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Full Length Article

# Experimental investigation on tool life and chip morphology in hot machining of Monel-400

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## ABSTRACT

In the present study, an experimental investigation has been carried out to examine the effect of heating through a gas flame in the hot turning of Monel-400. Monel-400 is a Ni-base copper alloy used in aerospace, marine, and power plant sector due to its high corrosion resistance, high hardness, and ability to retain at high temperature, etc. Machining Monel-400 alloy in conventional way is tough due to rapid tool wear, hence bad surface finish. Hot machining is novel technique to solve this issues without compromise quality and production cost. The machining was conducted at different cutting parameters and heating temperature. The effect workpiece temperature on tool wear, tool life, chip-tool contact length and chip morphology has been discussed. The increase of cutting speed with heating temperature, the tool life increased 85% compared to room temperature. It was found that with an increase of feed rate with heating temperature, the tool life decreased and build-up-edge formation was observed at low cutting speed conditions. However, the effect of depth of cut with heating has a less significant effect on tool life. The chip morphology and chip thickness characteristics were also studied.

## 1. Introduction

Nickel based alloys have gained various industrial uses like chemical plant equipment, frames for eyeglasses, aerospace applications, biomedical and musical instruments etc., due to its desirable characteristics, such as high resistant to corrosion, and high strength. Machining of these materials have faced a great challenge in the industry due to low thermal conductivity, high heat generation and chemical reactivity to all tool materials which decreases the tool life [1]. Monel-400 is a nickel and copper base alloy of solid solution, having high strength and toughness over wide temperature range. New techniques have been proposed for machining these types of materials like Non-conventional machining (ECM, EDM etc), cryogenic machining, and hard turning, but it requires high set up the cost and skill labor [2]. So avoid to these barrier, hot machining has been used, where an external heating source is supplied to the material surface, above the recrystallization temperature and hence, reduce shear strength, lower tool wear, and increase bulk removal of material. Fig. 1 shows shear strength vs temperature of nickel base alloys. The reduction of shear strength of nickel base alloys are generally occurs when the heating temperature reaches about 600 °C.

Softening of materials by heating is the more influence method to strengthen the tool materials compared to cooling the tool. The various thermal enhancing techniques have been carried out by different researchers and found that the selection of heating technique can enhance the machinability and reduce the cost [6]. Plasma enhanced machining was performed for high strength materials by different researchers, and they concluded that the advantages plasma assisted machining were increased material removal rate, tool life, reduce cutting force and surface roughness [4,7]. The Induction heating system was studied [8–12] and found that heating decreases the tool wear and improves surface finish compared to conventional machining processes. Maity and Swain [13] studied the tool life in the hot turning of hardened steel using gas flame heating. A full factorial design of experiment was carried out to find out tool wear, tool life, and chip reduction coefficient. The influence of cutting parameters on tool life was found at a low value of cutting velocity, followed by feed, depth of cut and high value of temperature and developed a tool life equation. Davami and Zadshakoyan [6] studied temperature generation in the cutting tool and quality of machined surface using the gas

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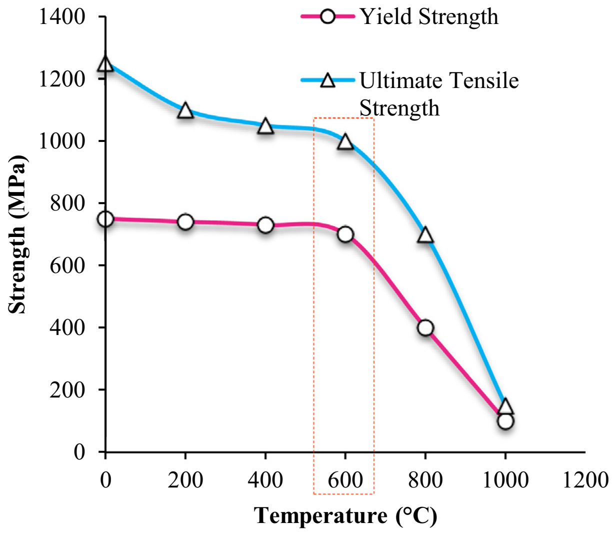

**Fig. 1.** Thermo-mechanical properties of nickel-based alloy [3–5].

flame heating technique. It was found that better surface finishes at hot machining and in low cutting speed, discontinuous chip produced in machining changed to the continuous. Tosun and Ozler [14] analyzed the tool wear of cutting tool by using regression analysis along with artificial neural networks (ANN). The selection of these process parameters on machining output parameters is the major concern in hot machining. Hot machining with different optimization techniques were used by researchers [15–18] to predict optimized results by reduce cutting force, tool wear, increase surface finish and material removal rate. Parida and Maity [19] studied the effect of heating on machinability of three nickel base alloy in hot machining processes. They concluded that heating improves machinability in terms of increase tool life, better surface finish, less tool wear etc. Ansari et al. [20,21] prepared $CuFe_{12}O_{19}$ nano-composite using sol-gel-auto combustion process. They studied facial synthesis, characterization and magnetic properties of the material. They observed that the presence of hexaferrite plays major biological role, which reduce low energy consumption and environment-friendly. The advantage of using gas flame as a heating source is it is low cost and simple, but it cannot use for machining Ti-base alloy due to carbon particles deposition and formation of oxide [22]. Lee et al. [23] studied machining of high strength material using hybrid machining processes. They used both heating and cryogenic cooling to improve the tool life. It was observed that the cutting force decreased by 65% with heating conditions and slightly increase in the cryogenic machining process. Compared to single machining processes, the hybrid technique (both cryogenic and heating) machining process increase tool life around 90%. Finite element analysis of hot machining using flame heating were studied [24,25] and found that the numerical results (cutting forces, chip thickness) were close agreement with the experimental data. Though lot of literatures available on machinings of high strength materials like Inconel 718, Ti-6Al-4 V and various hardened steel, research on machining of Monel-400 is lack behind. So in this study, an attempt has taken to study machining investigation of Monel-400 using gas flame heating techniques.

## 2. Experimental procedure

All machining trials were carried out with center machine tool (HMT Bangalore) with maximum spindle speed 1200 rpm. Monel-400 having 300 mm length and 50 mm diameter round bar received from the supplier (Narendra Steel, Mumbai, India) was used as workpiece materials. The hardness of workpiece was verified (170 HV) with hardness tester. The chemical composition and mechanical properties of Monel-400 are shown in Tables 1 and 2. The experiments were performed with different cutting conditions and workpiece temperature as listed in Table 3. Eight-sided cutting edges of uncoated carbide inserts (SNMG 120408) were used as cutting tool, and PSBNR 1616 k16 was used as tool holder (Kennametal). Flame heating (liquefied petroleum gas and oxygen) was used to heat the workpiece, and it is one of the best method for hot machining, as it requires low investment cost. The distance between the nozzle and workpiece is 40 mm and pressure regulator adjusted to kept constant flow of oxygen (30 ml/min) and liquified petroleum gas (110 ml/min). An automatic gear arrangement was used to avoid uninterrupted heating on the workpiece. The workpiece surface temperature was measured with a thermocouple (Alumel and Cromel) having a capacity of measurement the temperature ranges of (20 °C–1200 °C) and temperature indicator was used to measure the temperature which was sensed by thermocouple on touching to the workpiece while heating. In each single run, a fresh cutting edge was used for 5 min, and tool wear was recorded. An optical microscope was utilized to measure the flank wear of tungsten carbide tool at different cutting time, and 0.3 mm was taken as tool life criteria in accordance with ISO 3685 standard. The hot machining setup for machining Monel 400 is illustrated in Fig. 2.

## 3. Results and discussion

Before planning the experiments, a random trial was carried out for measurement of cutting, feed and radial forces and its impact on flank wear and tool life of cutting tool at cutting

**Table 1**
Chemical composition of Monel-400 used in experiment.

| Elements | Ni | Cu | Fe | Si | C | S | Mg |
|---|---|---|---|---|---|---|---|
| % | 63 | 31 | 2.5 | 0.5 | 0.3 | 0.024 | 2.0 |

**Table 2**
Physical and mechanical properties of Monel-400 [26].

| Properties | Values |
|---|---|
| Density ($gm/cm^3$) | 8.8 |
| Melting temperature (°C) | 1300–1350 |
| Tensile Strength (MPa) | 512–620 |
| Yield Strength (MPa) | 172–345 |
| Modulus of elasticity (GPa) | 179 |
| Poisson's ratio | 0.32 |

**Table 3**
Process parameters and levels.

| Parameters | Levels | | |
|---|---|---|---|
| | Low | Medium | High |
| Cutting speed (m/min) | 40 | 60 | 100 |
| Feed rate (mm/rev) | 0.1 | 0.13 | 0.15 |
| Depth of cut (mm) | 0.5 | 1 | 1.5 |
| Workpiece temperature (°C) | 30 | 300 | 600 |

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