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CRITERIA FOR DETERMINING MACHINABILITY AND TECHNIQUES OF IMPROVING MACHINABILITY OF STEEL AND ALLOYS

A.K.M. Nurul Amin[a]

[a] *Department of Industrial and Production Engineering, Bangladesh University*
of Engineering & Technology,
Dhaka-1000, Bangladeh

ABSTRACT

It has been established that during of steel and other work materials there is a definite cutting speed at which chip-tool-contact changes abruptly from contact with built-up-edge (BUE) formation to contact without BUE formation. This cutting speed has been termed as critical cutting speed, V_c. Intensity of wear of a tungsten carbide tool is minimum at a speed slightly lower that V_c, when a soft BUE protects the tool from intensive wear. In case of with Tungsten-Titanium carbide tool there is a second cutting speed, slightly above V_c at which a second peak of tool life is observed. These speeds have been referred to as optimum cutting speeds, $Vopt_1$ and $Vopt_2$ respectively. Since both these speeds have definite relationship with the critical cutting speed, V_c which has a specific value for every pair of work and tool materials and conditions of cutting, so the speed V_c may be used on an important criteria for determining machinability of work materials. Three different methods of determining cutting speed V_c has been discussed in this paper.

Two different methods of improving machinability of steel has been discussed in the paper. In the first method machinability has been improved by micro-alloying of steel with calcium, which leads to a considerable shift of V_c towards higher cutting speed (by approximately 140%). The reasons for this improved machinability has been explained in the paper.

In the second method low machinability of Titanium alloys and heat resistant steel, associated with instability of chip formation leading to micro and macro chipping of the tool is overcome by preheating of these materials to optimum temperatures. Preheating considerably raises tool life due to lower amplitude and average value of cutting force and higher chip-tool contact length resulting in lower stress, acting on the tool tip.

1. INTRODUCTION

Machinability is an important property of an engineering metals, material, because it determines how much effort is necessary to make a final product out of the material. A lot of research works throughout the world are devoted to improvement of machinability of materials. Machinability is dependent on the physio-mechanical properties of materials and may be determined as a function of cutting force, tool wear, cutting temperature, etc. In the present paper machinability has been treated mainly as a function of tool wear. It has been established by previous research works that wear of a carbide tool is a function of contact processes at the chip-tool interface, which in turn is dependant on cutting temperature, feed, depth of cut and other variables. Study of the chip tool contact processes shows that at a particular cutting speed built-up-edge (BUE) vanishes from the tool face. This cutting speed has been termed as critical cutting speed V_c. For a single carbide tool material the cutting speed corresponding to the minimum intensity of tool is abit lower than this critical speed and is termed as optimum cutting speed. On the other hand for a double carbide tool there is a second peak values of tool life at cutting speed abit higher than V_c. These speeds are referred to as optimum cutting speed, Vopt.1 and Vopt.2 respectively.

The magnitude of V_c is different for different materials. It is associated with the energy of plastic deformation and the rate of heat generation at the shear zone and at the chip-tool-job interfaces. Higher the rate of heat generation and lower the rate of heat dissipation from the cutting zone, lower is the value of critical cutting speed V_c. That is why harder and higher strength materials have lower value of V_c than softer and lower strength materials. Since minimum tool wear values are at cutting speeds very close to V_c, this speed may be used as a criterion for determining the machinability of a work material.

Heat treatment like annealing or normalizing and micro alloying of work materials with phosphorus, calcium and other ingredients lead to higher values of V_c and consequently in raising machinability of work materials.

It is also known that low machinability of heat resistant steel, titanium alloys and such other materials is associated with instability of the chip-formation process, which lads to micro and macro chipping of the cutting tool resulting in low tool life. Machinability of such materials may also be improved if the instability of chip formation may be removed or lowered by preheating of the job material to optimum temperatures. The present paper deals with some of these aspects of improving machinability of work materials.

2. EXPERIMENTAL SETUP AND CONDITIONS

Experiments were conducted on an engine lathe. A dropping tool apparatus was used for instantly withdrawing the tool from the cutting zone. A microhardness measuring instrument was used for measuring the hardness of the different sections of the frozen chip. A metallographic microscope was used to take photograph of the chip surface. An instrument microscope was used to measure the tool flank wear. A dynamometer was used to measure the cutting load. An induction furnace was used for preheating the workpiece.

Mechanically clamped single and double cemented carbide tools were used for cutting. Work materials experimented were : mild and medium carbon, low allowed steel and heat resistant steel, and titanium alloy in the form of shafts. Cutting parameters were varied in the following ranges:

Cutting speed, $V = 0$ to 200 m/min.
Feed rate, $S = 0.2$ to 0.5 mm/rot.
Depth of cut, $t = 1$ mm to 5 mm.

Geometry of the tool used was:

$$\gamma = 0^0, \quad \alpha = \alpha_1 = 10^0, \quad \phi = 45^0, \quad \phi_1 = 25^0$$

3. RESULTS & DISCUSSION

Experiments were carried out to determine the critical cutting speed for different combinations of work and tool materials and conditions of cutting. Three different methods were adopted for determining V_c. In the first method V_c was determined from the coefficient of chip shrinkage versus cutting speed curves. The highest value of the coefficient corresponds to the critical cutting speed, V_c. In the second method the chip-tool contact process was studied on frozen chip samples using metallographic microscope. The critical speed, corresponds to a cutting speed where the curve of height of BUE versus cutting speed intersects the axis of cutting speed i.e. where BUE just vanishes (Fig. 1). In the third method which is the simplest, chip samples at different speeds were collected and the tool touching faces of the chips were photographed. The first cutting speed in the ascending order of speeds, at which very little or no trace of built-up-edge is observed on the chip face corresponds to the critical speed (Fig 2 a,b,c). Results of the tool wear tests conducted to determine the dependence of tool wear on chip-tool contact processes. Typical results of tool wear tests are shown in Fig. 3. The results show that tool wear is minimum at $\leq V_c$ for a single carbide tool. The same for a double carbide tool and low alloyed steel work material shows two peak values of tool life one at $Vopt_1$, abit lower than V_c and the other at $Vopt_2$, abit higher than V_c [1].

Variation of V_c with the properties of the work materials is shown in Fig.4. The results show that V_c decreases with an increase in the mechanical properties of the work materials.

Influence of feed and depth of cut on V_c were investigated on low alloyed steel. An increase in feed and depth of cut results in lowering of the critical cutting speed V_c.

Lower value of V_c with the increase in the mechanical properties of the work materials and with the increase in feed rate and depth of cut (upto certain extent) is associated with higher rate of heat generation during the metal cutting process. At higher rate of heat generation the temperature at which built-up- edge becomes soft and is removed easily from the tool face is attained a lower cutting speed. That is why hard and high strength work materials have low machinability (Fig.5).

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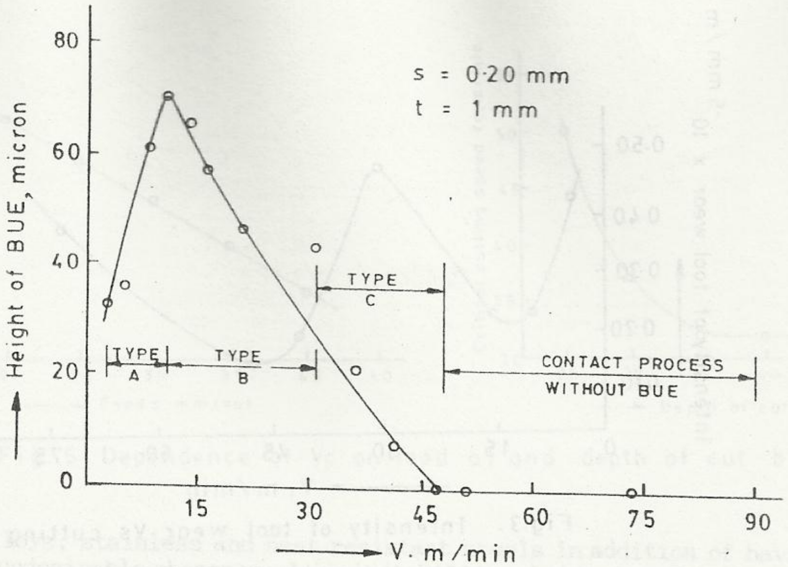

Fig.1 Height of B U E V_s Cutting speed

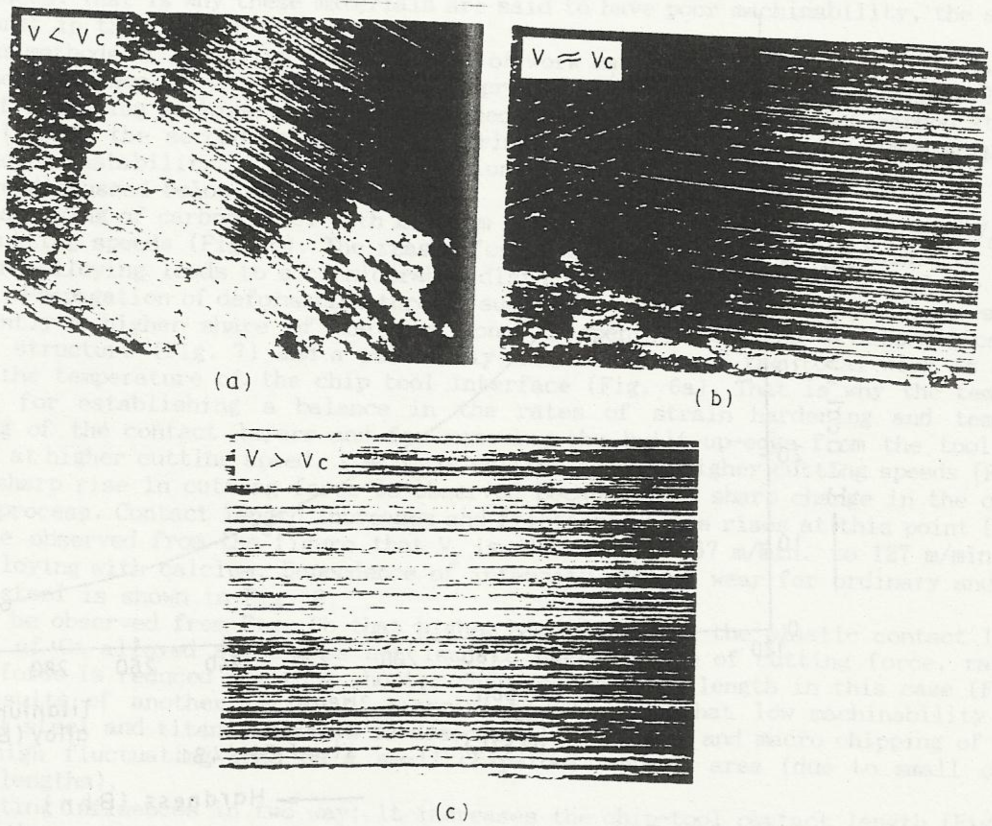

Fig. 2. Photographs of the tool touching surface of chips at cutting speed $V < V_c$ a) $V \approx V_c$ b) and $V > V_c$ c) material Mild steel Tool Cemented carbide

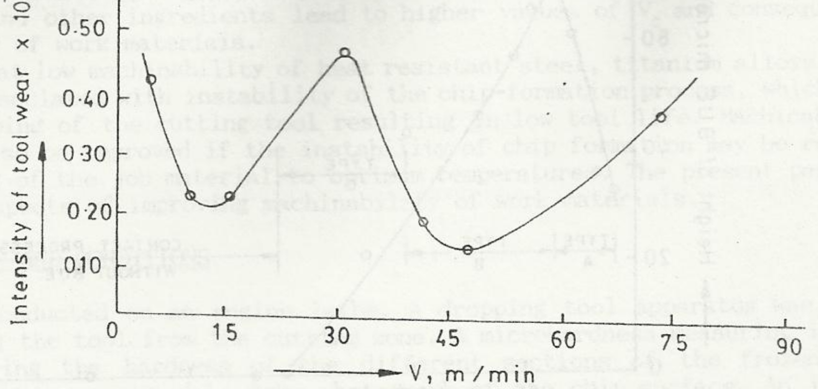

Fig.3. Intensity of tool wear Vs cutting speed

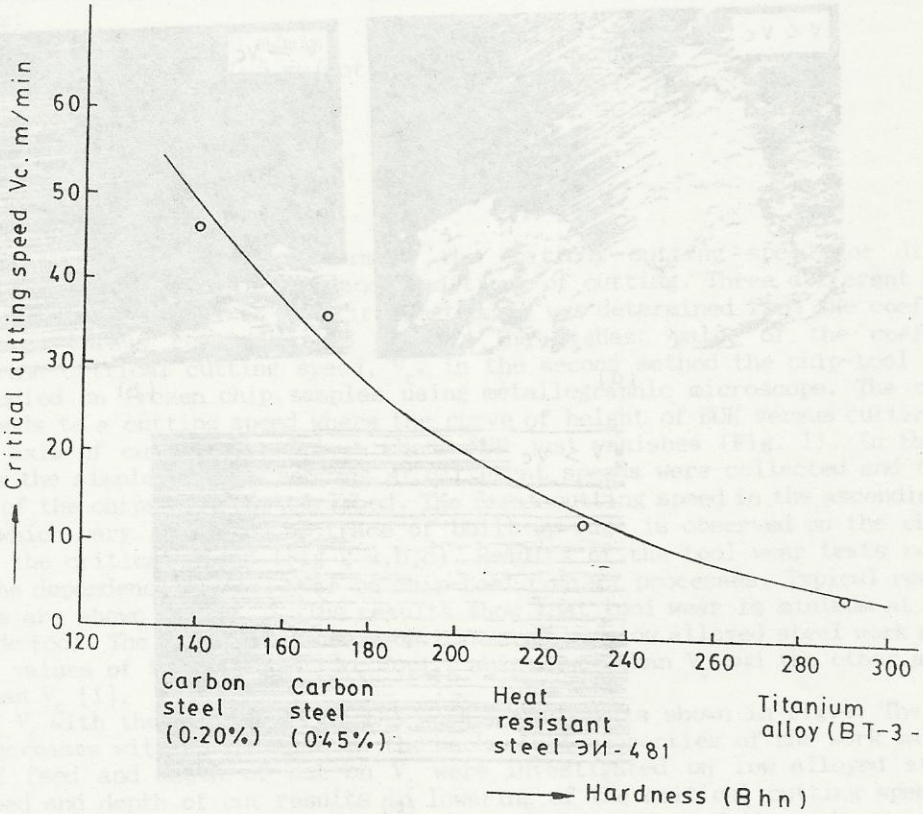

Fig.4 Relationship between Vc and material hardness Bhn of work material

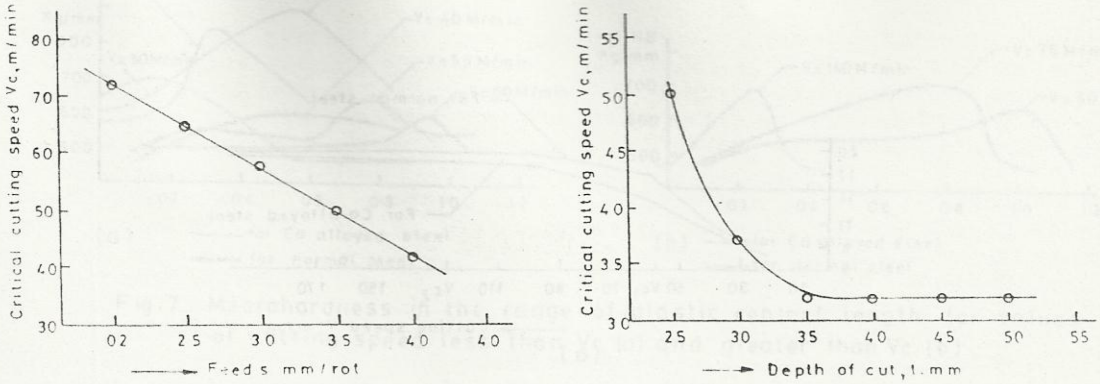

Fig. 5 Dependence of Vc on feed a) and depth of cut b)

Titanium alloys, stainless and heat resistant steels in addition of having lower V_c values, give rise to undesirable phenomena like instability of chip formation and chatter, which lead to the fluctuation of the cutting force and dynamic loading of the tool and the machine parts [2], [3]. Micro and macro chipping of tool and lowering of machine tool life are their consequences. That is why these materials are said to have poor machinability, the situation being worst in the case of titanium alloys.

Various methods of improving machinability of work materials are practised. In the current paper the influence of two methods in on improving machinability are discussed. The first method of improving machinability was attained through micro-alloying of carbon steel with calcium [4]. In the second method work materials were preheated upto optimum temperatures for reducing instability of the chip formation and chatter [2]. The main findings of these works are discussed below.

Micro-alloying of carbon steel with calcium leads to a considerable shifting of V_c towards higher cutting speeds (Fig. 6). The reason for this lateral shift is explained by the fact that micro-alloying leads to a considerable distortion of the space lattice of the metallic crystals. Propagation of deformation through such a distorted matrix faces higher resistance. Consequently a higher share of the work done is spent in causing a deformation of the internal structure (Fig. 7) and a relatively smaller share of the total work is spent in raising the temperature of the chip tool interface (Fig. 6a). That is why the temperature required for establishing a balance in the rates of strain hardening and temperature softening of the contact layers and for removing the built-up-edge from the tool face is attained at higher cutting speed, i.e. V_c is shifted towards higher cutting speeds (Fig. 6b). At V_c a sharp rise in cutting force is observed because of a sharp change in the chip-tool contact process. Contact length increases and frictional force rises at this point (Fig.6c). It can be observed from the figure that V_c is shifted from 57 m/min. to 127 m/min. due to micro-alloying with calcium. Dependence of intensity of tool wear for ordinary and calcium alloyed steel is shown in Fig. 8.

It may be observed from Fig. 6b that higher hardness along the plastic contact length in the case of Ca alloyed steel does not lead to higher value of cutting force, rather the cutting force is reduced due to a shorter chip-tool contact length in this case (Fig. 6c).

The results of another series of experiments [2] show that low machinability of heat resistant steel and titanium alloys is associated with micro and macro chipping of the tool due to high fluctuating load on a small chip-tool contact area (due to small chip-tool contact lengths).

Preheating influences in two way: it increases the chip-tool contact length (Fig. 9) and reduces the amplitude of vibration of the cutting load (Fig. 10). This leads to the elimination of the brittle breakage of the tool and consequently to low intensity of tool wear (Fig. 11). Relatively high absolute value of cutting load at the optimum preheating temperature is associated with high chip-tool contact length but the average load during cutting with preheating is low due to softening of the work material.

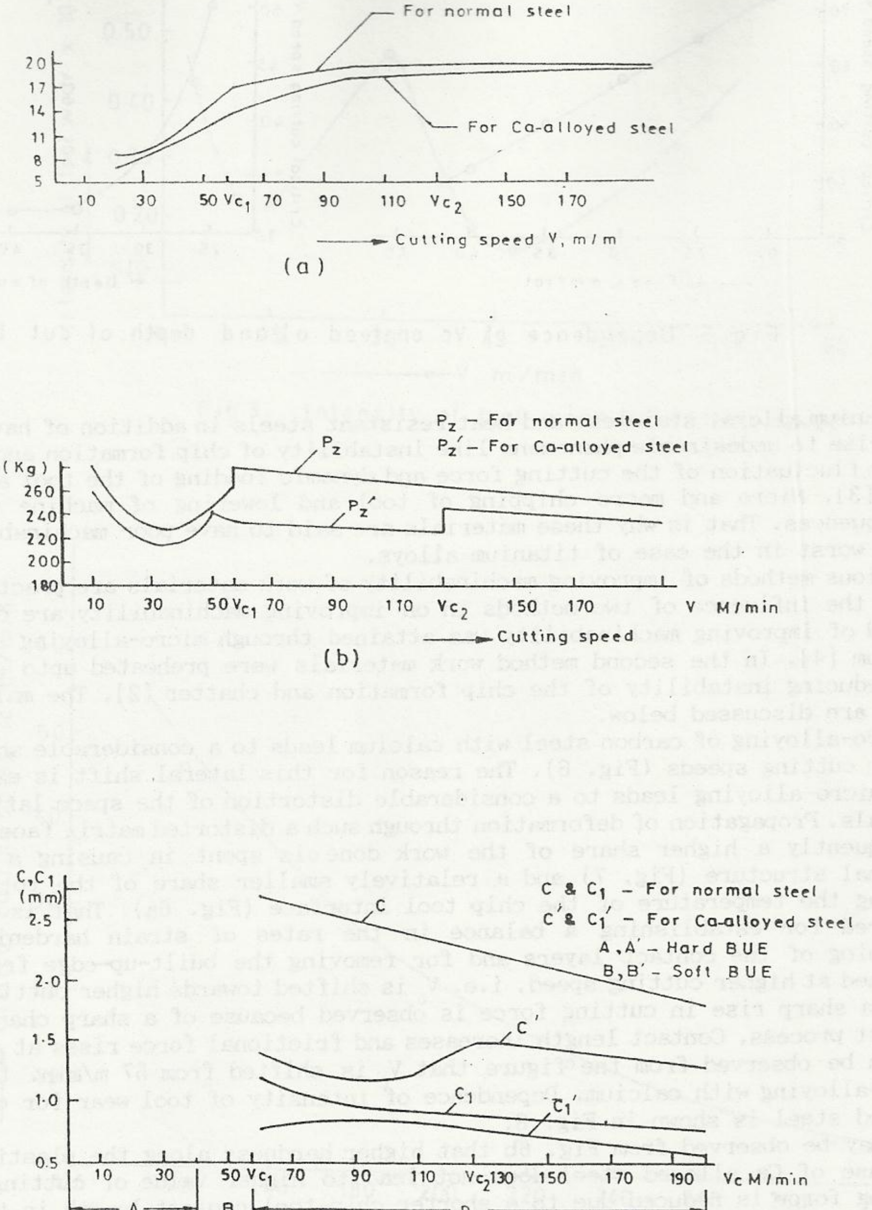

Fig. 6. Dependence of a) Temperature (emf) b) Cutting force P_z and C) Chip tool contact length cuttig speed for normal and ca-alloyed steel

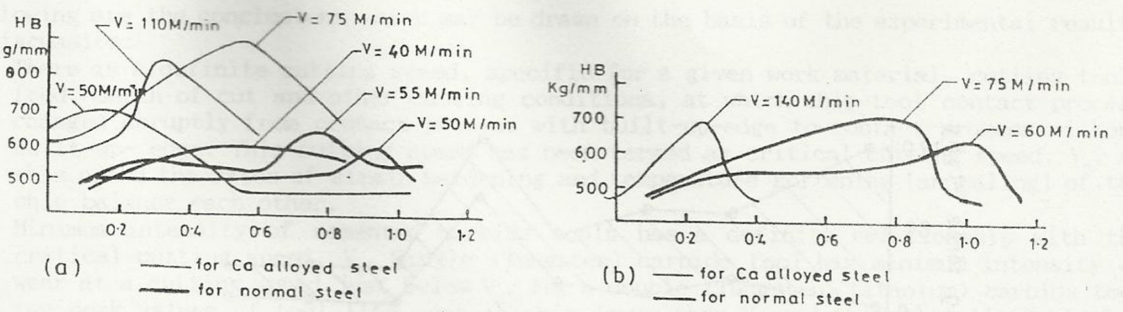

Fig.7. Microhardness in the range of plastic contact length for values of cutting speed less than Vc (a) and greater than Vc (b)

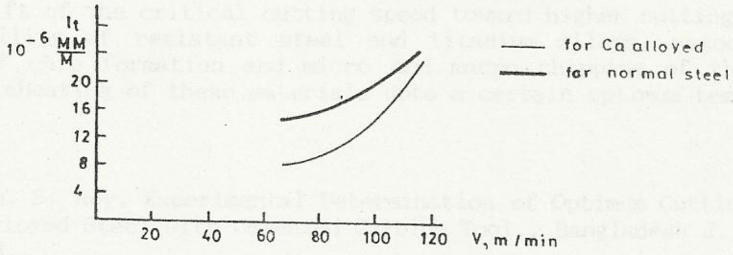

Fig. 8. Influence of cutting speed on the intensity of tool wear in machining normal and co-alloyed steel

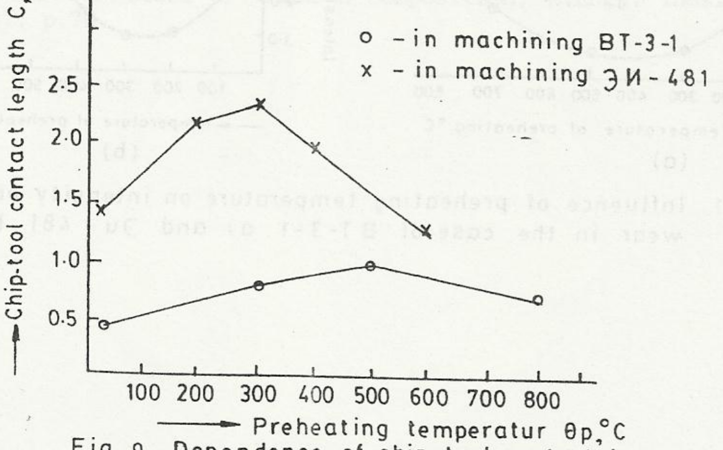

Fig. 9. Dependence of chip-tool contact length, C on preheating temperature, θp.

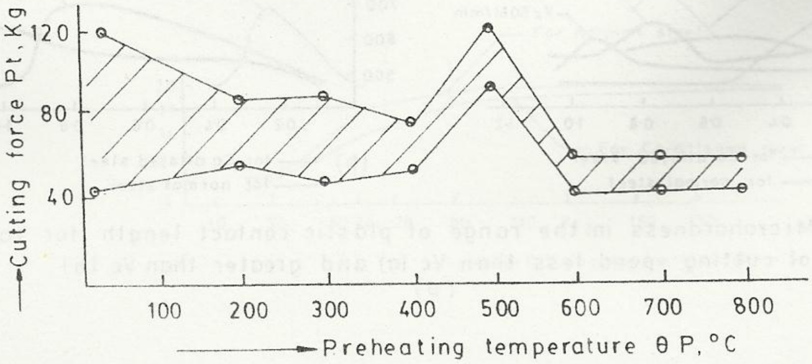

Fig. 10. Relationship between cutting force and preheating temperature θ p work material : BT - 3 - 1

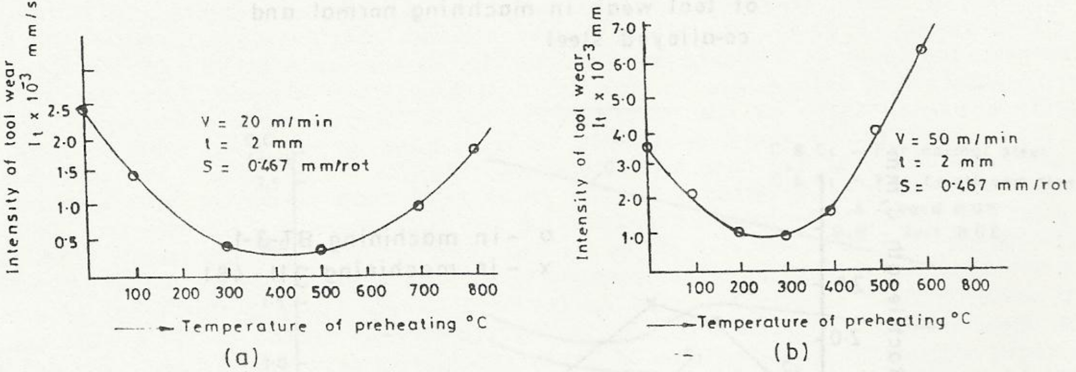

Fig. 11 Influence of preheating temperature on intensity of tool wear in the case of BT-3-1 a) and Эu - 481 b)

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4. CONCLUSION

Following are the conclusions which may be drawn on the basis of the experimental results and discussion:

1. There is a definite cutting speed, specific for a given work material, cutting tool, feed, depth of cut and other cutting conditions, at which chip-tool contact process changes abruptly from contact process with built-up-edge to contact process without built-up- edge. This cutting speed has been termed as critical cutting speed, V_c. At this speed the rates of strain hardening and temperature softening (annealing) of the chip balance each other.
2. Minimum intensity of cemented carbide tools has a definite relationship with the critical cutting speed, V_c. Single (Tungsten) carbide tool has minimum intensity of wear at a cutting speed just below V_c. For a double (Tungsten, titanium) carbide tool two peak values of tool life, one at abit lower than V_c and the other little higher than V_c. Since $Vopt_1$ and $Vopt_2$ are very close to V_c, this cutting speed may serve as an important criterion for determining machinability of work materials.
3. An increase in feed and depth of cut and hardness and strength of work materials leads to lower values of V_c.
4. Critical cutting speed V_c of work materials may be determined easily by plotting a curve of coefficient of chip shrinkage versus cutting speed or by observing the tool-touching face of the chip.
5. Machinability of steel may be improved by micro-alloying with calcium, which results in lateral shift of the critical cutting speed toward higher cutting speeds.
6. Poor machinability of resistant steel and titanium alloys, associated with the instability of chip formation and micro and macro chipping of the tool, may be improved by preheating of these materials upto a certain optimum temperatures.

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