Mech. Engg. Res. Bull.
Vol. 9, (1986), P P. 52—62

Influence of the Instability of Chip Formation and Preheating of Work on Tool Life in Maching High Temperature Resistant Steel and Titanium Alloys

A.K.M. Nurul Amin*
Talantov N.V.**

ABSTRACT

It has been established by experimental investigations that machinging of high temperature resistant steel and titanium alloys with cemented carbide tools is accompanied with inherent instability of chip formation. This type of instability causes micro and macro chipping of the tool tip and consequently decreases tool life to a great extent. It has been also established that tool life can be greatly increased by preliminary heating of the work upto a certain optimum temperature, which varies with work and tool materials and conditions of cut.

Introduction :

With the advancement of science and technology the requirement for new materials and alloys with high strength and hardness, wear, temperature and corrosion resistance is very much acute. To keep pace with these requirements the material science all over the world has brought to light different new materials and alloys, which in turn have placed new problems before the technologists. Severe problems are faced in machining these materials. For their machining and fabrication new tool materials and more powerful machine tools are required. Their heat treatment cycle is also very much complicated. The present work deals with the problems which arise in machining this type of materials.

It has been observed that machining of high temperarature resistant steel and titanium alloys, both of which are recently introduced groups of alloys, is always accompanied with Instability of chip formation (1), (2), (3). Instability of such type has definite cyclic nature. Frequency of such cycles depends on the physio-mechanical properties of the work and tool materials and conditions of cut.

It has been established earlier (1) that frequency increases with those changes in the material properties or conditions of cut which lead to the rise of cutting temperature and vice versa. Investigation of the different moments of chip formation cycle in machining such materials show that each such cycle consists of two phases-phase of compression and phase of shear along a thin section of chip (1), (2). These works have established the thermal nature of generation of such instability. It was further established (1) that instability is the primary

---

* Assistant Professor, Department of Industrial & Production Engineering, B. U. E. T., Dhaka, Bangladesh.
** Professor, Department of Technology of Machine Building, Volgograd Polytechnic Institute, Volgograd, USSR.

cause of "Chatter", which arises when the frequency of the instability of chip formation is close to the frequencies of natural vibration of individual parts of the Machine-Tool-Fixture-Work (MTFW) system. During machining carbon steel Chatter can be avoided by proper choice of the rigidity of the MTFW system and cutting conditions. But instability of chip formation, which arises in machining alloys of the titanium or high temperature resistant steel, can not be avoided by such measures.

Since the instability of chip formation is caused by factors which have thermal dependence, as mentioned above, the authors of the present work anticipated that it can be either fully or partially removed if the work is preheated up to a certain temperature. The present work was performed in order to investigate the actual influence of work material on instability of chip formation and tool wear.

Experimental Setup and Procedure :

The experiments were carried out in the laboratory of Principles of Metal Cutting of Volgograd Polytechnic Institutute (USSR) Experiments were mainly performed on lathe machine-model (USSR) 1M63 with infinitely variable spindle speed. For recording vibration of cutting force and temperature dynamometer model (USSR) 600 and oscillograph model H-115 were used. For frozen chip the "Dropping Tool", method was used. Micro-photographs were taken on metallographic microscope. During the experiments rigidity of the MTFW system was kept at a constant level. As work meterial, titanium alloy grade (USSR) BT3-1 and high temperature resistant steel grade (USSR) 3N-481 were used Machining was performed with cemented carbide tool grade (USSR) BK-8 with the following tool geometry : rake angle, $\gamma = 0°$, side clearence angle, $\alpha = 10°$, principal cutting edge angle, $\rho = 45°$, auxiliary cutting edge angle $\rho = 25°$. Machining conditions were as follows : depth of cut, t = 2 mm, feed, S = 0.467 mm/rev., cutting speed, V = 0.33 m/sec in machining BT 3-1 and V = 0.83 m/sec in machining 3N-481. Experiments were performed both at room temperature and with preheating of the work upto different temperatures at an interval of 100°C. For preheating the work an electric furnance model (USSR) CH3-6X12X4/10MI was used. To compensate for the heat loss during positioning and clamping the job on the machine and in performing the experiments the temperature of the furnance was maintained at a temperature 100°C higher than the experimental temperature. Moreover an additional carriage was mounted on the cross slide from the rear side of the lathe machine for holding the auxiliary cutting tool, which was used for removing the comparatively cooler outer layer of the work. A hole was drilled inside the work piece for placing the thermo-couple for measuring the temperature of the cutting layer. Scematically these arrangements are shown in Fig. 3. Micro-photographs of the frozen chip and rake and flank surfaces of the tool after definite periods of machining (τ= 360 sec for BT 3-1 and τ = 420 sec for 3N-481) were taken for room temperature and for optimum temperatures (Fig. 1, 2, 8 and 9). Tool wear was measured at definite intervals within this period and wear versus time curves were drawn for room and different preheating temperatures (Fig. 4, 5). From the oscillograms of the cutting temperature (in terms of EMF), θ and components of cutting force Pz, Py, and P_x curves of these vibrating perameters versus preheating temperature were drawn for the given work materials (Fig. 6, 7). Values of the coefficients of chip shrinkage, K and total chip-tool contact length, C were measured at room and differerent preheating temperatures and curves, K and C versus θp were drawn (Fig. 10).

Results and Discussion :

Results of the present experimental investigations reaffirmed that the chip formation process is unstable in machining these alloys (Fig. 1a, 2a). Uniform type of tool wear which is obsrved in machining carbon steel is completely absent in this case. Wear bears brittle nature, which is due to micro and macro chipping of the tool (Fig. 1b, 1c and 2b, 2c). From Fig. 6 and 7 it is observed that the cutting temperature and components of cutting force vibrate with high amplitudes at room temperature, but the total chip-tool contact length is comparatively low (Fig. 10). Calculations show that the maximum normal force, Pz acting on the tool tip per unit area in machining titanium alloy, BT 3-1 is as high as 375 kg/mm^2 and machining high temperature resistant steel 3N-481 160 kg/mm^2 (Fig 6, 7, 10), where as in machining medium carbon steel this value is only 90 kg/mm^2 (1). Amplitude of vibration of cutting force is also very high in machining the investigated materials (Fig. 6, 7). Practically no such instability is encountered in this cutting range in machining carbon steel (1).

Preheating of both the work materials upto certain temperature leads to the decrease of tool wear and amplitude of vibration of cutting force and temperature but preheating above that temperature results in continuous rise in tool wear. This particular temperature is known as optimum temperature of preheating, θ_{opp}. Values of θ_{opp} for BT 3-1 is approximately 500°C and for 3N 481 approximately 300°C (Fig. 4, 5). At this temperature chip formation process is more or less stable (Fig. 8a, 9a), and consequently the amplitudes of vibration of cutting force and temperature are brought to a minimum level (Fig. 6, 7). It is observed from Fig. 6 and 7 that the horizontal components of cutting force, p_x, p_y, are maximum at this temperature for both the materials. This is due to the increase in frictional force as a result of the increase in chip-tool contact length, C to its maximum value at θ_{opp} (Fig. 10). At the optimum temperature the metal becomes more ductile which leads to the decrease of shear angle. This in turn is responsible for maximum value of chip shrinkage, K (Fig. 10).

At the optimum temperature maximum value of the normal component of cutting force, p_z acting on unit area of the tool tip in machining BT 3-1 is only 110 Kg/mm^2 and in machining 3N-481 only 66 Kg/mm^2 (Fig. 6, 7, 10). So the minimum value of tool wear at the optimum temperature can be explained by the fact that the cutting force and especially its dynamic component per unit area is reduced to a great extent as compared with machining without preheating 3.14 times in the case of BT 3-1 and 2.42 times in the case of 3N-481). Preheating above the optimum temperature leads to intensive wear of the tool due to intensification of diffusion type of wear at the elevated temperature (Fig 4, 5). It is also to be noted that at the optimum temperature the values of P_x, P_y, C and K are maximum. This phenomenon can be successfully employed in finding the optimum preheating temperature of these materials (and also perhaps for other materials) without performing tests on tool wear. It would be easier to plot a curve of K versus θ_p for this purpose.

Conclusions :

The intensive and brittle type of wear of cemented carbide tool in machining titanium alloys and high temperature resistant steel is due to the high value of normal component of cutting force acting on unit area of tool and its dynamic nature.

Preheating of work upto the optimum temperature practically stabilizes the process of chip formation and the length of chip-tool contact is greatly raised. This leads to considerable decrease of normal component of cutting force per unit area which results in low and uniform tool wear.

Optimum preheating temperature can be determined only by measuring the values of chip shrinkage, K at various preheating temperatures. Value of K is maximum at optimum preheating temperature.

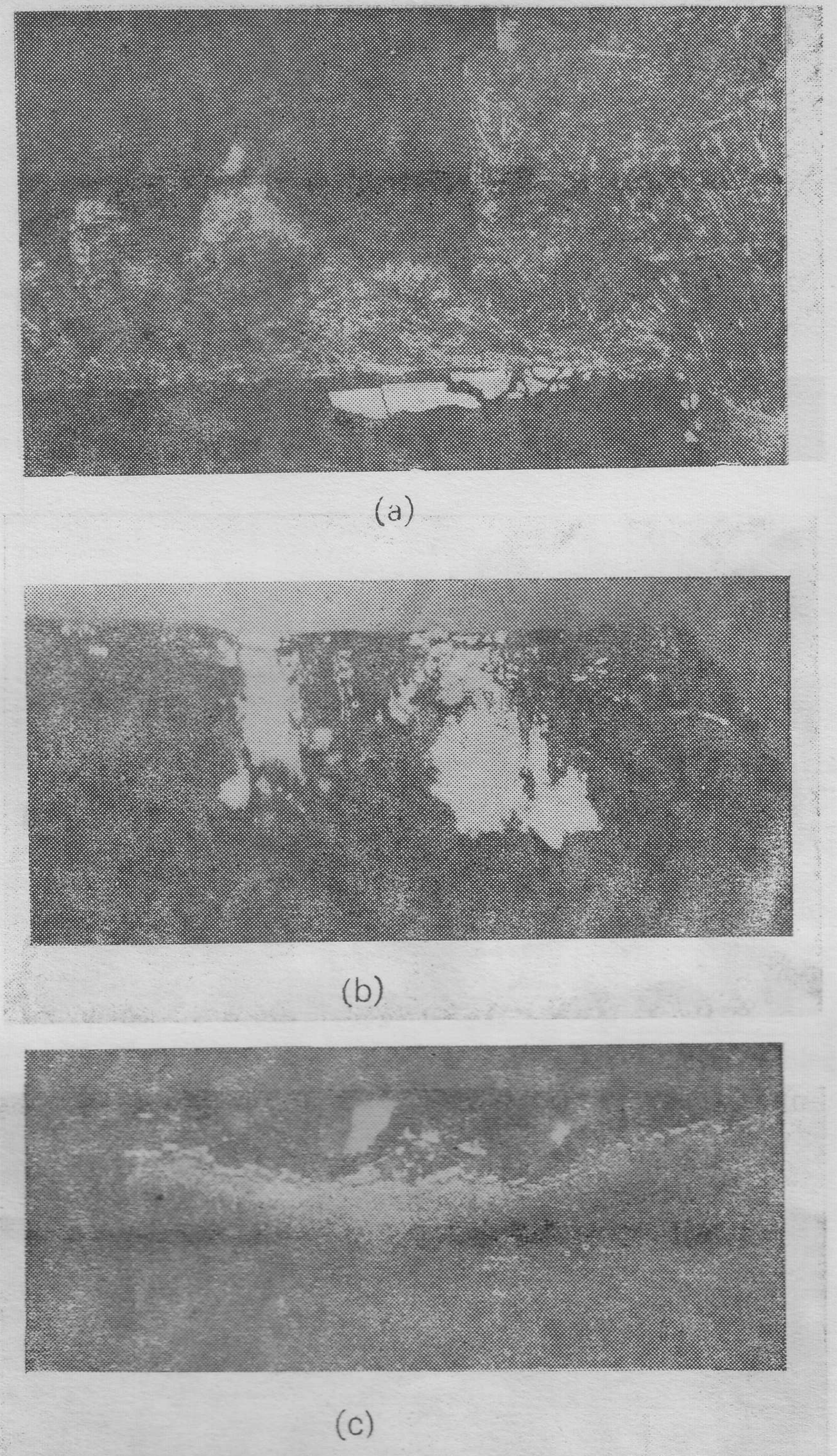

Fig. 1. Micro-photographs of frozen chip (a), rake (b) and flank (c) surfaces of tool in machining BT 3·1 without preheating.

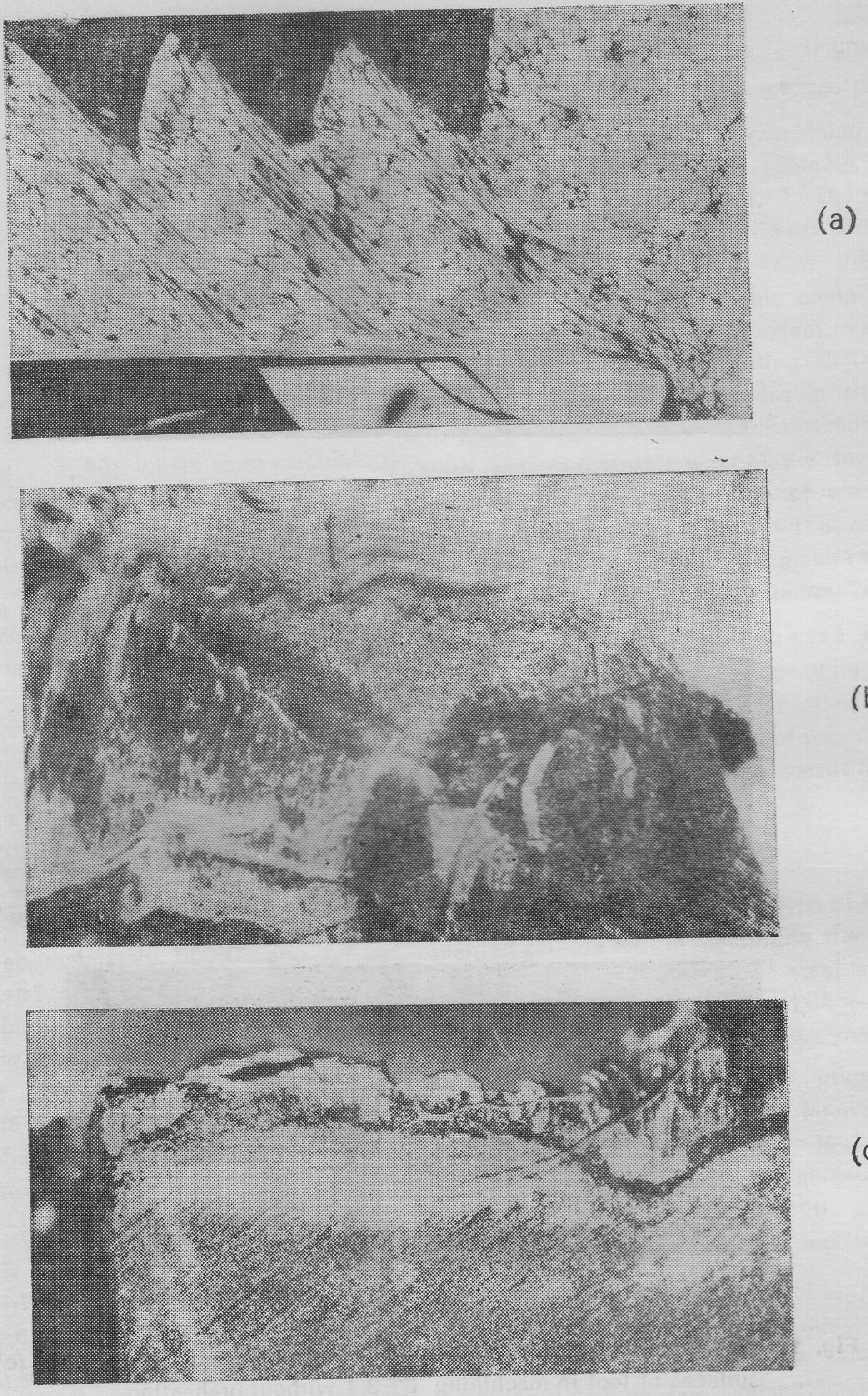

Fig. 2. Micro-photographs of frozen chip (a), rake (b) and flank (c) surfaces of tool in machining 3N-481 without preheating.

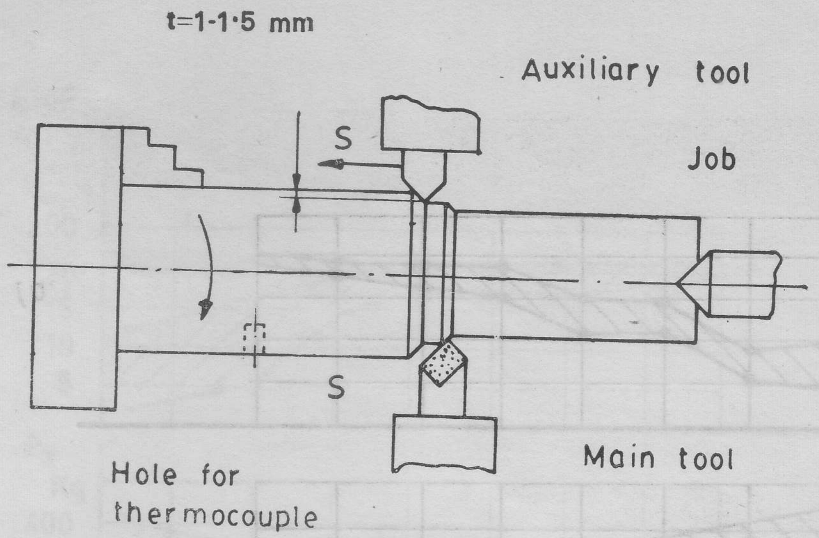

Fig. 3. Schematic diagram of the cutting arrangement with preating of work.

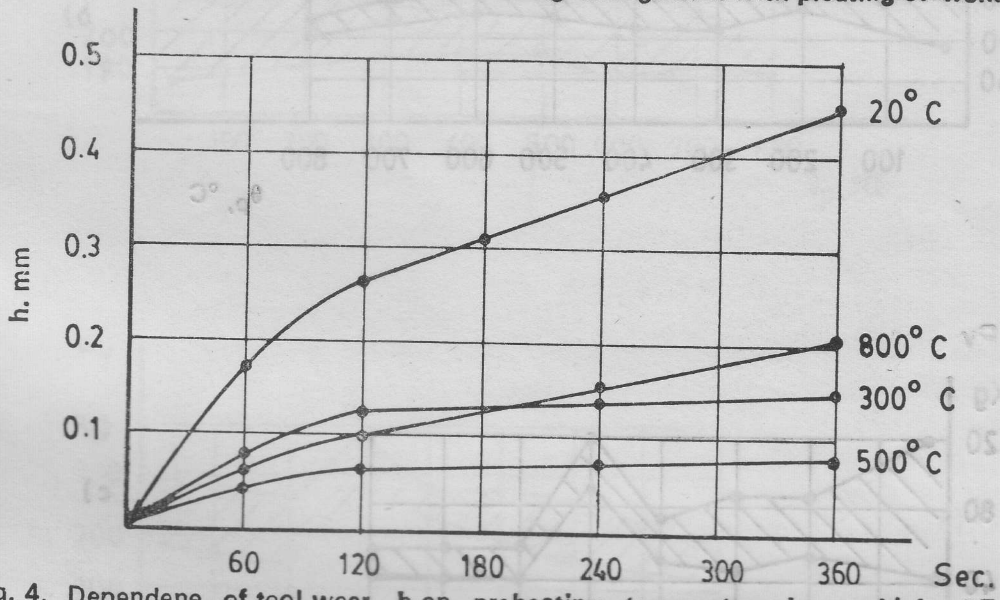

Fig. 4. Dependene of tool wear, h on preheating temperature in machining BT 3-1.

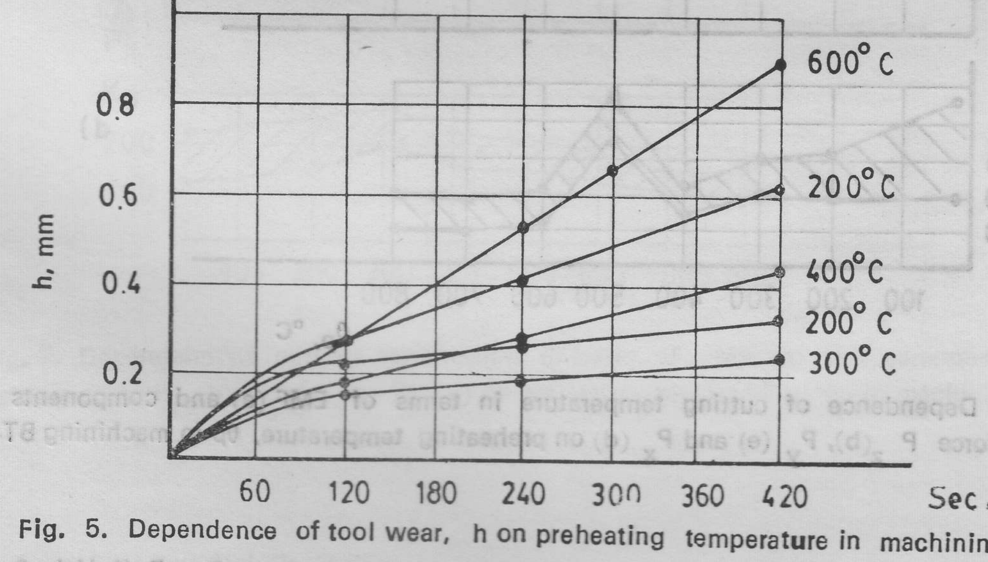

Fig. 5. Dependence of tool wear, h on preheating temperature in machinin 3N-481

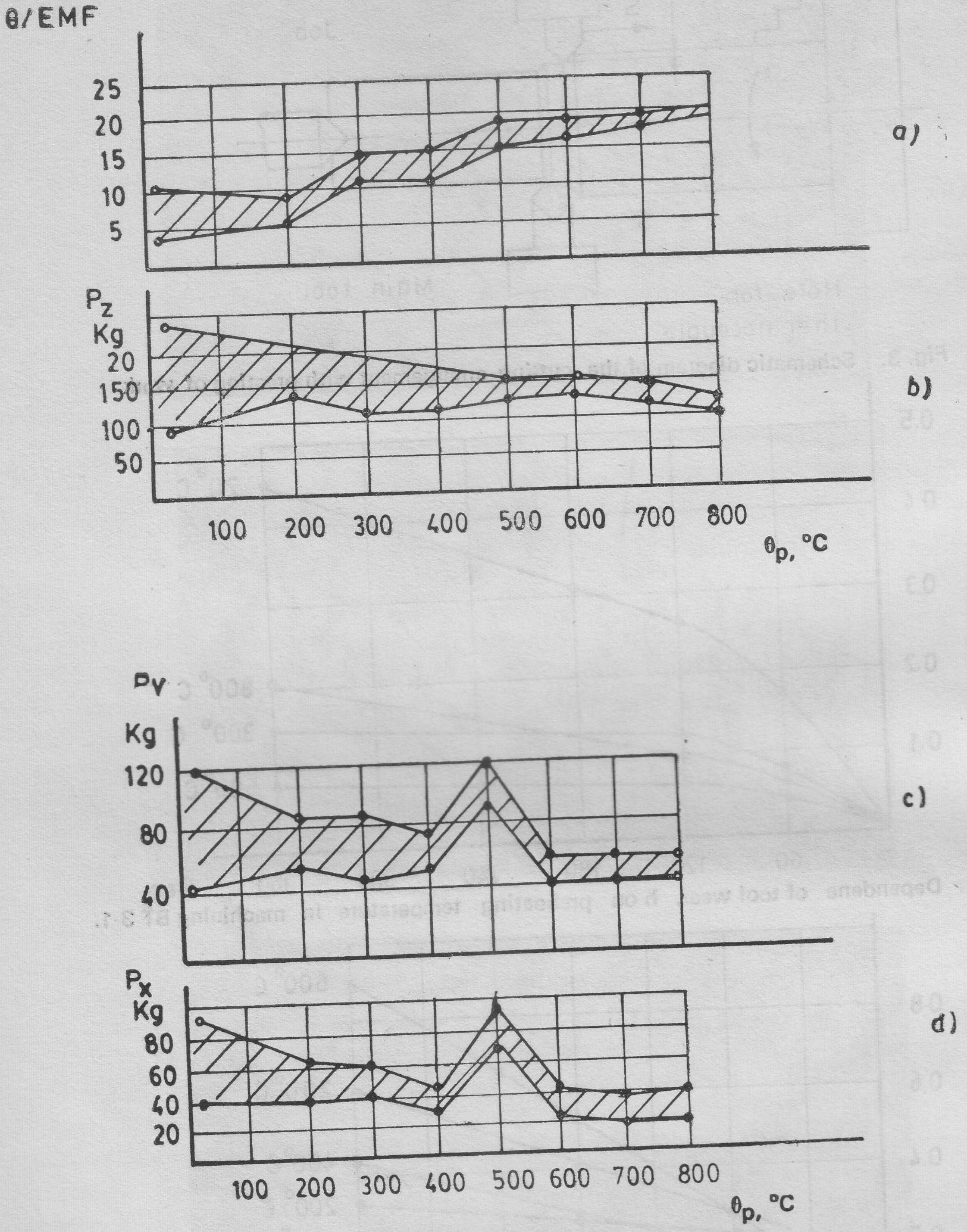

Fig. 6. Dependence of cutting temperature in terms of EMF (a) and components of cutting force P_z(b), P_y (e) and P_x (d) on preheating temperature, θp in machining BT-3-1.

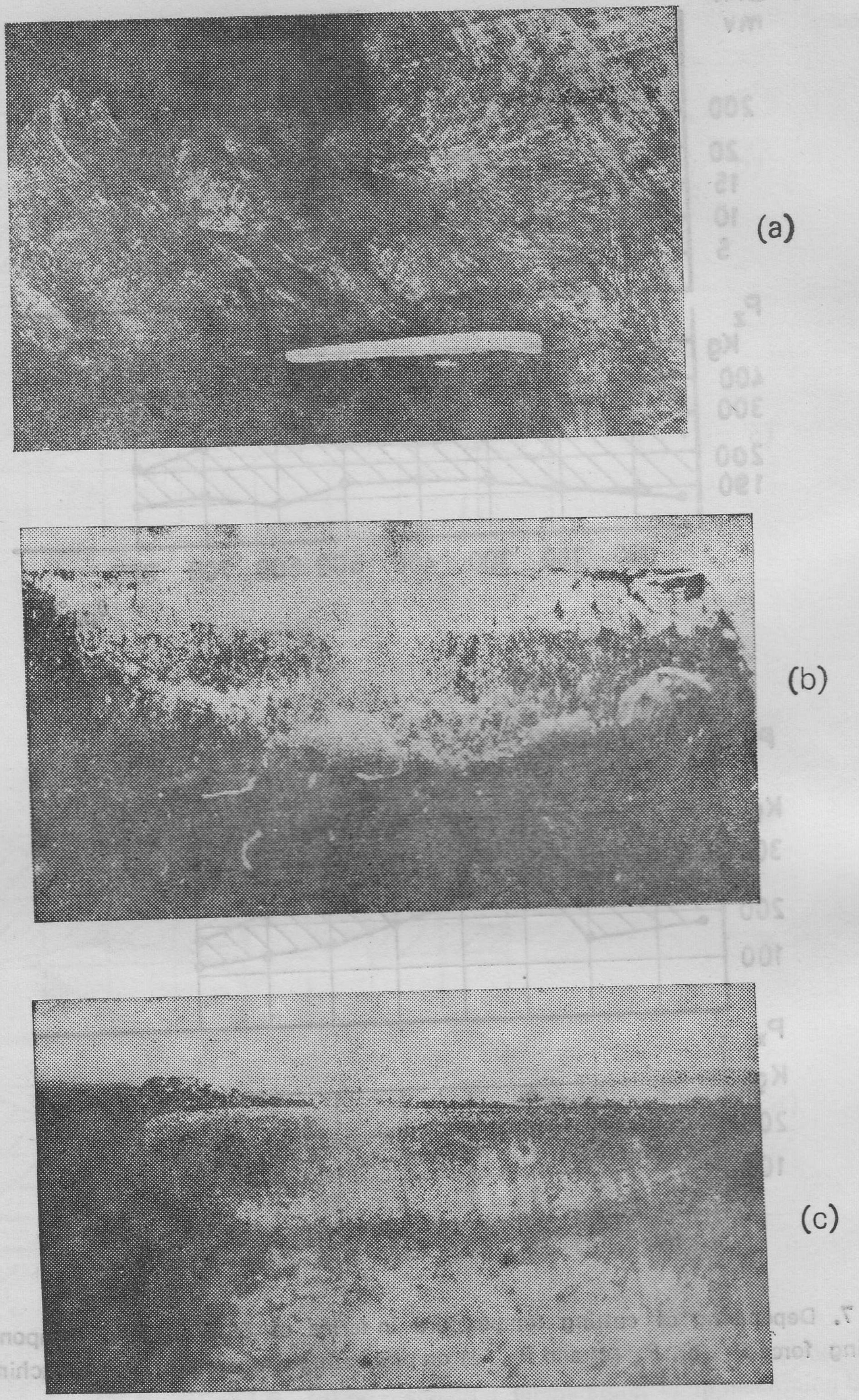

Fig. 8. Micro-photographs of frozen chip (a), rake (b) and flank (c) surfaces of tool in machining BT 3—1 with preheating upto 500°C.

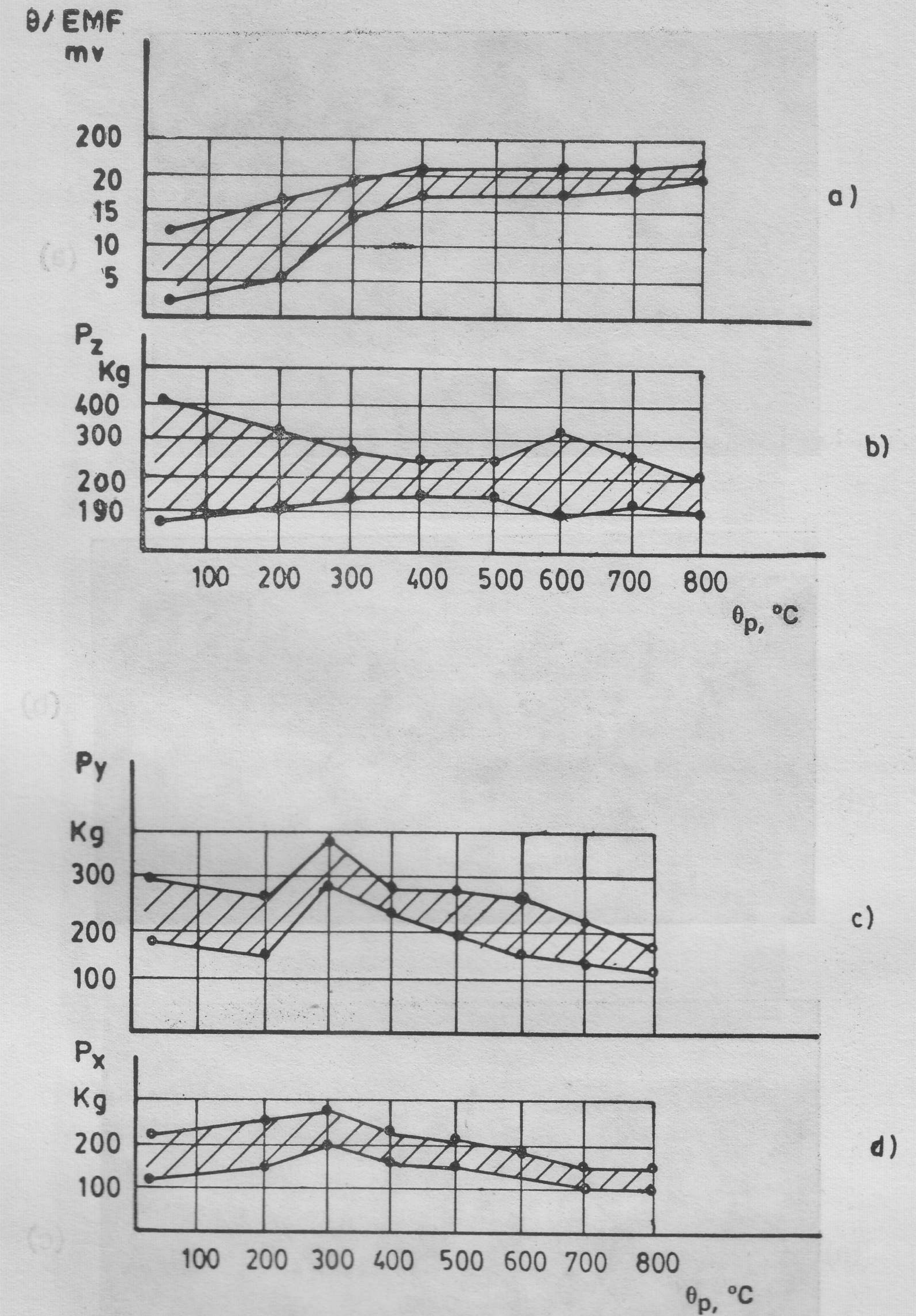

Fig. 7. Dependenc cf cutting temperature in terms of EMF (a) and components of cutting force P_z (b), P_y (c) and P_x (d) on preheating temperature, θp in machining 3N-481

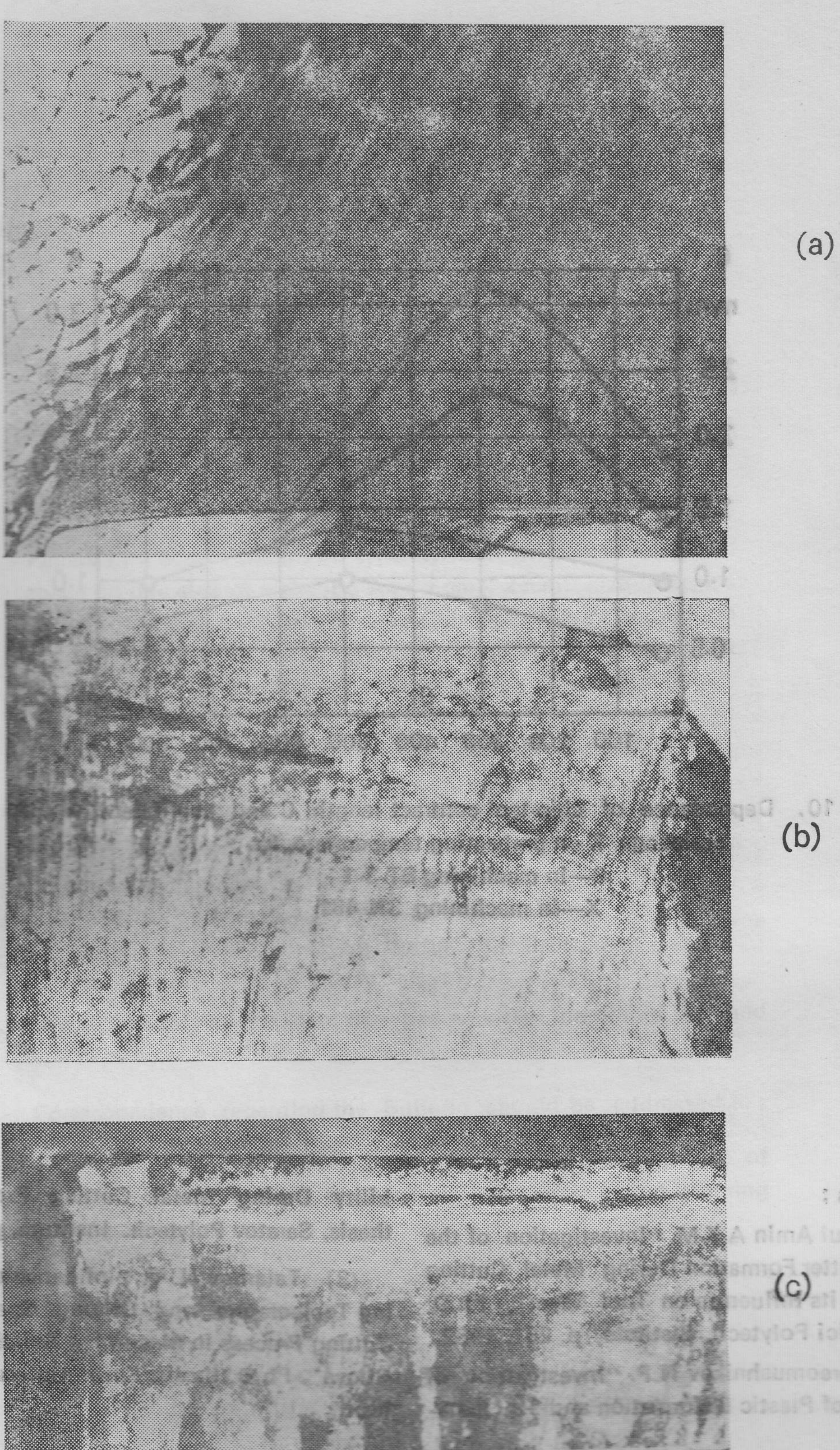

Fig. 9. Micro-photographs of frozen chip (a), rake (b) and flank (c) surfaces of tool in machining 3N-481 with preheating upto 300°C.

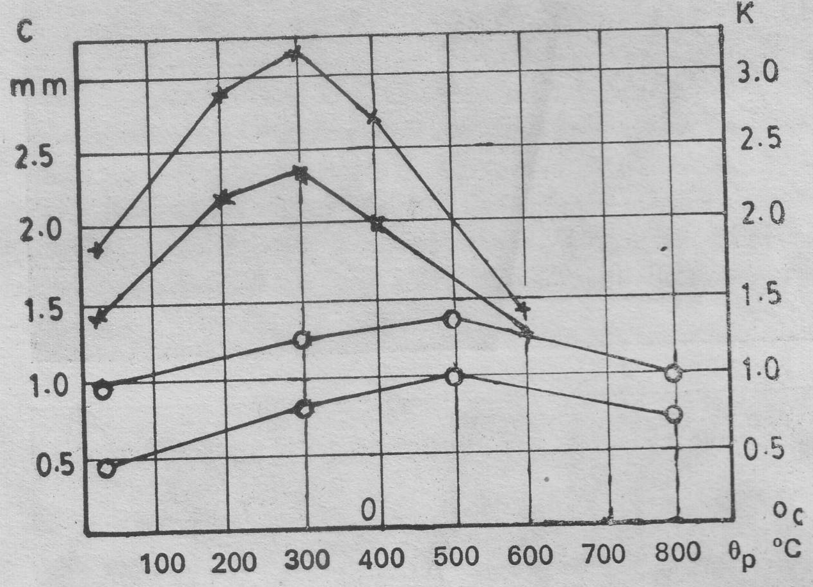

Fig. 10. Dependence of chip-teol contract length, C and coefficient of chip shrinkege K on preheating temperature, θp.
0—In machining BT-3-1
X—in machining 3N-481

References :

(1) Nurul Amin A.K.M. "Investigation of the Laws of Chatter Formation During Metal Cutting Process and Its Influence on Tool Wear", Ph.D. thesis, Tibilici Polytech. Institute, p. 261, 1982.

(2) Chereomushnikov N.P. "Investigation of the Process of Plastic Deformation and its Instability During Metal Cutting Process", Ph.D. thesis, Saratov Polytech. Institute, p. 267, 1980.

(3) Talantov N. V. "Influence of the Preheating Temperature and Cutting Speed on Metal Cutting Process in Machining Aviation Steel and Alloys", Ph.D. thesis, Kazan University, p. 170, 1956.