Effect of cooling condition over surface quality in turning of aluminium alloy 6082-T6

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Abstract. Cutting fluids play an important role in machining operations helping reduce friction, workpiece heating, tool wear and also with chips detachment and evacuation. The usage of cutting fluids also have a number of drawbacks that are related with the environmental threats and costs. Dry matching and MQL-minimum quantity of liquid seem to be promising solutions for these problems. But these solutions are not feasible under all machining applications. The present paper purpose is to investigate the effect of cutting and cooling conditions over surface quality in aluminium alloy 6082-T6 turning operations.

1. Introduction

Aluminium alloys are frequently used in the manufacturing industry because of their mechanical and physical proprieties. The main advantage that this materials offer is the lightness- strength ratio that is significantly higher than the ones of steel or cast iron. Machining these materials is carried out with some difficulties because mostly of their tendency to form build up edge, high thermal expansion and poor chip breaking. The machinability of aluminium alloys is strongly related with their chemical composition, material structure and the machining process used. Wrought alloys have higher machinability than cast alloys.

AL 6082-T6 is part of the wrought aluminium-magnesium-silicon family. The high corrosion resistance, plasticity, medium strength and fine-grained structure recommends this aluminium alloys for highly loaded structural applications. The machinability of this aluminium alloy it is consider good although special cutting-edge geometry for chip breaking is required.

The cooling method selected for the machining process has a great influence on the material deformation mechanism and process stability and therefore on the dimensional accuracy and surface quality. The behaviour of aluminium alloys during cutting processes is known to be different from that of commonly used industrial materials. This is because their low melting point, work material build-up layer on the rake face of the cutting tool and poor chip detachment.

Aluminium alloys cutting processes are traditionally carried out in presence of high quantities of cutting fluids. These conventional cutting environments proved to be extremely expensive due to complex installations, maintenance and disposal and a real threat for environment and human health. In recent decades dry or green machining had been considered as a viable technical solution for many machining processes. The idea of cutting processes without any coolant could be investigated and industrially applied for some materials because of the new machine tools capabilities in terms of increased cutting speeds and the advantages that were achieved in the field of cutting tools materials and...
coating technology. The new developed coated cutting tools offered many benefits in terms of lubrication, cooling and life performance.

2. Literature review

Yigit [1] carried out an investigation and analysed the off effect of minimum quantity lubrication in machining 6082 aluminium alloy. He concluded that MQL technique was able to reduce flank wear, and improve tool life when higher cutting speeds were applied. MQL with rapeseed oil has only a small lubricating effect when reduced cutting speeds are applied. The boundary film developed was not strong enough to sustain low friction and to avoid abrasion of the work material.

Chaudhary et al [2] carried out an optimization study for the machining parameters such as spindle speed, feed and depth of cut for minimum surface roughness in dry end milling operation. Taguchi method was used to optimize these parameters. They concluded that surface roughness decreases with increasing spindle speed and increases with increasing feed rate. The optimum values of machining parameter for minimum surface roughness in dry end milling operation were speed 1600 rpm, feed 100 mm per min. and depth of cut 1.0 mm.

Kłonica M. [3] analysed the cutting feed influence over the 2D and 3D surface quality parameters after the turning process of AW 6082 T6 aluminium alloy. In the whole range of applied feed speeds, an increase in surface roughness parameters was observed – both 2D (Ra, Rz) and 3D (Sa, Sz, St).

Kabbir et al. [4] investigate the influence of thickness, roughness, water quality and the type of nozzle on the cooling of Aluminium 6082. The results they obtained indicate that the cooling rate is faster in the case of tap water due to salt deposition on the material. It was also observed that nucleate boiling was dominating due to the full-jet nozzle compared to spray nozzle because the full-jet nozzle does not support the formation of a vapor layer on the material.

Radhika et al. [5] had investigated the cutting parameters during turning of aluminium 6082-T6 alloy using non edible oils as cutting fluid such as Neem, Karanja oil and Petroleum based oil. The Surface roughness results obtained were much better for the case of non-edible oil as cutting fluid compared with other two machining process.

The present paper investigates the influence of cooling environment and cutting parameters on the machined surface quality. The machining test were carried out using L9 Taguchi array and surface quality was analysed using DOE Taguchi R/N analysis and 2D and 3D machined surface profile parameters.

3. Experimental setup

The orthogonal machining experiments have been carried out on a CNC lathe Lynx 220. Three cutting environments were considered: cooling with compressed air, minimum quantity of lubricant MQL and dry. The compressed air pressure was of 2.6 bars. Three levels were also considered or the machining parameters- cutting speed, cutting feed and depth of cut, as showed in table 1. The workpiece material was a AA 6082-T6 bar with a diameter of 50 mm. DCGT11T304-AK H01- Korloy uncoated tool inserts, specially designed for aluminium alloy machining were used in the experiments. For the first two cutting environments we had used an air/oil coolant mist system and a compressor. For the tests carried out in MQL conditions we used a mineral oil recommended for cutting aluminium and nonferrous alloys type Valona MS 7023 HC.

The research instrument used in ordered to investigate the machined surface quality 3D and 2 d parameters was an optical measuring instrument with subnanometer resolution that uses as measuring principle confocal microscopy and white light interferometry- Mahr CWM 100 produced by Mahr. The measuring tests were made with KFM objective lenses 10x0.5µm. For a more accurate estimation of the roughness and surface texture parameters three different areas from each machining test carried out were inspected. The experimental data was analysed using an free evaluation version of the statistical software Minitab.
4. Analysis and discussions
In Taguchi’s design method the noise factors are considered the factors that cannot be controlled by designers, such as vibration, apparatus accuracy, etc. and that are influential for the process quality. In this analyse signal to noise (S/N) ratio are used to take both the mean and the variability of the experimental result into account. Th S/N ratio depends on the quality characteristics of process to be optimized. For this particular study the lower is better criteria was selected because the machining process objective is minimizing the surface roughness.

In table 1 the experimental plan and the experimental data are presented. Figure 1 presents the main effect plots for the surface roughness measured for the turned aluminium alloy surfaces.

| No. | Cutting environment | s [rev/min] | fl [mm/rev] | ap [mm] | Ra [µm] | Ra_1 [µm] | Ra_2 [µm] | S/N ratio | Ra_mean | Std |
|-----|---------------------|-------------|-------------|---------|---------|---------|---------|---------|---------|-----|
| 1   | Compressed air      | 3500        | 0.15        | 0.2     | 1.90    | 1.87    | 1.89    | -5.514  | 1.887   | 0.015 |
| 2   | Compressed air      | 4000        | 0.24        | 0.6     | 3.95    | 4.04    | 3.96    | -12.005 | 3.983   | 0.049 |
| 3   | Compressed air      | 5000        | 0.5         | 1       | 18.50   | 17.20   | 22.10   | -25.746 | 19.267  | 2.538 |
| 4   | MQL                 | 3500        | 0.24        | 1       | 25.40   | 25.10   | 25.00   | -28.016 | 25.167  | 0.208 |
| 5   | MQL                 | 4000        | 0.5         | 0.2     | 17.20   | 16.60   | 20.60   | -25.210 | 18.133  | 2.157 |
| 6   | MQL                 | 5000        | 0.15        | 0.6     | 2.13    | 2.04    | 2.09    | -6.390  | 2.087   | 0.045 |
| 7   | Dry                 | 3500        | 0.5         | 0.6     | 19.50   | 19.10   | 20.00   | -25.817 | 19.533  | 0.451 |
| 8   | Dry                 | 4000        | 0.15        | 1       | 6.20    | 6.00    | 6.13    | -15.721 | 6.110   | 0.101 |
| 9   | Dry                 | 5000        | 0.24        | 0.2     | 4.39    | 4.33    | 4.31    | -12.756 | 4.343   | 0.042 |

**Figure 1.** S/N Ratio for surface roughness vs. cutting medium, cutting speed, cutting feed and depth of cut.

Figure 2 shows the main effects plots for means. According to the graphs obtained for the experimental data surface roughness decreases with increasing spindle speed and increases with increasing of cutting feeds and depth of cut. The cutting environments that assured lower surface roughness was compressed air and the worst cooling method turned out to be MQL. In figure 1 it is clear that S/N ratio increases with increasing spindle speed and decreases with increasing cutting feed and depth. According to table 2 and 3 the that the cutting feed is the most influencing factor followed by.
depth of cut for means and spindle speed for S/N ratio. The optimum conditions for S/N ratio and means are level 1 for cutting environment parameter (compressed air), level 3 for the spindle speed (5000 rev/min), level 1 for the cutting feed parameter (0.15 mm/rev) and level 1 for the depth of cut factor (0.2 mm).

![Main Effects Plot for Means](image)

**Figure 2.** Surface roughness means vs. cutting medium, cutting speed, cutting feed and depth of cut.

| Level | Cutting environment | s [rev/min] | fl [mm/rev] | ap [mm] |
|-------|---------------------|-------------|-------------|---------|
| 1     | -14.422             | -19.783     | -9.209      | -14.494 |
| 2     | -19.872             | -17.646     | 40.05       | -14.738 |
| 3     | -18.098             | -14.964     | 22.94       | -23.161 |
| Delta | 5.45                | 4.82        | 16.38       | 8.67    |
| Rank  | 3                   | 2           | 1           | 4       |

**Table 2.** S/N Response for Material surface roughness parameter Ra.

| Level | Cutting environment | s [rev/min] | fl [mm/rev] | ap [mm] |
|-------|---------------------|-------------|-------------|---------|
| 1     | 8.379               | 15.529      | 3.361       | 8.121   |
| 2     | 15.129              | 9.409       | 11.164      | 8.534   |
| 3     | 9.996               | 8.566       | 18.978      | 16.848  |
| Delta | 6.75                | 6.963       | 15.617      | 8.727   |
| Rank  | 3                   | 4           | 1           | 2       |

**Table 3.** Response Table for Means.

Sq represents the square deviation of the surface within the definition area. This parameter defines the standard deviation of heights and can be used for machining stability evaluation. Figure 3 presents the root mean square height Sq variation. The best machining stability according to the values obtained for this parameter was achieved when turning in MQL cutting medium with higher spindle speeds.
Table 4. Surface profiles of machined surfaces.

| Parameter Description | Length | Unit |
|-----------------------|--------|------|
| Compressed air, s=3500 rev/min, fl=0.15mm/rev, ap=0.2mm, R_pc=53l/mm | 1.93 | mm |
| Compressed air, s=4000 rev/min, fl=0.24mm/rev, ap=0.6mm, R_pc=40.6l/mm | 1.93 | mm |
| Compressed air, s=5000 rev/min, fl=0.5mm/rev, ap=0.6mm, R_pc=7.95l/mm | 1.93 | mm |
| MQL, s=3500 rev/min, fl=0.24mm/rev, ap=1mm, R_pc=32.6l/mm | 1.93 | mm |
| MQL, s=4000 rev/min, fl=0.5mm/rev, ap=0.2mm, R_pc=4.42l/mm | 1.93 | mm |
| MQL, s=5000 rev/min, fl=0.15mm/rev, ap=0.6mm, R_pc=59.2l/mm | 1.93 | mm |
| Dry, s=3500 rev/min, fl=0.5mm/rev, ap=0.6mm, R_pc=2.65l/mm | 1.93 | mm |
| Dry, s=4000 rev/min, fl=0.15mm/rev, ap=1 mm R_pc=47.2l/mm | 1.93 | mm |
| Dry, s=5000 rev/min, fl=0.24mm/rev, ap=0.2 mm, R_pc=30.9l/mm |

Peak Counting (R_pc) offers information on the spacing of roughness peaks. RPC is measured in peaks per cm and it is an important surface quality evaluation parameter in friction surfaces. A higher value of peak counting parameter is characteristic to intense plastic deformation and tearing. In table 6 the microscopic 2D profiles of the machined surfaces obtained in each experiment are presented. As it can be seen, when dry machining was applied, lowest value for the cutting feed parameter and the medium level for the spindle speed parameter the profile obtained does not have a repeated form and
presents sign of build-up edge and vibrations. Higher cutting feed values resulted in lower peaks for all three cutting environments tested.

![Graph showing Sq parameter variation vs cutting environment and spindle speed.](image)

**Figure 3.** Sq parameter variation vs cutting environment and spindle speed

5. **Conclusions**

Orthogonal cutting tests were carried out to investigate three different machining environments (compressed air at 2.6 bars, MQL and dry) and cutting parameters variation over aluminum alloy AA 6082-T6 machined surface quality. The optimum conditions for S/N ratio and means are level 1 for cutting environment parameter (compressed air), level 3 for the spindle speed (5000 rev/min), level 1 for the cutting feed parameter (0.15 mm/rev) and level 1 for the depth of cut factor (0.2 mm).

The lowest Ra was achieved by machining with compressed air cooling. Microscopic images of the machined surfaces profiles showed the significant differences in the case of the test carried out using MQL and the lowest value for the cutting feed parameter. The profile mentioned before showed signs of Build-up edge and vibrations. According to the values obtained for the Square deviation of the surface-Sq parameter, machining test carried out in dry cutting environment presented higher levels of instability. In the case of compressed air cooling better machining stability was obtained for the lowest values of the spindle speed parameter and when dry machining was applied better machining stability was obtained when higher spindle speed were used.

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**References**

[1] Yigit R 2014 An experimental investigation of effect of minimum quantity lubrication in machining 6082 aluminum alloy *Kovove Mater.* **52** 2014 29–33

[2] Chaudhary A, Saluja V 2017 Optimization of machining parameters affecting surface roughness of al6082 in dry end milling operation on VMC *Int Res J of Eng and Tech* **04**: 08 82

[3] Kłonica M 2018 Analysis of selected surface roughness parameters the AW 6082 T6 aluminum alloy after turning process *Mechanik* **91** 8–9 730–732

[4] Radhika A, Rao S, Hemanth N 2018 Experimental Studies On Cutting Parameters During Turning Of Aluminium 6082-T6 Alloy Using Non Edible Oils As Cutting Fluid, *Int J of Pure and App Mathematics* **119** 14 179-186

[5] Kabbir A, Amna R, Usman M, Irfan M, Jami M 2019 An investigation of the influence of surface roughness, water quality and Nozzle on spray cooling of Aluminum alloy 6082 *Therm Sci and Eng Progress* **10** May 280-286.