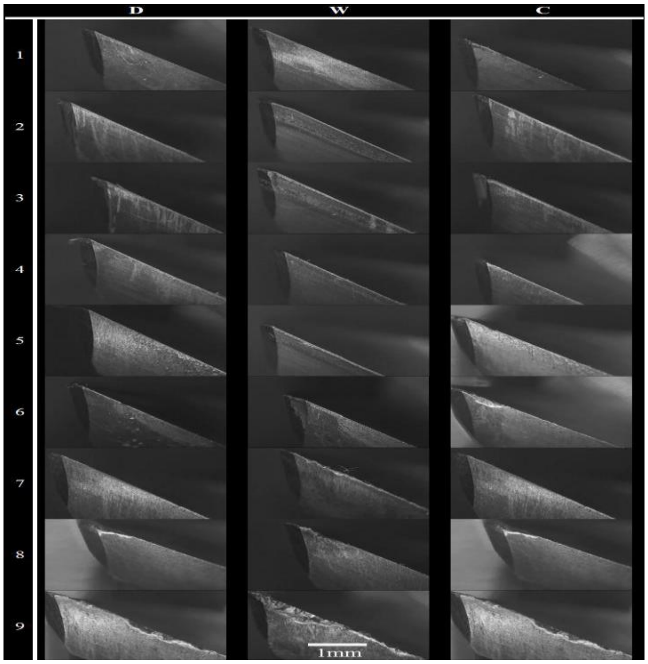
ThesurfaceroughnessvaluesR$_a$,ofthemachined samplewere measured three times for each set of cutting process parameters and cooling conditions to evaluate the characteristic of the machined surface and averaged to obtain mean values. The obtained $R_a$measurements reflect the surface quality in machining with cryogenic coolant, and were found to be consistentlysuperiortothatobtainedindrymachining.Also shows a mapped region called “turning replaces grinding’’ where cryogenic hard machining produced comparable

$R_a$values with grinding. For both cooling conditions with chamfered tools (Tests 1–4), the mean surface roughness decreases with the increasing cutting speed and for samples at 54 HRC; in contrast, honedtoolsproduceaworsesurfaceroughnesscompared with chamfered tools

Tool wear measurement

After machining operations, the cutting tools were cleaned by pressured air and prepared to be examined by optical microscopy for tool wear. A Nikon tool makers' microscope was used to observe and measure the tool wear on the cutting tools. The microscope has a 60X magnification and was equipped with a digital camera. Prior to measuring the tool wear, the microscope and camera were calibrated and the same calibration was used for all the samples. The instructions provided by ISO 8688-2 (1989) were strictly followed in order to identify and measure the tool wear. A high resolution digital image of the flank faces of each cutting tool was taken and the one with maximum flank wear was selected to present the flank wear of the respective cutting tool. The images of the flank face of the cutting tools used for each machining experiment according to DoE.

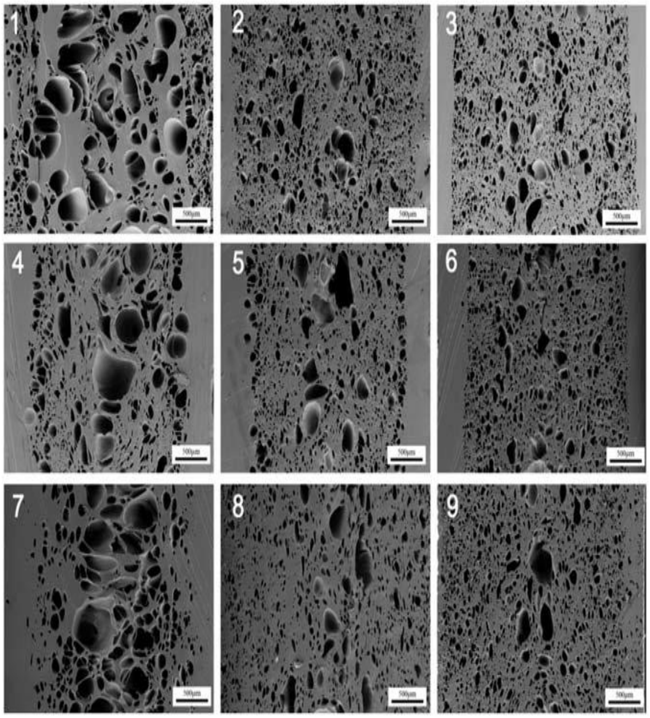




SEM Photography

Unlike optical microscopes, operate in a vacuum and rely on electric fields to work, sample preparation can be a complicated process. Researchers start by cleaning it of any dust or debris. Once clean, it's ready to be mounted in the SEM if the specimen is fairly conductive. Otherwise, it's coated in a conductive material like gold or platinum through a process called sputter coating before it's ready for viewing. Sputter coating allows a sample to be grounded, preventing it from being damaged by the electron beam.

Since specimens placed in the microscopes also are subject to a vacuum, they sometimes undergo additional preparation to ensure that they hold up under such extreme conditions. Biological samples, for instance, are typically dehydrated before being placed in an SEM. Otherwise, the low atmospheric pressure of a vacuum would cause the water in biological samples to evaporate quickly, destroying the sample in the process. Other specimens are frozen before they are examined, and still others are chemically treated so that they survive the magnification process.



5. Conclusion

Experimental observations reported in this study suggest that theuseofcryogeniccoolantinmachiningofHastelloy significantly affects the surface integrity. In particular, cryogenic cooling conditions limit the white layer thickness and offer better surface roughness. In contrast, dry machining offers betterperformanceonresidualstressprofile andthereforewould contribute to improved fatigue life. Overall, this study demonstrates that machining hastelloy under cryogenic cooling has the potential for surface integrity enhancement for improved productlife.

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