ABSTRACT
Adverse effects of the use of cutting fluids and environmental concerns with regard to cutting fluid disposability is compelling industry to adopt Dry or near Dry Machining, with the aim of eliminating or significantly reducing the use of metal working fluids. Pending EPA regulations on metal cutting, dry machining is becoming a hot topic of research and investigation both in industry and federal research labs. Although the need for dry machining may be apparent, most of the manufacturers still consider dry machining to be impractical and even if possible, very expensive. This perception is mainly due to lack of appropriate cutting tools that can withstand intense heat and Built-up-Edge (BUE) formation during dry machining. The challenge of heat dissipation without coolant requires a completely different approach to tooling. Special tooling utilizing high-performance multi-layer, multi-component, heat resisting, low friction coatings could be a plausible answer to the challenge of dry machining. In pursuit of this goal Argonne National Labs has introduced Nano-crystalline near frictionless carbon (NFC) diamond like coatings (DLC), while industrial efforts have led to the introduction of composite coatings such as titanium aluminum nitride (TiAIN), tungsten carbide/carbon (WC/C) and others. Although, these coatings are considered to be very promising, they have not been tested either from tribological or from dry machining applications point of view. As such a research program in partnership with federal labs and industrial sponsors has started with the goal of exploring the feasibility of dry machining using the newly developed coatings such as Near Frictionless Carbon Coatings (NFC), Titanium Aluminum Nitride (TiAIN), and multi-layer multicomponent nano coatings such as TiAlCrYN and TiAIN/YN. Although various coatings are under investigation as part of the overall dry machinability program, this extended abstract deals with a systematic investigation of dry machinability of Aluminum 6061 and 2024 using uncoated carbide, TiN coated carbide, and TiAIN coated carbide inserts. Central Composite Design (CCD) is used to study the effect of speed, feed, depth of cut, workpiece material, and cutting tool material on the resulting forces, surface finish, temperature, chip morphology and tool wear. Each of the machining responses is measured and compared under 15 different machining conditions. Results from CCD experiments have been used to develop linear and logarithmic models for forces (Fx, Fy, Fz, & Fr) surface finish (Ra), and temperature. Furthermore, chip morphology and tool wear have also been compared. From the comparison of forces, surface finish, temperature, chip morphology, tool wear and the corresponding statistical models, it is clear that in general TiAIN results in lower forces, better surface finish, greater fragmented chips, and lesser tool wear.

KEYWORDS
Dry Machining, Cutting Fluids, Aluminum Alloys, Cutting Tool Coatings, High Temperature Coatings

INTRODUCTION
In metal cutting industries the use of coolant has become more problematic in terms of both employee health and environmental pollution [1-2]. It is well known that the cost of cutting fluids alone is in the range of 14-16% of the total production costs, which does not include the cost related to the equipment needed to spray the coolant, dispose of the coolants after use, and its adverse effects on both operators and environment [3]. The traditional methods that use coolants are now obviously becoming obsolete. As such there is an increasing need for use of dry machining for environmental safety and waste reduction [4-5]. Today companies are faced with increasing demands on managing environmental issues. It is assumed that managing environmental issues and ecofriendly production methods will be the next milestone in production engineering. The metal industry has been among the first to implement quality management. In many cases, quality certificates are in fact, prerequisites for trade. Coolants are widely used in machining processes to cool the tool and workpiece, and to help remove chips from the cutting zone. Despite these benefits, the use of cutting fluids can present potential environmental problems. The driving forces for dry machining include: high owning and operating costs for cooling systems, cutting fluid related health problems, pending environmental regulations to reduce exposure levels from 5mg/m² to 0.5mg/m², and increasing disposal cost of cutting fluids.
**EXPERIMENTAL PROCEDURE**

Dry machining experiments have been conducted using two workpiece materials (Al-6061 and Al-2024) and three different cutting tools (uncoated, TiN, TiAlN). The experimental plan is arranged in a Central Composite Design Matrix shown below, consisting of 8 corner points, 9 center points, and 6 star points with one repeat, resulting in a total of 29 experiments in each of the six different experimental sets investigated.

<table>
<thead>
<tr>
<th>Design Factors</th>
<th>Units</th>
<th>Coded Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed</td>
<td>(in/min)</td>
<td>-1.6818 -1 0 1 1.6818</td>
</tr>
<tr>
<td>Speed</td>
<td>(m/min)</td>
<td>1260 3937 7874 11811 14488</td>
</tr>
<tr>
<td>Feed</td>
<td>(in/rev)</td>
<td>32 100 200 300 368</td>
</tr>
<tr>
<td>(mm/rev)</td>
<td>0.005 0.008 0.012 0.020 0.018</td>
<td></td>
</tr>
<tr>
<td>Depth of Cut</td>
<td>(in)</td>
<td>0.132 0.2 0.3 0.4 0.468</td>
</tr>
<tr>
<td>(mm)</td>
<td>0.005 0.008 0.012 0.020 0.018</td>
<td></td>
</tr>
<tr>
<td>0.466 1 1.5 2 2.34</td>
<td></td>
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</tr>
</tbody>
</table>

A Kistler piezoelectric high impedance dynamometer, model 9265B with tool holder model 9441B, is used to measure the feed force Fx, radial force Fy, and cutting forces Fz. Based on the above CCD, 29 experiments were done for each material with each tool coating, using various speeds, feeds and depths of cuts. A Mitutoyo Surf Test SJ-301 was used to measure the surface roughness Ra of the workpiece material after each experiment. Extreme care was taken to ensure that the stylus traverse was parallel to the axis of the cylindrical turned part. Two measurements were made for each turning test and the average of the two was used as the final surface roughness Ra. An Omega temperature sensor measured the surface temperature T of the workpiece material after each test. The temperature was measured immediately after the turning test to ensure minimum heat loss. The chips from the workpiece material were also collected and analyzed after each experiment.

**EXPERIMENTAL RESULTS**

The results of the machining tests conducted randomly as per the design of experiments table given in the previous section yielded various responses like forces, surface finish, temperature, and chip morphology.

**Force Results:** The components of the forces produced during machining in the x, y and z directions namely Fx, Fy and Fz were collected by the data acquisition system. The forces produced at each speed, feed and depth of cut were calculated by averaging 4000 data points (200 revs with 20 data/rev). Linear and logarithmic models were generated from the data and 2-D and 3-D contour plots drawn to study the influence of cutting parameters on the three components of the cutting force and the resultant force Fr.

**Surface Finish and Temperature Results:** Again linear and logarithmic models were developed from the data collected and 2-D and 3-D response surfaces drawn to study the influence of machining parameters on temperature and surface finish.

**Chip Morphology:** Chips were collected for all the six sets of experiments (2 workpiece materials and 3 coatings).

Critical comparison of chip morphology was made both with respect to machining parameters and between six sets of 29 experiments.

**Tool Wear:** Although tool wear was not measured after each experiment, it was measured after each of the six CCD sets of 29 experiments. Flank wear and crater wear were studied using high-resolution optical microscopy.

**CONCLUSIONS**

1. The Feed force, Fx produced by TiN coated tool is 17% lower than that of uncoated and TiAlN coated tools when machining Al-6061 and Al-2024.
2. The Thrust force, Fy produced by TiAlN coated tool is 15% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
3. The Cutting force, Fz produced by TiAlN coated tool is 21% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
4. The Resultant force, Fr produced by TiAlN coated tool is 18% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
5. The Surface Finish, Ra produced by TiAlN coated tool is 14% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
6. The Temperature T produced by TiAlN coated tool is 17% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
7. The Chips produced by TiAlN coated tool are more fragmented than those produced by uncoated and TiN coated tools when machining Al-6061 and Al-2024.
8. The Tool wear for TiAlN coated tool is 19% lower than that of uncoated and TiN coated tools when machining Al-6061 and Al-2024.
10. Using TiAlN coated tool the optimum speed, feed and depth of cut with is 300m/min, 0.2mm/rev and 1mm for Al-6061 and 300m/min, 0.3mm/rev, and 1.5mm for Al-2024 respectively.

**REFERENCES**