Cutting regime optimization in turning operations of mild steels for industries in Bangladesh for sustainability

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Abstract:

Mild Steel (MS) is the most widely used material for machine component manufacturing. In Bangladesh, the small and medium scale companies occupy the major portion of the country's machine or machine components manufacturing using MS and other materials. Most of these companies do not have enough engineering skills on adequate and economical machining processes design. This paper demonstrates an easiest real life experimental methodology of determining optimal cutting regimes for locally available MS using homemade cutting tools in the workshop environment. As the application of this experimental methodology the authors have also displayed preliminary results of optimization of cutting regimes (speed, feed, and depth of cut) for machining locally available Mild Steel using high speed steel cutting tool (homemade). The results have witnessed that the user-friendly methodology can be used in any metal machining company of any sizes. The significance of this paper is to widely publicise the methodology which is highly benefitable for metal machining industries.

Keywords: *optimization of cutting regimes, single point cutting tool, tool geometry, surface finish, mild steel.*

1. INTRODUCTION

Mild Steel (MS) is a widely used material for manufacturing machine components, in many cases more than 70% components are made of MS. In most of the cases mild steel components are produced by various subsequent machining operations. Developing countries like Bangladesh locally produces MS for its consumption or uses imported MS from countries mainly like China and India. Ironically mild steels either imported or locally produced are not always compliant to the standard chemical composition and mechanical properties. This noncompliance of standard composition may happen due to various reasons. Normally mild steels produced in different steel mills may differ in chemical compositions, as well as, that may differ from batch to batch of production even produced in the same steel mills. This type of noncompliance of chemical and mechanical properties makes machining processes difficult, uncertain, less productive, more defect products, lower surface quality and un-necessary higher operation times, because machining processes designers as well as machine operators and their shop supervisors are strongly used to follow standard given cutting regimes provided by the cutting tools suppliers for particular types of cutting tools. Surface finish and surface quality of machined products are highly dependent on cutting regime selection for particular cutting tools. Deviation of chemical composition and physiomechanical properties demands changes in optimum cutting regimes provided by the cutting tools suppliers.

Literature search shows that optimized cutting regimes: speed (v), feed rates (f) and depth of cut (h) are ones of the major criteria, amongst many others, influencing the productivity of metal machining industries. So, if these parameters are controlled in such a manner that the desired surface finish as well as the quality of the product are ensured, the combination of optimization will be achieved. For achieving this combination, a significant number of operations should be carried out and the outcomes should be compared. As every parameter influences the total outcome vitally, no minor change should be ignored; otherwise the result will be erroneous. Close observation of every operation and accurate collection of raw data can ensure the entire experiment flawless and the proper interpretation of the collected data will lead to the point of optimization.

The output of the current research must be economically helpful for local metal machining industries to become more sustainable in their business. The results of this research work are vital essences for use of machining processes designers. Not only for Bangladesh, this research may lend a hand for all of the countries who are using mild steels for producing different machine elements because without being efficient no organization can sustain in the global competition. As the technology improves, the organizations are running for better efficiencies and to gain this very efficiency every single job should be studied well to reach its optimum level. This research will contribute vividly to maintain the machining processes optimized, eventually which will smoothen the way to sustain in the global business successfully and eternally.

2. THEORETICAL ASPECTS OF MACHINING PROCESSES OPTIMIZATION

Adequate manufacturing processes design is one of the major criteria for achieving longer sustainability of any industry in its business particularly during this worldwide global economic crisis period. But, in many developing countries like Bangladesh, to maintain the optimized conditions of all the cutting regimes while machining is not so easy and consequently the metal machining industries, particularly small scaled, are facing a significant losses every year. Currently with the affect of globilisation machine manufacturing companies in Bangladesh really represent small scale industries. For this reason, the optimization of cutting regimes are being experimented by the researchers since long time and some of them are highly successful for some particular metals and cutting tool combination. In this paper, the experiments displayed were carried out on mild steel using a single point cutter, specifically for turning operations, as these are the major operations for the local manufacturers. Since the optimization of cutting regimes differs from material to material and also depends on the cutting tool material and its geometry, this paper exhibits the optimization of different parameters by keeping the tool and job materials as well as the tool geometry constant. As much as the cutting regimes optimized, the productivity and the job quality will be improved which leads to more profit for the machine manufacturing industries.

Optimal machining condition is the key to economical machine manufacturing processes. Optimization of metal cutting operations means determination of the optimal set of operating conditions to satisfy an economic objective within the operation constraints [1].

Turning is the process of machining external cylindrical and conical surfaces [2]. It is usually performed on a lathe. The cutting forces, resulting from feeding the tool from right to left, should be directed toward the headstock to force the work-piece against the work-holder and thus provide better support. Usually, the selection of appropriate machining parameters is difficult and relies heavily on the operators' experience and the machining parameters tables provided by the machine-tool builder for the target material [3]. The first source of optimal cutting parameters for certain cutting tool are the cutting tools suppliers / manufacturers. Various Mild Steels are used by different manufacturing industries to produce numerous machine elements.

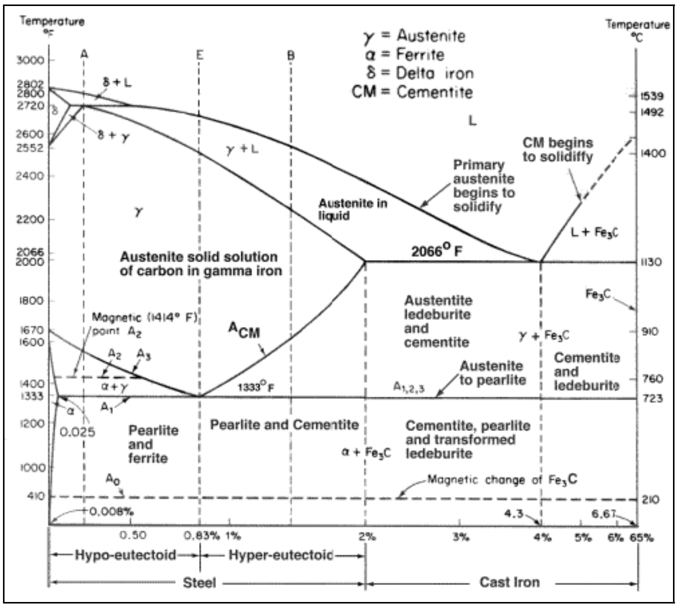

Figure 1. Phase diagram of iron-carbon

Mild Steel is also known as low-carbon steel which has less than 0.30% Carbon [4]. Fundamentally mild steel contains 0.16–0.29% of Carbon by mass. Chemical composition of mild steel referring to local and international standards [5] are 0.25 wt.% C, 0.06 wt.% P, 0.06 wt.% S and 0.42 wt.% Ce. Density of mild steel is 7,861.093 kg/m³, the tensile strength is a maximum of 500 MPa (72,500 psi), percentage of elongation is 7% and it has a Young's modulus of 210 GPa. It becomes malleable when heated and the color is shiny after polished. Referring to the Figure 1, the melting point of mild steel [6] is around 1426–1538 °C (2600–2800 °F). As the properties of material is a vital factor for any metal cutting operation, the properties of Mild Steel also influence a lot to optimize the cutting parameters.

Following the research outcomes of many researchers including the authors' finding it has been hypothesized [7] that the following are the most required key issues for optimization of metal machining processes:

- Advanced cutting tool materials; search for better suitable cutting tool materials suitable for particular material to be machined;
- Establish optimized cutting regimes: optimal cutting speed (v m/min) zone, feed rates (f) and optimal depth of cut (h);
- Optimizing cutting (tool) edge geometry such as front rake angle, wedge angle, end-relief angle, side rake angle, nose angle and nose radius;
- Suitable machine tools selection (for achieving certain dimensional tolerances), including high speed spindle applications;
- Consideration of theoretical analysis of heat generation and heat transfer in cutting zone;
- Analysis of chemical reactivity at atomic and molecular level between cutting tool materials and job material;

- Consideration of chatter and vibrations during metal cutting processes in the MFTW (machine, fixture, tool, workpiece) system.
- Efficient cooling liquid, and cooling process development;

This paper concentrates on the second point from the above list, which is optimization of cutting regimes for locally available mild steels available in Bangladesh using home-made high speed steel (HSS) cutting tool. In this paper, the cutting regimes considered are speed (v), feed rates (f) and depth of cut (d). All of these parameters are highly responsible to determine the efficiency of turning operations. The main issue was to maintain the quality of the surface finish so that the maximum utilization of our machine tool and time can be achieved. In this regard, all of these parameters are adjusted so that the best result can be found. The process of optimizing machining processes is well known [7] to metal machining community; it is a process of repetition and refinement to minimize production costs as well as operation time for currently used materials using advanced cutting tools and tool materials.

3. METHODOLOGY OF TURNING OPERATIONS OPTIMIZATION

Metal cutting phenomenon is so much complicated in that sense that so many known and unknown parameters are involved in physics of metal machining. In this research, the methodology which was followed is the real life experiments. As the experiment was carried out in a lathe machine, a three-jaw chuck was used for this purpose to hold the work-piece. In turning, the primary cutting motion is rotational with the tool feeding parallel to the axis of rotation. The RPM value of the rotating work-piece, N, establishes the cutting velocity, v, at the nose of cutting tool [2].

Cutting speed, v is calculated by the following equation –

$$v = \frac{\pi DN}{1000} \text{ m/min}$$

where,

D = diameter of the work-piece, mm
N = number of revolutions of the spindle/work-piece per minute, RPM.

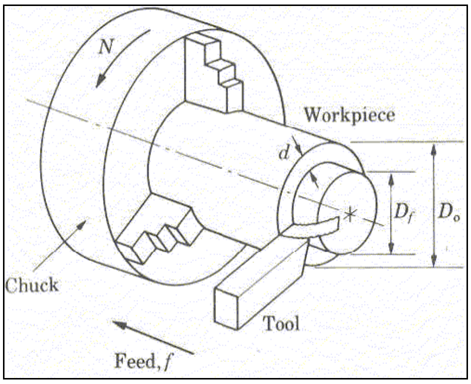

Figure 2. Basic turning operation in a lathe machine

The work-piece was a Mild Steel (MS) bar procured from local market. A slide calipers was used to measure the diameter of the bar during the different stages of operation and a surface finish comparator was used to assess the roughness of the surface of the job. This comparator is a precision roughness gauge for assessing the surface integrity obtained in various machining processes. It provides a convenient and reliable visual method of quickly determining the approximate roughness value of a production part. Roughness is defined as closely spaced, irregular deviations on a scale smaller than that of waviness [4]. It is expressed in terms of its height, its width, and its distance on the surface along which it is measured.

At the first stage the mild steel bar was turned, as in Figure 3, using a homemade single point HSS cutting tool with variable values of cutting speed v. During this stage both feed rate f and depth of cut d were kept constant at their normal values. After every turning operation of a particular cutting speed the surface roughness R_z was assessed by the surface finish comparator. Then the data are plotted in a graph (R_z vs. v) that displays the range of optimized cutting speeds v_{opt}. The produced graph clearly shows the best cutting speeds providing best possible surface roughness.

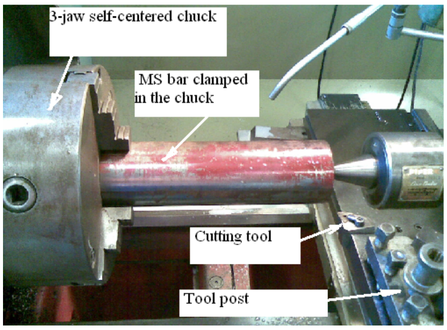

Figure 3. Experimental set-up

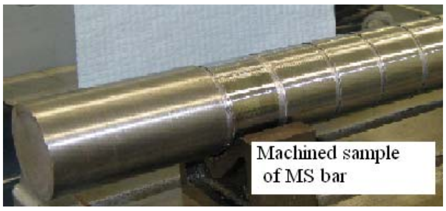

Figure 4. An example of machined sample of MS bar

The same operations were carried out again by keeping the cutting speed, v = v_{opt} and the feed rate constant. But, at that time the depths of cut, d were changed by different values. Similarly as before, after every turning operation the surface roughness was measured by the surface finish comparator and recorded. The obtained data from these operations are plotted again with the depth of cut versus surface roughness and as a result the optimum depth of cut was achieved from the graph in the similar method as it was in the case of cutting speed.

On the third stage, the previous operations were repeated by keeping the cutting speed, v and depth of cut, d to their achieved optimum values. But, in this stage the feed rates, f were varied by different values. The surface roughness was compared after completing every cycle of operations and recorded for plotting the graph with feed rate (f) versus surface roughness (R_z). From this graph, the range of optimum values of feed rate was easily determined.

When all of the above operations were carried out successfully, the optimum values of the cutting regimes – cutting speed v, feed rate f, and depth of cut d were found which are desired to optimize the turning operations as well as to make the operations efficient and cost effective. The above mentioned operations were carried out very sincerely so that the true and perfect values may come from the experiment. The lathe machine was operated by a skilled operator and the speed of the chuck was adjusted accurately.

4. RESULT DISCUSSION

As the experiment was conducted to optimize the cutting regimes, it was very important to record all of the data very carefully with maximum accuracy. Surface roughness is nothing but the quality of works, so the more the metal is cut with surface finish, the more the quality of the work is ensured. But, to maximize the efficiency, the cutting parameters should be adjusted in such a manner that both the quality and quantity are achieved.

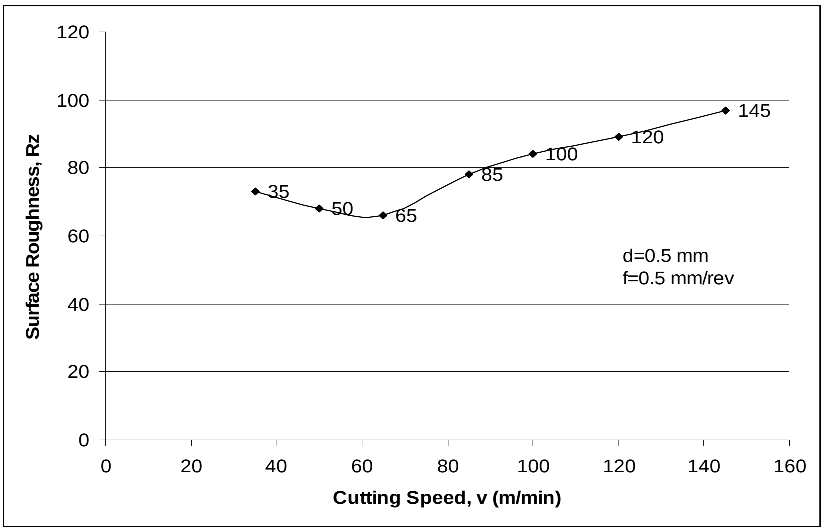

Figure 5. Optimization graph for cutting speed

From the above graph (Figure 5) the optimum cutting speed found for minimum surface roughness is 60 m/min and so this value or close to this value of cutting speed is used for the next graph.

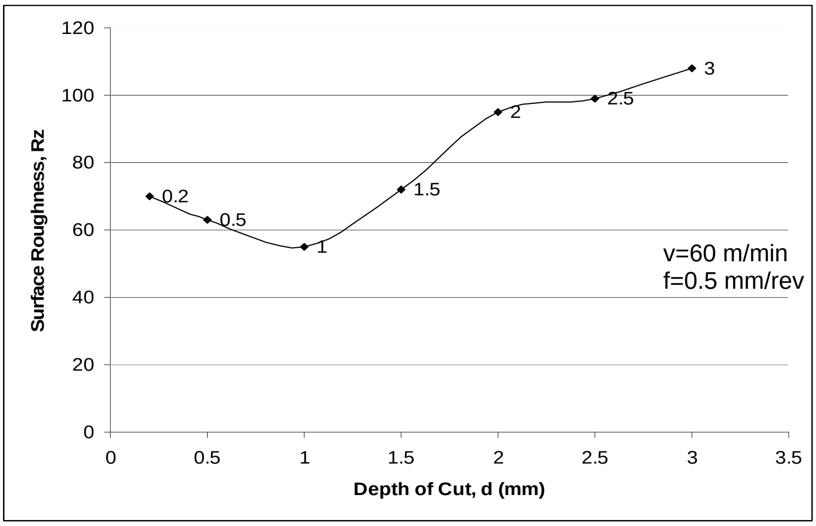

Figure 6. Optimization graph for depth of cut

In Figure 6, the graph displays, the optimum depth of cut, d is found 0.94 mm for minimum surface roughness and similarly as before this value is an input for the following graph.

According to this final graph, it is found that the feed rate should be 0.32 mm/rev to obtain the best surface roughness. Hence, it can be concluded that for a mild steel specimen in turning operation, the cutting speed v should be maintained 60 m/min, depth of cut d should be 0.94 mm and the feed rate f should be 0.32 mm/rev to achieve the better surface finish in an economic way. This is an optimum combination for cutting regimes (v, d, f) found from the experiment.

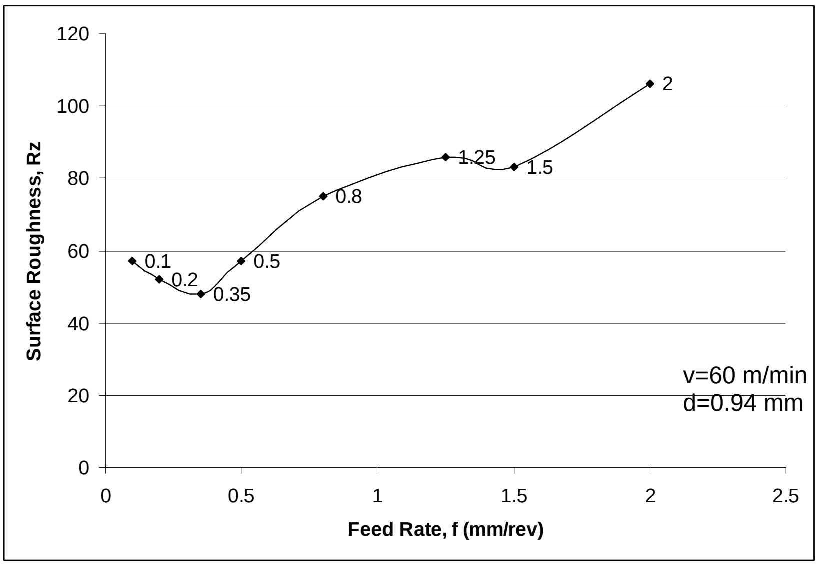

Figure 7. Optimization graph for feed rate

During the experiment, the types of chip formation were also observed and found that as the surface roughness increases the chips were getting discontinuous or segmented. In fact, as the targeted parameters were increased, the vibration of the work-piece was also increased which resulted poor surface quality. The job was adequately located and clamped in the 3-jaw self-centered chuck supported in the centre of the tailstock and sufficient coolant was supplied to avoid raising high temperature.

5. CONCLUSION

Optimization of cutting regimes in turning operations of mild steel will play a significant role over the manufacturing industries in Bangladesh, because as a developing country the manufacturing sector of Bangladesh in metal processing is getting enriched day by day. Not only large industries are contributing in this sector, but also different small and medium industries produce various mechanical parts from mild steel. So, if these industries are knowledgeable adequately about the optimum cutting parameters, their profit will arise in such a position that they can easily compete with different world renowned companies and will easily survive in the long run.

A low cost and user-friendly methodology for metal cutting regime optimization applicable in workshop environment has been displayed and publicised; the methodology can be easily used practically by any metal machining workshop.

Though the output of this paper is simply applicable for machining mild steel, this technique will be applied for any type of materials. It is clear from the experiments performed that cutting speed, feed rate and depth of cut all are highly responsible for maintaining the surface quality of a machined part; therefore, these parameters should be controlled in an efficient way.

From this study it can be concluded that if the cutting speed is increased, the surface roughness will increase and after a certain speed if the cutting speed is decreased, the surface roughness will increase again. Similarly, it is found that when the feed rate and depth of cut are increased, the surface roughness will also increase. To end with all the circumstances are examined properly to reach to the optimum condition which will ensure the maximum surface finish as well as will ensure the minimum production cost.

The research output and the displayed methodology are highly helpful for metal machining, machine tools and cutting tools, machine manufacturing industries for their longer sustainability.

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