An Analysis of Chip Formation in Wood Machining

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This preliminary report on fundamental machining research considers the photographic analysis of chip formation. Basic types of chip formation and the associated surface characteristics are identified. The influences of various factors which control chip formation are discussed.

Historical Review

ADVANCES IN WOODWORKING MACHINERY during the last few decades have been important in helping wood-using industries meet the demands of quality at low cost. It is significant, however, that basic concepts of wood machining have received little attention; our progress has been limited primarily to accelerating old processes. With few exceptions, there has been no appreciable advance in the fundamental technology of machining.

In attempting to secure sound information on the cutting of wood it quickly becomes apparent that our present lack of fundamental knowledge precludes the possibility of obtaining either empirical or theoretical data that can be utilized to best advantage. In the course of machining studies at the University of Michigan's Wood Technology Laboratory the need for basic information has been clearly demonstrated. This prompted an initial study in 1951 of the cutting action of a shaper. During this work, observation of the cutting process was made possible by use of microflash photography. With suitable triggering devices, a sequence of photographs was obtained showing the knife at any desired position during cutting. These photographs provided sharp, detailed images of chip formation, but due to equipment limitations sequences could not be made on a single chip.

Concurrent with the micro-flash experiments, a Fastax high-speed motion picture camera was used for machining research. This photographic equipment, which in a sense permits the magnification of time, provided a means of watching high-speed cutting at a rate that could be followed by the eye. Using a high magnification lens system, it was possible to observe the cutting process involved in the formation of a single chip. The films obtained proved extremely valuable as a research tool and as an instruction aid.

High-speed motion picture photography is an exceptionally revealing research technique and has found wide usage in all phases of motion analysis. It has, however, certain limitations when used for studies in wood machining. Not only is the equipment initially expensive, but great quantities of film are consumed. A one-hundred foot reel of film will usually record the happenings of only one second. The film image often lacks the detail desired because of peculiarities of the lens system. Further, the intense light sources usually required generate heat in such quantities that temperature and moisture control is difficult.

Method of Study

The value of motion picture photography for studies of cutting action was established by use of the Fastax camera. In attempts to improve this method of observation, it was assumed that if the cutting action could be slowed down sufficiently without altering chip formation, it would be possible to use standard motion picture methods and thus overcome the above-mentioned limitations of high-speed filming. In view of general agreement that speeds of 10,000 feet per minute are desired in wood cutting, the prospects of reducing velocities to a few inches per minute without seriously changing cutting characteristics were not encouraging. Nevertheless, the advantages to be gained by successful reduction of speed were great, and since planer studies showed no apparent change in cutting action between 5,000 and 10,000 feet per minute, an investigation of the relationship of cutting velocity and chip formation was thought to be justified.

Using the high-speed motion picture camera, chip formation at various velocities was studied. It was found that when all conditions were held constant except cutting velocity, the process of chip formation was virtually unaffected so long as a truly dynamic situation existed. As static conditions were approached, a gradual change in the cutting process was observed. This behavior is undoubtedly closely related to the changes in the strength properties of wood as the rate of loading is reduced from impact to static conditions.

Early in the study of the cutting process it became obvious that chip formation varied with changes in machining conditions. Further, it was observed that each chip removed during the rotary-cutting process was in fact a combination of chip forms. The study of these forms of chip removal, rotary-cutting, was initiated by the continuously changing conditions during the separation of a single chip. The trochoidal path of the cutting edge resulted in changes in such factors as cutting angle, clearance angle, instantaneous chip thickness, and relative grain angle. In order to obtain constant conditions it was necessary to consider a special case of rotary cutting where the cutting circle was of infinite diameter. This could then be treated as orthogonal cutting, where the cutting edge of the tool is perpendicular to the direction of relative motion of tool and workpiece and generates a plane surface parallel to the original work surface.

Thus simplified by the elimination of high cutting velocities and the complexity of rotary cutting, wood machining can be studied quite readily. Using orthogonal cutting with velocities of several inches per minute, a fundamental program of research was inaugurated to study factors influencing chip formation. A milling machine was adapted for this purpose, as shown in Figs. 2 and 3, with the work pieces held in a fixture on the table feeding against a stationary cutter. Interchangeable cutting bits, ground to the necessary specifications, were mounted in a specially designed dynamometer calibrated to compute the forces on the cutting bit normal and parallel to the cutting path. These forces were continuously recorded by means of a double channel strain analyzer and oscillograph. Simultaneously, a 16 mm. motion picture camera equipped with a magnifying lens system made a photographic record of the process of chip formation. In this way it was possible to correlate the force...
patterns with the measurements and observations from the motion pictures.

The information obtained from this method of study has been valuable in understanding the fundamental concepts of wood machining. The following general discussion of chip type includes some of the early findings based on photographic analysis, and covers only the initial phases of the complete study. Reports on various other phases of this research will be made in the near future.

**Chip Type**

When cutting parallel to the grain, three basic types of formation can be distinguished. Type I chip is formed when cutting conditions are such that the wood splits ahead of the knife by cleavage until failure in bending as a cantilever beam occurs as seen in Fig. 4. Type II chip results when failure of the wood is due to diagonal shear as in Fig. 5. The Type III chip forms by compression and shearing of the wood as illustrated in Fig. 6. Certain variations of these basic types of chip formation will occur when the cutting path is not exactly parallel to the grain of the wood, Figs. 7 and 8, or when friction on the face of the knife is excessive, Fig. 9.

When cutting perpendicularly to the grain on a side grain surface, as in slicing veneer, or when cutting end grain, limited investigation has shown that the types of chip formation also fall into the three general classifications given above. As would be expected, the character of the chip varies considerably due to the wide range in the wood properties with respect to grain direction.

The Type I chip provides the most efficient means of removing material and causes comparatively little wear on the cutting edge, but it can cause severe surface defects. This type of chip is most frequently found when large cutting angles are used and chip thicknesses are great. Under these conditions, the tool face exerts large forces in a direction normal to the plane of cutting, causing the wood ahead of the knife to fail in cleavage, after which the partially removed chip acts as a cantilever beam. As long as
the strength of the beam exceeds the cleavage strength, the chip continues to split ahead of the knife, following the grain of the wood. When the beam reaches a critical length the bending moment becomes large enough to cause failure and the chip continues to slide up the face of the knife until the cutting edge again contacts the work and the cycle is repeated.

When the path of the cutting tool is parallel to the grain of the wood, or the cut is into sloping grain, the surface produced is of good quality, since a secondary chip of Type II is commonly formed and determines the quality, Fig. 7. If the cut is against the grain however, the splitting of the chip will frequently follow the grain before bending failure occurs and the surface displays the defect ordinarily called fuzzy grain, as commonly found when surfacing woods such as aspen. It is apparent that this variation of the Type III chip will be encouraged by dull cutting edges for reasons discussed below.

Factors Controlling Chip Formation and Surface Quality

It can be seen from the above discussion that the quality of the surface produced during machining as well as the efficiency of the operation is grossly dependent on the type of chip formation. Ideally, on should strive to obtain the Type II continuous chip for best surface quality and the Type I splitting chip for optimum efficiency of material removal.

The rotary cutting method offers a unique opportunity for combining these two goals. At the time the cutting edge is nearest the surface to be generated, the chip thickness is small and conducive to Type II chip formation if the tool edge is sharp. When the knife position in the work is farthest from the plane of the new surface, the chip thickness is near its maximum and tends to encourage a Type I chip. Examination of planer machine chips indicates that the change in chip formation is the general rule and that the balance between the types largely determines whether a surface will be good or poor.

Where surface quality is the primary consideration, as in making light finishing cuts prior to machining with coated abrasives, the rotary cutting process appears to be somewhat inferior to orthogonal or straight-line cutting. A well-designed machine operating on a principle similar to the scraper would seem to be indicated, since it could produce high quality surfaces free of machine marks and give relatively long tool life. In some instances, a rotary cutter and orthogonal cutter might well be combined in a single machine.

In rotary and orthogonal cutting, surface is determined by chip formation, which is in turn determined by many factors, some of which are easily controlled and others for which control is impractical or impossible. In the former group are chip thickness, cutting angles, and cutting velocity. In the latter are natural variations of the material, the grain direction of the wood, and the physical and mechanical properties of the wood excluding the effects of moisture. Grain direction has arbitrarily been put in the uncontrollable category because in high production machining it is not practical to make certain that cutting against the grain is avoided at all times.

The uncontrollable factors obviously must be accepted as such, and the controllable factors adjusted accordingly. Chip thickness is readily controlled by changes in the depth of cut and in rotary cutting also by changes in the feed per knife. In most instances, the feed per knife is
accomplished in several ways. The changes in other factors may permit 
ules.

angle of the tool face greatly in-

chip formation, it can be seen that the 

costs. From the previous discussion of 

increase the forces normal to the sur-

general, increased friction tends to in-

This is evidenced by the sound of 

chipped grain caused by the Type I 

breaker could be of significant value 

prevented.

chip type and surface quality.

Formation of a particular chip type 

determined by a number of factors, 

some of which may be controlled. 

points in which constant surface quality, is in many cases poor 

as chip load are kept constant by 
maintaining a uniform rpm-feed rate 

ratio. Current use of high spindle 

speeds to secure lighter chip loads and 

more knife marks per inch at a feed 

rate consistent with production de-

mands, in order to obtain satisfactory 

surface quality, is important. When making heavy 

surfacing cuts or where exhaust capac-

ity is insufficient to remove chips, the 

centrifugal forces associated with high 

spindle speeds will often help clear 

the knives of chips and prevent chip 

marks. However, it has been found 

from preliminary experiments that the 

control of static electricity may be a 

more efficient method of eliminating 

this defect.

Conclusions

The wood cutting process involves 

the formation of basic chip types with 

associated surface characteristics. 

When cutting parallel to the grain, 

chip formation may be classified as: Type I, in which splitting ahead of the 

cutting edge may result in the defect 

chipped grain; Type II, in which 

continuous diagonal shear produces 

excellent surface quality; and Type 

III, where compression and shear 

failures in the wood often cause the 

resultant surface to be fuzzy. Variation 

of the grain direction with respect to 

the cutting path of the tool will alter 

chip formation due to the anisotropic 

nature of wood. 

Formation of a particular chip type 

determined by a number of factors, 

some of which may be controlled. 

Knowing certain of these factors, it is possible to adjust the remaining to ob-

tain the desired type of chip forma-

tion. Under practical conditions, 

where close control of variables may 

be difficult, it should be possible to 

make a statistical determination of 

chip type and surface quality.