CHAPTER 6

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6.1 CONCLUSIONS:

Experiments are conducted to investigate the mechanism of MQL in HSM of hardened steel comprehensively. From the experimental work and the analyses carried out by the author, it has been possible to consolidate and highlight some fundamental findings, not available earlier, in regard to comparison of dry, MQL and flooded milling. By application of servo cut S as oil lubricant during the MQL milling, which when mixed with water, produce adequate cooling effect and subsequently result in significantly low values of surface roughness and tool wear with optimum values of speed, feed and depth of cut.

Results obtained by the author are summarized as a concluding part of the thesis, which would bring adequate knowledge base for professional technocrats working in the manufacturing areas.

Important conclusions are put as under:

An innovative aerosol spray gun (MQL delivery system) having uninterrupted supply of MQL at required coolant pressure over a reasonably long cut has been developed and used during experimentation. Aerosol is impinged at a high velocity through the nozzle on the chip-tool interface.

The exponential equations (first and second order) for surface roughness in case of MQL parameter optimization are reproduced here:

From the above equations it can be concluded that

1. In case of MQL parameter optimization of AISI H13
   • It is observed that the MQL parameters namely coolant pressure, angle of impingement, spot distance have their own influence on the cutting performance during end milling of hardened AISI H13 steel.
• The analysis of variance confirmed that the above models (Eq.3.3 and Eq.3.4) are adequate for determining the optimum MQL parameters at 95% confidence interval.
• Size of individual droplet is inversely proportional to exit velocity of coolant pressure.
• As the coolant pressure at the nozzle outlet is high, better penetration will be facilitated leading to better lubrication at the contact surfaces.
• Minimum spot distance retains maximum momentum of aerosol.
• At medium impingement angle and lower spot distance the momentum of MQL acts more directly against the momentum of the chip flow.
• MQL yielded a minimum surface roughness value 0.17μm, while end milling AISI H13 steel, when CP=5.633 bar, A=41.924°, and SD=20.003mm.
• The coolant pressure effects upon surface roughness are large compared to the effects of angle of impingement and spot distance.
• Outcome specifies that surface finish improves with increase in coolant pressure followed by lowering the spot distance and keeping the angle of impingement moderate.
• The cutting performance of MQL machining is better than that of dry and flooded machining because MQL provides the better surface finish.
• Fewer burrs formed during machining with MQL which is a distinct advantage compared to dry cutting and the flood cooling method resulting in a lower deburring cost in MQL.
• Surface finish also improved mainly due to reduction of wear and damage at the tooltip by the application of MQL.
• Less deformed, saw tooth type golden yellow colored broken chips which could be easily handled were observed in MQL milling experimentation specially at higher coolant pressure. These chips are generated due to deeper penetrability of the high pressure cooling jet into chip tool interface.
• Milling with MQL mode protects the operator’s health and reduces the detrimental effects on the environment.
• Result in this work indicated that end milling with new external application MQL unit holds promise for the development of a commercial environment friendly near dry machining application scheme with particular reference to end milling of hardened AISI H13 steel.
• The study indicates clearly that the Genetic Algorithm analysis accomplished effectively the optimization of surface roughness.

2. Experiments are conducted to investigate the behavior of new set up of mechanism of MQL spray gun in machining (HSM) of hardened steel AISI H13 comprehensively for cutting parameters viz. cutting speed, feed and depth of cut. In case of MQL milling of AISI H13 the exponential equations (first order and second order) for tool life and surface roughness are as follows.

For tool life:

For surface roughness:

• It is found that comparing with dry and flooded cutting, the tool performance of MQL can be enhanced in this study.
• Lower surface roughness and higher tool life values were found at the following cutting conditions.
  Cutting Speed: 160m/min, feed: 0.20 mm/rev, Depth of cut: 0.25mm,
  \[Ra = 0.22 \text{ } \mu\text{m}, \text{ TL}= 3800 \text{ mm}\]
• The analysis of variance confirmed that the above models are adequate for determining the optimum quality characteristics at 95% confidence interval.
• MQL jet provides reduced tool wear, improves tool life and better surface finish as compared to dry and flooded end milling of hardened steel.

• Surface finish and dimensional accuracy improved mainly due to reduction of wear and damage at the tool tip by the application of MQL. Such reduction in tool wear would either enhance tool life or productivity, allowing higher cutting speed and feed.

• Effects of cutting speed and axial depth of cut are significant whereas feed effect is less significant on tool life.

• Tool life is minimum when feed and cutting speed are at their higher limits and is maximum when feed is at the 0.2 mm/rev and cutting speed is at the lower limit 120m/min.

• Tool life increases with increase in depth of cut up to 0.45mm for lower values of cutting speed and after word decreases. Tool life tends to decrease with increasing cutting speed.

• Tool life is minimum when depth of cut and feed are at their higher limits and is maximum when depth of cut and feed are at their lower limits.

• From SEM photo (Experiment. No.5) it is found that severe groove wear and notch wear at the flank surfaces in the insert for the experiments where value of depth of cut was maximum.

• The reason of very unsatisfactory tool life under flood cooling condition is due to the occurrence of thermal cracks on the cutting edge caused by thermal shock.(SEM photo) (Experiment. No.22)

• The percentage increase of tool life for MQL as compared with dry and flooded cutting is 46.05% and 94.47% respectively.

• Effects of cutting speed and feed are significant whereas effect of axial depth of cut is less significant on surface roughness.

• It was found that surface roughness decreases with increasing cutting speed and when feed was increased, the roughness was found to increase.

• It appears that surface roughness grows quite fast under dry and flooded machining due to more intensive temperature and stresses at the tool-tips.
The present MQL systems enabled reduction in average chip-tool interface temperature and even such small reduction enabled significant improvement in the major machinability indices.

The cutting performance of MQL machining is better than that of dry machining because MQL provides the benefits mainly by reducing the cutting temperature, which improves the chip-tool interaction and maintains sharpness of the cutting edges.

The most significant contribution of application of MQL in machining the steel by the carbide insert undertaken has been the high reduction in flank wears, which would enable remarkable improvement in tool life.

The thesis suggests a newly developed and fabricated set up for MQL milling which gives encouraging results leading to minimum surface roughness and tool wear. This set up can be used in the industry for the betterment of productivity and quality.

MQL is consumption lubrication, that is, the most of the lubrication applied is evaporated at the point of application. This evaporation in combination with the compressed air cools the work piece and tool remains nearly dry in ideally adjusted MQL system. MQL reduces induced thermal shocks and helps to increase the work piece surface integrity in high tool pressure.

Servo cut S oil gives encouraging results in MQL milling of AISI H13.

3. MQL improves surface finish depending upon the work tool materials and mainly through controlling the deterioration of the cutting edge by abrasion, chipping and built up edge formation.

4. From the discussion presented in this study, it is apparent that MQL systems possess many advantages over dry and flooded coolant system. However, some modification of machine tools for obtaining the best performance out of them is also required. When the flood coolant system is not present, the machine tools should be equipped with a chip removal system. There is additional cost involved in the equipment for MQL. A cost-benefit analysis is required before implementing MQL system.
5. Minimum quantity cooling lubrication systems are a considerable possibility to realize the function lubrication, necessary for instance to realize a certain surface quality or to achieve economic tool-life, with a minimum amount of cooling lubricant. It depends on the machining operation and the technology, whether this cooling lubrication technology is practicable. The results of the experiments illustrate that MQL can be applied to various machining operations. An additional potential for the increase of the economic efficiency is given by the loss of the waste disposal problems for the worn out cooling lubricant and oiled-up chips or the possible renouncement of workpiece washing operations.

6. A Particle Swarm Optimization (PSO) algorithm optimization is used to cross validate the results obtained by Genetic Algorithm in case of MQL milling operations.

Results by GA:
Cutting Speed: 153.30 m/min, feed: 0.12 mm/rev, Depth of cut: 0.25 mm, Ra = 0.21 μm,
TL = 5585.81 mm

Results by PSO:
Cutting Speed: 137.25 m/min, feed: 0.1 mm/rev, Depth of cut: 0.25 mm, Ra = 0.21 μm, TL = 7664.5 mm

By using PSO algorithm, the improvement in objective function for TL over GA is 8.95% and 37.21%, when Ra value is 0.15 μm and 0.21 μm for both the case respectively. From the above results it is concluded that in PSO the solution is continuously improve and also it gives better results as compared to genetic algorithm. The above optimization algorithms are easy to use, simple to implement, and can efficiently handle the multimodal and multiobjective optimization model. The improvement by using the PSO algorithm is due to the collaborative population based search, which the PSO algorithm follows. The PSO system combines local search methods through self experience with the global search methods through neighboring experience, thus attempting to perfect balance the exploration and exploitation process. The GA process of moving from one population of points to another enables it to discard potential local solutions.
and also to achieve the superior solutions in a computationally more efficient manner. These solutions provide the industry person and researcher with superior estimates of interpolation data.

6.2 FUTURE SCOPE:

The demand of safe environment force the industry using minimum quantity of lubrication (MQL) tending to near dry machining. The work in this area of MQL needs to be amplified specially in hard-to-cut materials. Optimum parametric relationships of input and output parameters, developing mathematical equations would help and lead cost conscious professional technocrats towards green and clean environment on shop floor keeping workforce away from occupational hazards and diseases.

Meticulous experimentation on commonly used materials with nano fluids should be a next step to study in depth for the parameters operating in a wide range of values affecting different process outputs, which are of functional and operational importance. Similar type of work can be carried out on composite materials and nano materials. The output parameters like material removal rate (MRR), temperature, forces can be considered. Modifications in MQL equipment can also be the new area of research. The similar work can be deployed for different manufacturing operations.

The methods like Teaching Learning Based Optimization (TLBO), Harmony Search (HS), and Artificial Bee Colony (ABC) algorithm can be considered for optimization purpose.

The data base may be prepared for optimum parametric relationships. The ready-to-use data, thus be made available to manufacturing technocrats for simple and rapid process planning and also for designing of products.