ABSTRACT

Machinability of a material provides an indication of its adaptability to a machining process. In general, machinability is defined as ease of machining of a material, characterized by low cutting force, high material removal rate, good surface finish, accurate and consistent work-piece geometrical characteristics, low tool wear rate and good curl or chip breakdown of chips etc.

In this research work different concentrations of various solid lubricants in SAE-40 oil were applied to the chip-tool interface by a new technique and their effect on various machinability parameters of EN-31 steel were studied under turning operation. In the new technique solid-liquid (mixture) lubricant was applied with a brush at the machining zone, so that the lubricant seeps into the chip-tool interface. This reduces the chip-tool interface temperature and lubricates the surface, and makes cutting easy. All the machinability parameters studied were found to improve by this technique, the amount of lubricant that seeped to the chip-tool interface was negligible, thus a true minimum quantity lubricant (MQL) cutting or near dry (ND) cutting conditions were achieved.

EN-31 steel was selected for machinability studies, because it is widely used in automotive industry for the production of axle, roller bearings, ball bearings, shear blades, spindle, forming and molding dies, etc. Turning is the main machining process for the production of these parts. Therefore EN-31 steel was chosen for the machinability studies under turning operation.

The machinability criteria chosen for this study were, chip-tool interface temperatures, cutting forces, specific cutting force, power consumption, surface roughness, tool wear rate, chip thickness, chip micro hardness, chip-tool contact length, shear angle, cutting ratio, type of chip formed and coefficient of friction. Cutting velocity, feed rate, depth of cut and tool nose radius were the machining variables used. Dry cutting, cutting under flooded liquid coolant/lubricant and with three different (solid-liquid) mixtures of lubricants were used under different machining conditions and different machinability parameters were evaluated.

A tool-chip mercury pool thermocouple was designed and fabricated for these studies and it was calibrated using a new technique developed by the author. The calibration process is described in this work.
The percentage of solid lubricants in SAE-40 oil was varied and optimum percentage of the solid lubricants was determined on the basis of cutting force and chip-tool interface temperature. It was found to be 10% of graphite, MoS$_2$ and boric acid powder. For further studies this percentage was used throughout the investigations.

The planning of experimental conditions was done by composite factorial design, instead of one-factor at a time approach. The results were analyzed graphically as well as statistically by using ANOVA. Statistical modeling of various machinability criteria were done by response surface methodology coupled with factorial design. Combined Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to the Ideal Solution (AHP-TOPSIS) multi-criteria decision making method was used for selecting the right lubricant amongst a number of lubricants used during steel turning operation. Optimum combination of process parameters for various machinability parameters were found by using rotating square evolutionary operation (ROVOP) method by determining the cooling efficiency of different solid-liquid lubricants. Then response surface method with grey relational analysis was used for optimization of multiple performance characteristics. Moreover, the principal component analysis was applied to evaluate the weighting values corresponding to various performance characteristics so that their relative importance can be properly and objectively described. In addition, a multi-objective performance characteristic called as grey relational grade was calculated by using grey relational analysis technique. The combination of machining parameters that gives the highest grey relational grade is the optimum combination that produces all the targeted machining indices (temperature, cutting force, feed force, surface roughness, tool wear rate and chip thickness) minimum. A response surface model was developed to correlate the multi-performance characteristic (grey relational grade) and machining parameters. The new method of combining response surface modeling and grey relational analysis was found to be an efficient method of multi-performance characteristics optimization.

Lastly, the effect of temperature of solid-liquid lubricant on machinability of EN-31 steel was investigated. For this study, Taguchi Design was used and Taguchi Utility Concept was used for optimization of surface roughness and metal cutting power consumption simultaneously.
This research work has conclusively proved that application of solid-liquid lubricants at the cutting zone with a brush is a novel and more efficient technique than the flooded coolant application of a liquid coolant for improving all the machinability parameters. A negligible quantity of solid-liquid lubricant seeps into the tool-chip interface, lubricating the surfaces and the chip-tool interface temperature reduces because of less heat generation rate than the cooling action of flooded fluid generally applied. This is a real minimum quantity lubricant (MQL) technique.

Out of the solid-liquid lubricants tested 10% boric acid + SAE-40 oil is found to be the best lubricant for EN-31 steel in turning operation. The application of the 10% boric acid + SAE-40 oil lubricant at temperatures less than the room temperature further improves the machinability of EN-31 steel.

Various statistical models for the different machinability indices have been developed and given in this work. These models can be directly used in the industries for selecting the cutting parameters for a specific level of a machining index selected.

Further, optimal combinations for various machining parameters for different machinability criteria have also been developed and reported. These can be used by the industries to improve their productivity and product quality.