Effect of Type of Workpiece Material on Chip Formation Process

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Abstract

This paper looks at the process of chip formation in metal cutting as being dependent not only on the work piece material but, even on the micro and macro structures of the work piece materials. Cutting operations were carried out on a universal lathe machine thereby making turning operation the basis for the experimental works for the research. Three major types of work piece materials were used: mild steel, stainless steel and titanium. The cutting operations were carried out dry for the three work piece materials used. Cutting conditions chosen are; cutting speed, v, between 2-120m/min; cutting feed, s, 5 mm/rev; and cutting depth, t, 3 mm. The cutting tools used were uncoated, and a jig, known as quick stop mechanism was developed to facilitate obtaining the chip roots which were later studied. 1,500 chip roots of titanium and over 600 chip roots each of both mild steel and stainless steel were studied. It was discovered that; the micro-structural block of titanium and its alloys play major roles in the chip formation process, the type of tool grade does not affect the process of chip formation, tool geometry does not affect the process of chip formation, and the shear zone during the process of turning titanium is not constant.

Keywords: *Chip formation, work-piece material, cutting operations.*

Introduction

The problem of chip formation generally is a very important one to the manufacturers. This is not unconnected with the problem associated with the classification of chips and most importantly, the theory behind the chip formation. This paper is looking into the formation of segmented (which we shall be referring to as continuous with built up edge) chips during turning of titanium, stainless steel and mild steel and its alloys in a semi-finished cutting process. Though chips are only by-products of machining operations, they are very important in the study of machinability of metals as well as the study of cutting tool wear. The classification of chips is generally into three groups: discontinuous chips; continuous chips and chips with built-up-edges (not continuous chip with built up edges). This is based on the chip formation theory of a single shear plane.

This, on its own, is based on the Merchant's theory or law of 1945 (Astakhov 1999; Astakhov and Shvets 2004; Astakhov *et al.* 1997). In actual fact, the law was first propounded in 1870 and later modified in 1877 by Time, a scientist of the Imperial Russia (Astakhov 1999).

The better-armed one is, the greater his chances of survival. Wood gave way for metal and the metals also give way for other better metals in our development (Adejuyigbe 2000). In this research, three materials have been chosen for consideration they are: stainless steel, mild steel and titanium. Since titanium has been found, it has pushed other metals of interest to a lower stage. This is due to its properties; light in weight, strong, high ductility, inactive, non-corrosive and non-magnetic (Gurevich 1972). Before the discovery of titanium, stainless steel has been the pace setter after it pushed mild steel and iron to stages lower. Stainless steel lost out to titanium in properties, most especially in weight/strength. Titanium is about 3-5 times lighter than stainless steel but 5-7 times stronger. It is, however, about 4-6 times more expensive than stainless steel. The cost of titanium made it not to be common which eventually led to other problems of acceptability and availability a wide range of users. Technical books only treat the problems of titanium on the surface; scientists on the metal cutting line have not much reference. This led to a lot of theoretical modelling of happenings during turning of titanium. Others even try to write on titanium only on the events of turning like-metals. Others turn titanium on micro speeds and generalize their finding for titanium. Very much unlike other metals, titanium even has a problem of classification. This is not only that different countries classify the same titanium alloy differently, but, even in the same country, different companies do classify some alloy differently (Chechulin and Hesin 1987). Despite these the problems, it is very difficult to reject titanium and so engineers are sticking to it as much as possible. The introduction of titanium into engineering intensifies the research into it and most especially in the field of metal cutting. Chip formation in titanium is different from that of similar metals though the chips, at first sight, may look alike and only serious study with the aid of strong and powerful microscopes will reveal the differences.

The process of chip formation, which forms an important part of the metal cutting theory, has always been of great importance and interest to scientists in the field of metal cutting. The problem of chip formation generally is a very important one to the manufacturers. This is not unconnected with the problem associated with the classification of chips and most importantly, the theory behind the chip formation. The classification of chips generally into three groups: discontinuous chips, continuous chips and chips with built-up-edges is, to say the least, not satisfactory. This classification is based on the chip formation theory of a single shear plane. This, on its own, is based on the Merchant's theory of 1945 (Astakhov 2005). In actual fact, the law was first propounded in 1870 and later modified in 1877 by Time, a scientist of the Imperial Russia (Astakhov 2005). As important as this process of chip formation is and as dynamic as the workpiece (construction) materials are, it however remains unexplained in any of the available literature why the law guiding the process of chip formation as well as its theory is still based on a law dating as far back as 1945 by Merchant, E.M., or even 1870 by Time, and even without concrete reference to the workpiece material. This paper is looking at the process of chip formation in metal cutting as being dependent not only on the cutting conditions and the type of workpiece material but, even on the micro and macro structures of the workpiece materials. Also the formation of segmented (continuous with built-up-edge) chip during turning of titanium, stainless steel and mild steel in a semi-finished cutting process was looked into. Though chips are only by-products of machining operations, they are very important in the study of machinability of metals as well as the study of cutting tool wear. There are others who have done tremendous work in this area they are, among others, Komanduri and Hou (2002); Hayajneh *et al.* (1998) and Astakhov and Outeiro (2004).

Methodology

The experiment was carried out in the Department of Advanced Manufacturing Technology, Faculty of Manufacturing Technology and Machine Tools, Volgograd State Technical University. Volgograd, Russia. Cutting operations are carried out on a universal lathe machine thereby making turning operation the basis for the experimental works for this paper. Three major types of work-piece materials were used: mild steel, stainless steel and titanium. Cutting operations are carried out dry, that is, without the use of coolants for all the three work-piece materials used for this experimental works. Cutting conditions chosen are: cutting speed, V, between 2 – 120 m/min; cutting feed, *s*, 0.467 mm/rev and cutting depth, *t*, 3 mm.

The cutting tool used are the tungsten carbides also known as straight carbides, coded

BK and the tungsten-titanium carbides, also known as double carbides, and coded TK under the USSR State Standard Specifications (GOST). All the cutting tools used for the experiment are uncoated. A jig, known as quick stop mechanism (falling / dropping tool), was designed and constructed to facilitate obtaining the chip roots which were later studied. The chip roots form the bases for the studies and that is the reason why the method for obtaining them is of great importance. The jig is made for the tool so that it allows the tool to drop at any desired time to the operator. The jig is called a falling (dropping) tool because of the fact that it could be made to drop or fall out of contact during operation without changing or distorting the cutting operation, maintaining the conditions of cutting, due to the very high withdrawal speed of the tool. In other words, the chip root specimen is a "frozen cutting condition" of a particular cutting operation comprising of the activities in the zone of chip formation as well as the chip-rake face contact interface. The specimen is cut off the workpiece, prepared, stained and studied for chip formation as well as chip-tool contact. The jig is constructed in a way that the tool could be knocked out of contact with the work piece with a striking force. Since it is a sudden discontinuation of the cutting process, the cutting process could be said to have been frozen at that point in time in most cases a part of the tool, actually taking part in the cutting process, breaks off the parent tool, due to adhesion, and stays onto the chip root, thus making a unique connection "work piece- tool-chip" as shown in Fig. 1. The sudden force is needed to knock the tool out of contact with the work piece avoiding reduction in cutting depth that might be caused as a result of gradually withdrawing the tool. Since the chip root is to fix the last moments of cutting, gradual removal of the tool would have altered the cutting depth, and of course the picture of the last moment of the "work piece – tool – chip" connection. The operator stops the machine afterwards. Since the specimen is on the work piece, it must be cut out using a saw. The specimen is balanced on a piece of glass so that the part, during cutting operation that is facing the head stock, is placed inside a frame for convenient holding, the frame on the glass and a cold working acrylic powder solution is poured into the form and left to solidify. The specimen is afterwards removed from the frame and the glass before it is being prepared for study under the microscope. It is that sawed out part that is called a chip root and the part that is being studied is the specimen. With the help of abrasives of different grades and forms, starting from the rough to smooth grade in both plates and pastes, avoiding scratches on the polished surface, the specimen is gradually ground to the middle. The grinding is made to the middle or mid way into the chip root in the direction of the cutting depth. Care must be taken however, that during the process of grinding, the perpendicularity of the chip root and the plane of grinding is maintained. It has been proved that the study of metal cutting and chip formation must be made around the mid way into the cutting depth (Talantov 1992). This is the reason why the chip root must be ground to the middle, in other words, ground to the tip of the cutting tool. After that the chip roof is later treated with chemicals (stained) to expose the structures of the particular metal. All these processes are done manually one at a time. The difficulty in obtaining a creditable chip root specimen, unlike other methods of explaining metal cutting theory, is responsible for the uncommon though acceptable way of explaining the metal cutting theory.

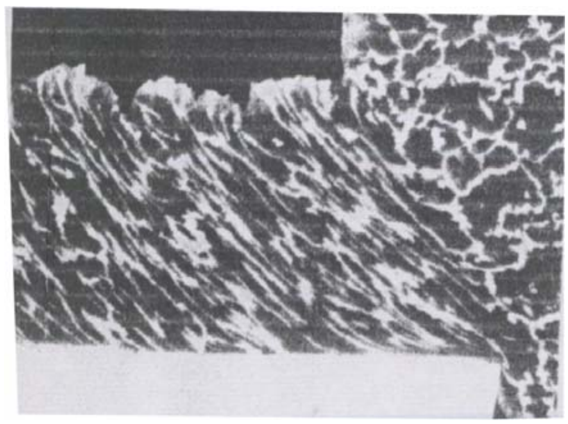

Fig. 1. A chip root specimen ready for study.

The chip root specimen is later subjected to micro-hardness tests since chip formation is inevitable in metal cutting, and then it is only right to learn how to control it. During cutting operation the following parameters were used: cutting speed, *V*, = 5m/min – 80m/min; Feed *s* = 5 mm/rev; Depth of cut *t* = 3mm and the machine tool used is Universal lathe machine.

Results and Discussion

Fig. 2 shows a chip root from mild steel showing the formation of a continuous chip under microscope (X1500) this further confirmed that mild steel will naturally, under normal conditions, have continuous chips during turning. For any other chip to be produced, the cutting speed must have been over 90 m/min, the wear of the tool must have been much more than the recommended value and the resonance range (level) of the machine must have been exceeded. In that case there will be a segmented chip, which can also be called discontinuous chip. This types of chip from mild steel is not useful for any scientific study, it is used only to establish the fact of its existence.

Fig. 3 shows the chip root from stainless steel while turning stainless steel of different grades. The type of chip formed is called the segmented chip. It was observed that a segmented chip is formed while turning stainless steel of all grades not minding the type of tool material used contrary to the belief of some scientists, that type of tool material will have effect on the type of chip formed. The segmented chip formed during turning of stainless steel is observed to be identical. This shows that the process of chip formation, taking place during turning of stainless steel is constant. Optimal type of tool grade should be used to turn the metals in the group of stainless steel.

Segmented chips were also formed during turning of titanium. Titanium was observed to be much more difficult to machine than stainless steel which implied that cutting speeds required for turning titanium are not industrial (titanium is turned in micro-speeds). This is a disadvantage since process of chip formation under the regime of micro-speeds is very much different from that of industrial speeds

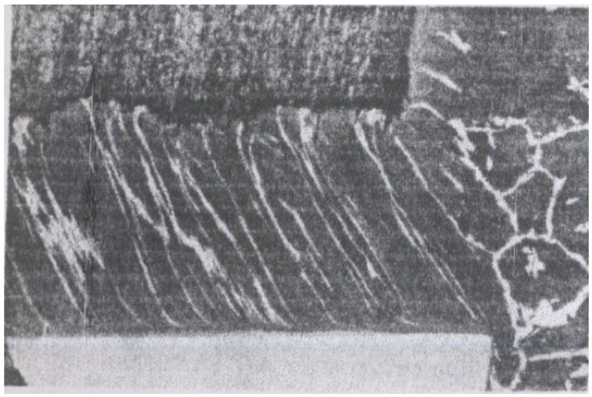

Fig. 2. A chip root from mild steel showing the formation of a continuous chip (x 1500).

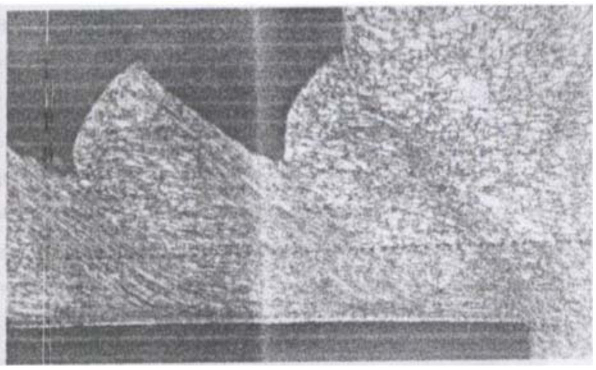

Fig. 3. Segmented chip formation in turning stainless steel.

After studying over 1,500 chips roots of titanium and over 600 chip roots of both mild steel and stainless steel the following conclusions were drawn based on Figs. 4 and 5:

i. the microstructural blocks of titanium and its alloys play major roles in the chip formation process;
ii. the type of tool grade does not affect the process of chip formation in titanium and its alloys as widely asserted by scientists;
iii. tool geometry though very important does not affect the process of chip formation in titanium and its alloys;
iv. the shear zone, during the process of turning titanium and its alloys, is not constant. It sometimes appears and sometimes disappears. This means that not all parts of the segmented chip passes through the shear zone.
v. the shear zone, when present, is reduced and even sometimes could not be called a shear zone but a 'shear line' (shear plane)

and passes through the boundaries of the microstructural blocks since they tend to be the weakest parts of the structures;

vi. shear line some times passes through the microstructural blocks if it can be turn or if it has a defect.

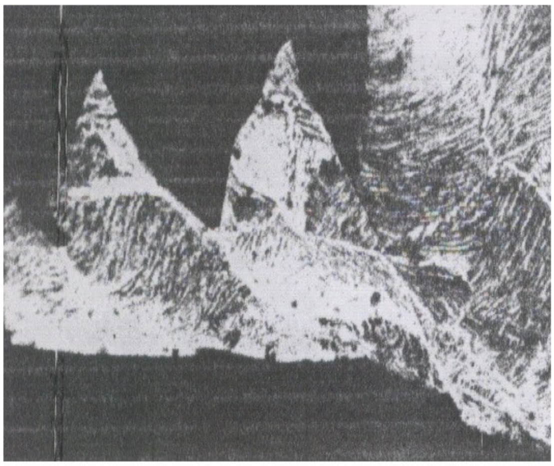

Fig. 4. A typical chip root common with titanium and its alloys (x1500).

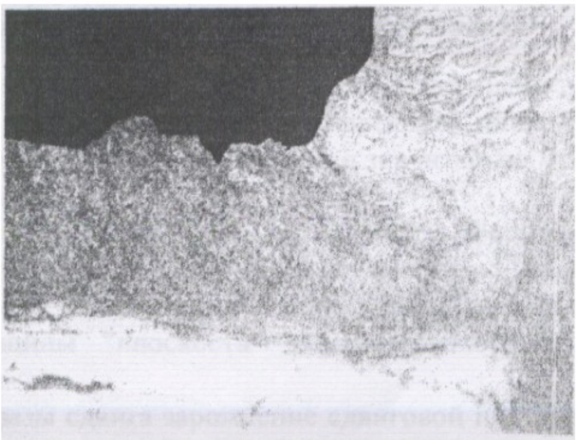

Fig. 5. Chip root of titanium that was first made public in 1994. It buttresses the dominating role of the microstructures of the structural blocks of titanium in chip formation. (x1500)

In Fig. 4, one can see how the different structural blocks determine the type and size of the elements of the segmented chip. The difficulty in obtaining a chip root could be considered as a major reason why scientists have never before related or attributed, to this level, the effects of the structural blocks on chip formation in titanium and its alloys. In the same way, it is very easy to notice that the elements of the segmented chip in titanium, unlike in stainless steel (Fig.3), are not identical. This shows that the blocks are very much responsible for the emergence of the elements of the segmented chips.

It can be seen in Fig. 5. that the type of chip normally known to come along with turning of titanium and its alloys, but at the same time, a continuous chip formation could clearly be seen over a period of time. This was explained as a favourable placement (orientation) of the predominant block in the micro-structural level. This favorable placement of the predominant micro-structural block, falling in the in the shear zone (zone of chip formation), was deformable while passing through the shear zone just like in the case of mild steel, thus producing a continuous chip for the period of time that the micro-structural block remains in the zone of chip formation.

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