Investigation of the Physical causes of Improved Machinability of Steel Alloyed with Calcium

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ABSTRACT

Investigations have been carried out to determine the possibility of improving machinability of steel by alloying with calcium or other ingredients and also to explain the physical causes of improved machinability. Results of the experiments show that machinability of steel can be raised several times without adversely affecting its physiomechanical properties. Causes of the improvement of machinability is due to higher degree of hardening of the sulphides due to micro alloying with calcium Hardened sulphides are capable of effectively resisting the movement of dislocations in the chip-tool plastic contact zones and as a result the percentage of the total work of plastic deformation spent in changing the internal energy of metal is much higher in the case of alloyed steel than that of the normal steel. And consequently the percentage of total work spent in raising the cutting temperature is much lower in the case of the alloyed steel. Relatively lower lower value of cutting temperature ultimately facilitates higher tool life, i. e. higher machinability of calcium alloyed steel,

Introduction :

For the last few years investigations have been carried out in various countries to improve machinability of construction steel by means of alloying with different types of elements such as sulphur, selenium, Tellurium calcium etc. In these research works attempts are made to keep unchanged the physio-mechanical properties of the steel after such alloying. Care is also taken to keep the manufacturing process of the steel safe for the operator's health since, some of the elements mentioned above are poisonous. Influence of different methods of alloying steel with calcium on the improvement of machinability was shown for the first time by German scientists Baitman and others in 1936. In the years 1950-1960 German scientists opitch, Kening, Vichter, Pape and others (3) actively worked in the same direction. In the mid-sixtees Japanese scientists T. Araki, T. Ito, M. Maruyma and others (3) paid great attention to the investigation of such steel. In the USSR investigations on calcium alloyed steel have been carried out by Goldstein Y.E., Zaslavsky A.Y., Talantov N.V., Kurchenko A.I. and others (3, 2).

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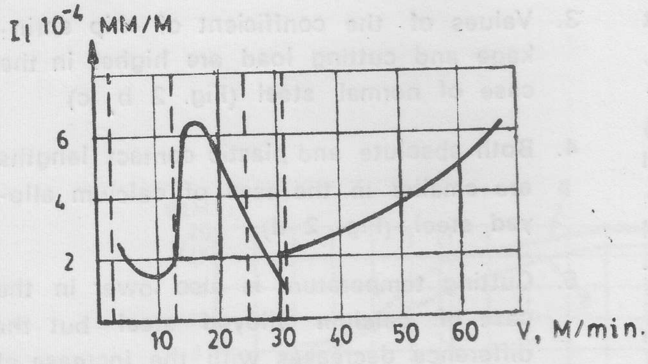
Causes of the improvement of machinability of calcium steel are explained by different investigators in various ways. One group of authors (Opitch, Vichter, Pape and others) (3) relate improvement of machinability of such steel to the deposition of oxide films on the tool face, which protect the tool from intensive wear. According to another group (Kening and others(3)) low tool wear in machining. calcium alloyed steel is due to the oxidation of the binding material-cobalt. As a result of this the bond between carbides of Tantallum (and Titanium) with cobalt becomes stronger. Third group of authors (D.Hitli ano other(3)) concluded after analysing the conditions under which the non-metallic ingredients crystallise that, in the case of calcium alloyed steel "secondary sulphudes form spherical oxisulphides, equially distributed inside the ferrous matrix and as a result the tool wear is minimised to a great extent. There exist as well controversies regarding the range of temperature and cutting speed at which the improved machining conditions for such steel are realised. According to some authors the affect of introducing calcium can be realised only at high temperature i.e. at high cutting speeds, since high temperature is a prerequisite for the formation of oxide films on carbide tool, defending the tool against intensive wear. But then question arises, why is the effect of improved machinability observed in machining such steel with HSS tool, although the cutting temperature in that case is not that high (500-600°C).

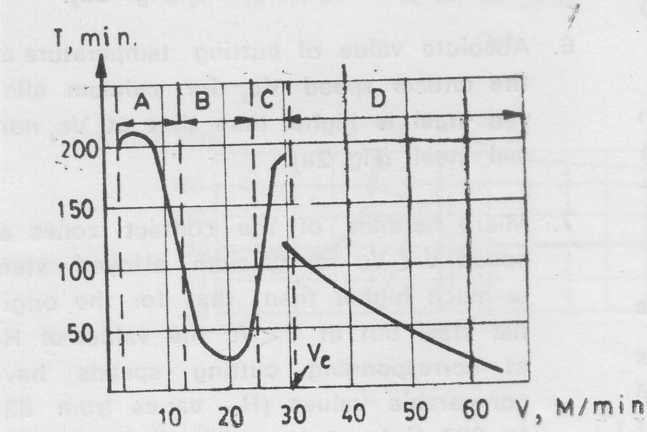
From the above discussions it was concluded that the physical causes of improved machinability are still confused and the ranges of cutting speed and conditions, where this affect is best realised is not clear. To find a solution to these problems in order to facilitate extensive use of calcium steel in production the present investigations were carried out.

The work was a part of the M.Sc thesis of the author, performed in 1979 at the Volgograde Polytechnic Institute (USSR) under the able guidance of Prof. Talantov N.V. and Kurchenko A.P. of the department of Technology of Machine building.

It has been earlier established by Talantov N. V., Tanahin A. T. and Hochriakov L.A., (i) that tool wear is a function of chip tool contact process and miaimum tool wear is observed in a definite range of cutting speed, where the built-up-edge becomes "pulsation" (unstable) type. With the increase of cutting speed the "pulsation" contact changes abruptly at a definite speed— Vc (critical cutting speed) and stationary contact between chip & tool is realised. Dependence of tool wear on cutting speed, determined experimentally by the same authors, is shown in Figure 1. As it can be seen from the figure, built-up-edge has been divided into three types by these authors. By type A, built-up-edge of relatively smaller dimensions is meant. This type is periodically carried away mainly along the rake face of the tool. This is why tool wear is low in this range. Built-up-edge type B is relatively bigger in dimensions. This type is periodically "dragged" away along the rake face of the tool, as a result of this intensity of tool wear is very high in this range. Unstable type built-up-edge is softer than the previous two types due to higher cutting temperatures. This type is periodically carried away along the rake face of the tool. This results in low intensity of flank wear of the tool (Fig. 1) From the same figure it can be also observed that, tool wear changes abruptly at V_c' with the change in chip-tool contact process.

From the above discussion it can be assumed that improvement of machinability of calcium alloyed steel is due to definite





A = Range of cutting speed with built-up-edge type-A

B = Range of cutting speed with built-up-edge type-B

C = Range of cutting speed with 'pulsation' type chip-tool contact (or with unstable built up-edge).

D = Range of cutting speed with stagnant chip-tool contact.

Fig. 1 Influence of cutting speed on the intensity of tool wear (a) and tool life (b).

changes in the temperature-deformation conditions at the chip-tool contact zones. In order to varify the above mentioned hypothesis and also to determine the nature of the changes that occur, investigations of the physical nature of the metal cutting process of the given steel were carried out.

Experimental set up and procedure

As work materials bars of normal alloyed steel grade (USSR) 30XM (containing 0. 3%C, 1% Cr, 1% Mo) and the bars of the same material with the addition of calcium (in definite propertions aud methods) were chosen for detailed investigations.

Machining was carried out with cemented carbide tool material grade (USSR) CK 8 (content : Carbide of tungstan-92%, binging material cobalt-8%).

Cutting conditions were as follows : depth of cut, t = 2 mm, feed, S = 0.467 mm/rev. Machining was carried out on engine lathe model (USSR) IM63 with infinitely variable spindle speeds.

The following parameters were chosen for investigation chip-tool contact process, cutting temperature, cutting load, coefficient of chip shrinkage, magnitude and distribution of tangential stress at the chip-tool contact zones and tool wear depending on cutting speed.

For studying chip-tool contact processes the following apparatus and special attachments were used : attachment for fast withdrawal of tool from cutting zone, attachment for obtaining frozen chip, micro-hardness measuring instrument model (USSR) MT-3 for measuring hardness at the contact zones, instrumental microscope for measuring contact lengths and magnitude of tool wear and metallographic microscope for photomicrographs of the frozen chips. Components of cutting load in three perpendicular directions Px, Py, Pz were measured with the help of dynamometer model (USSR) YDM-600.

Cutting temperature was measured in terms of electro-motive-force (in milli volts) with the help of a specially designed cutting tool and special attachements.

Results of Investigations & Discussions

According to the results of experiments the following curves were drawn for normal and calcium alloyed steels : Coefficient of chip shrinkage (K), cutting load (Px; Py, Pz), cutting temperature (θ), plastic & total contact lengths (C_l and C respectively) and tool wear as a function of cutting speed (Fig. 2, 4) and micro hardness (Hv) as a function of distance from tool nose (Fig.3).

From the curves the following observations were made :

1. "Pulsation" contact zone (unstable built-up-edge) starts at approximately 40 m/min for both calcium alloyed and normal steel (Fig. 2b peaks 1' and 1 respectively)

2. Disappearance of "pulsation" contact zone takes place at $Vc_1 = 60$ m/min. in the case normal steel and at $Vc_2 = 130$ m/min. in the case of calcium alloyed steel (Fig. 2)

3. Values of the confficient of chip shrinkage and cutting load are higher in the case of normal steel (Fig. 2 b, c)

4. Both-absolute and plastic contact lengths are smaller in the case of calcium alloyed steel (Fig. 2 d).

5. Cutting temperature is also lower in the case of calcium alloyed steel but the difference decreases with the increase of cutting speed beyond Vc_2 (Fig. 2a).

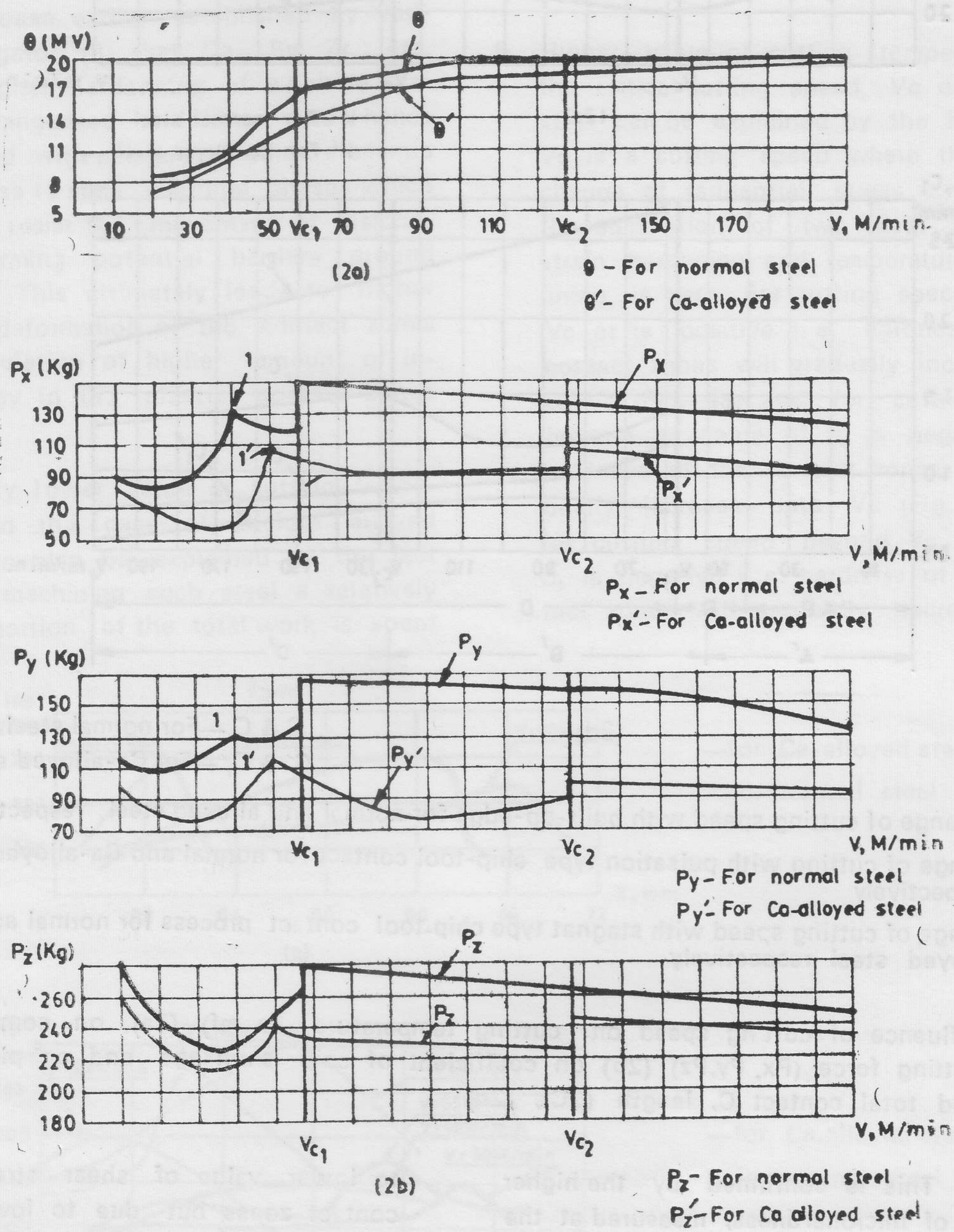
6. Absolute value of cutting temperature at the critical speed Vc_2 for calcium alloyed steel is higher than that at Vc_1 normal steel (Fig. 2a).

7. Micro hardnee of the confact zones at speed $V < Vc$ for calcium alloyed steel is much higher than that for the original steel but at $V < Vc$ the values of Hv at corresponding cutting speeds have comparable values (H_v varies from 820 to 900 Kg/mm² for calcium alloyed steel in the range of cutting speed from 75 m/min to 110 m/min. against a variation of Hv from 480 to 640 kg/mm² in the range of cutting speed from 40 to 55 m/min for normal steel (Fig. 3a).

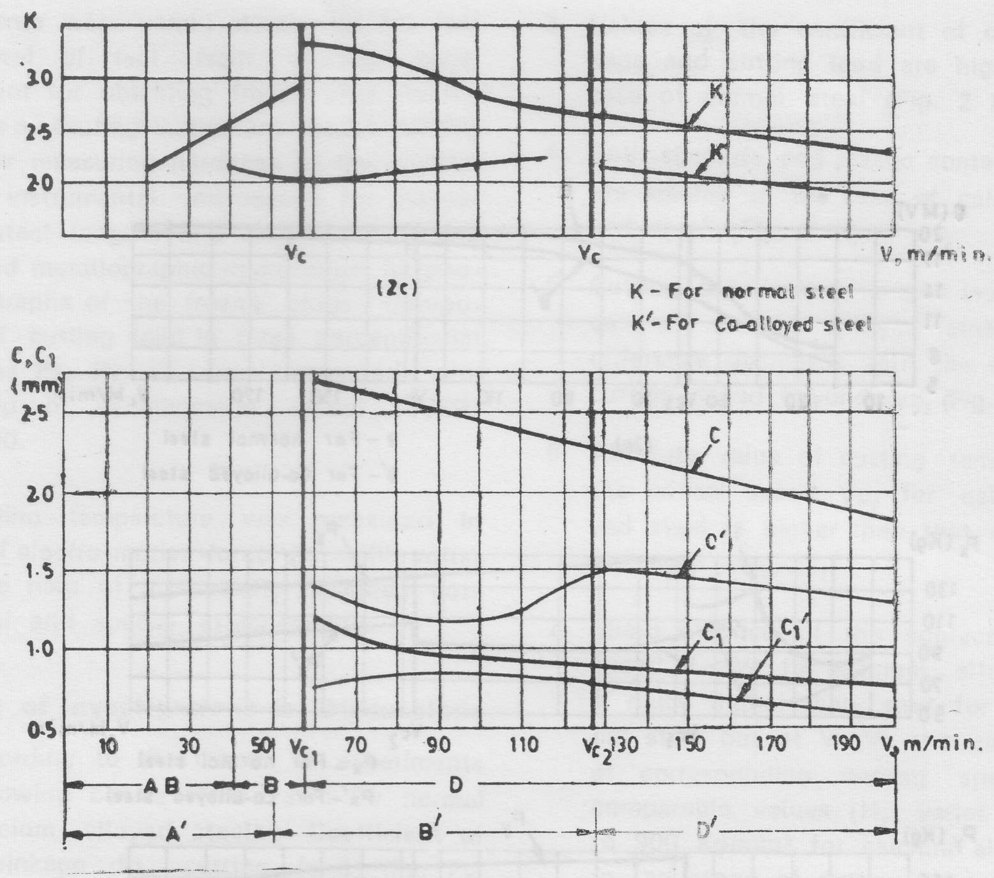
From the above observations the following logical conclusion can be drawn :

1. Improvement of machinability i. e. lower intensity of tool wear in machining calcium alloyed steel (Fig.4) up to high cutting speed is due to the change in critical cutting speed from $Vc_1 = 60$ m/min. to Vc_2 - 130 m/min, upto which unstable built-up-edge protects the tool from intensive wear (Fig.2).

2. Lower values of contact lengths of calcium alloyed steel indicate higher intensity of deformation process at the contact



θ (M V)
θ
θ′
V, M/min.
(2a)
θ - For normal steel
θ′- For Ca-alloyed steel
P_x (Kg)
P_x
P_x'
V, M/min.
P_x – For normal steel
P_x'- For Ca-alloyed steel
P_y (Kg)
P_y
P_y'
V, M/min
P_y- For normal steel
P_y'- For Ca-alloyed steel
P_z (Kg)
P_z
V, M/min.
(2b)
P_z- For normal steel
P_z'-For Ca alloyed steel



(2d)

C & C_1—For normal steel
C' & C_1'—For Ca-alloyed steel

AB, A'—Range of cutting speed with built-up-edge for normal and alloyed steel respectively

B, B'—Range of cutting with pulsation type chip-tool contact for normal and Ca-alloyed steel respectively

D, D'—Range of cutting speed with stagnat type chip-tool contact process for normal and Ca-alloyed steel respectively

Fig.2. Influence of cutt ng speed on. cutting temperature (e. mf) (2a), on components of cutting force (Px, Py, Pz) (2b) on coefficient of chip shrinkage and on plastic (Cl) and total contact C, length (2C), (2d)

zones. This is confirmed by the higher values of microhardness, measured at the chip-tool contact zones of calcium than that of the normal steel (Fig. 4).

3. Lower value of cutting force in the case of calcium alloyed steel is not due to lower value of shear stress at the contact zonss but due to lower values of contact length. Higher value of shear stress is due to higher density of dislocations in the plastic contact zones. And higher value of the density of dislocation may be due to effective blockage

of the movement of dislocations by the nonmetallic oxides, formed due to micro allowing of steel with calcium, selenium, zirconium, lead or other elements.

It has been earlier established by various investigator (3) that Ca, Se, Zr, etc. facilitate higher hardenning of sulphide phases than manganese and iron. And hence steel alloyed with calcium or allied elements will give rise to such sulphide phases which will better resist the movement of dislocation by forming potential barriers around themselves. This ultimately leads to higher degree of deformation of the contact zones i. e. accumulation of higher amount of internal energy in the plastic contact zones of chip.

4. Relatively lower value of cutting temperature in the case of calcium alloyed steel can also be explained by the fact that, in machining such steel a relatively bigger portion of the total work is spent in changing the internal energy of the contact zones and consequently a relatively smaller portion of the work is given out in the forms of heat energy i. e. spend in raising cutting temperature.

5. Higher value of cutting temperature at the critical cutting speed, Vc of alloyed steel can be explained by the following: Vc is a cutting speed where the rate of change of tangential stress d_t, due to the summation of two rival processes strain hardening and temperature softenning, is zero. For cutting speeds below Vc at is positive i. e. hardness of the contact zones will gradually increase up to Vc (Fig. 4a) and for cutting speed beyond Vc value of d_t is negative i. e. hardness of the contact zones will gradually increase upto Vc (Fig. 4a) and for cutting speed beyond Vc value of d_t is negative i. e. hardness of the contact zones will gradually decrease (Fig.

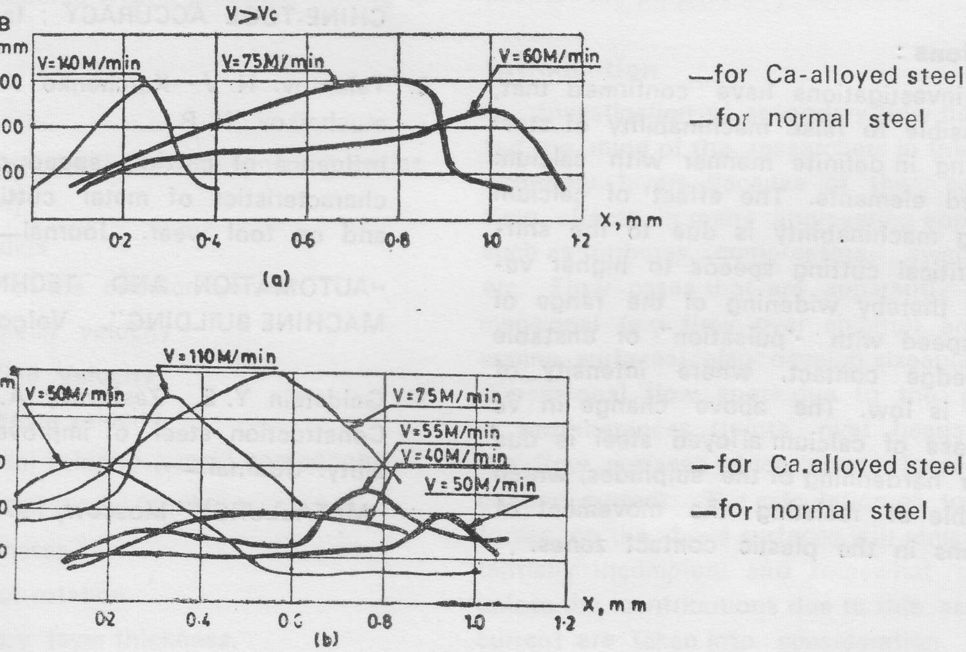


Fig. 3. Microhardness in the range of plastic contact length for values of cutting speed less than Vc (b) and greater than Vc (a).

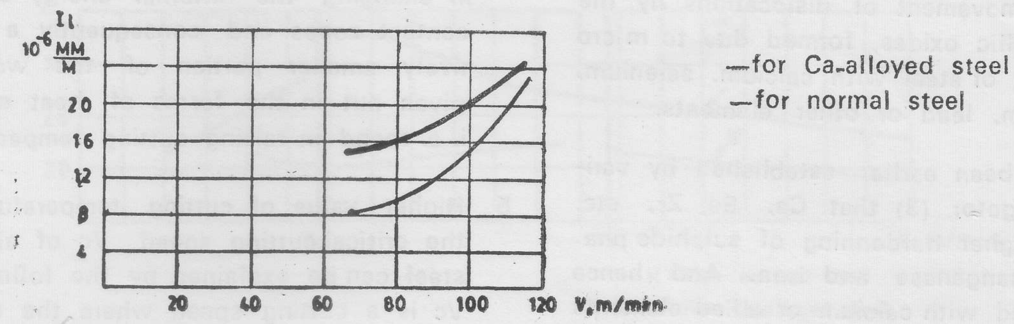


Fig. 4. Influence of cutting speed on the intensity of tool wear in machning normal and Co-alloyed steel.

4b). Now, since in the case of Ca alloyed steels the rate of growth of shear stress d_t is higher due to faster increase of strain hardenning effect equilibrium of hardenning and softenning proceses is attained at a higher critical cutting speed-Vc_2 and a higher cutting temperature is necessary to counter balance increased strain-hardness of the plastic contact zones (Fig. 2a).

Conclusions :

The investigations have confirmed that, it is possible to raise machinability of steel by alloying in definite manner with calcium and allied elements. The effect of calcium in raising machinability is due to the shifting of critical cutting speeds to higher values and thereby widening of the range of cutting speed with "pulsation" or unstable built-up-edge contact, where intensity of tool life is low. The above change in Vc in the case of calcium alloyed steel is due to higher hardenning of the sulphides, which are capable of resisting the movement of dislocations in the plastic contact zones.

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