

SCIENTIFIC EVALUATION OF CUTTING-OFF PROCESS IN BANDSAWING

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Abstract: In metal processing industries, bandsawing plays a key role in cutting off variety of raw materials as per to the customer required dimensions. The chip formation in bandsawing is a complex process owing to its distinctive relationship between edge geometry (edge radius: $5\ \mu\text{m}$ - $15\ \mu\text{m}$) and the layer of material ($5\ \mu\text{m}$ - $50\ \mu\text{m}$) removed. This unique situation in bandsawing can lead to inefficient material removal with complex chip formation characteristics compared to a single point cutting tool. In this paper, scientific evaluation of the performance of bandsaw by full product and time compression simulation techniques has been discussed. Specific cutting energy parameter calculated based on cutting force and material removal data has been used to quantitatively measuring the efficiency of the metal cutting process or the machinability of a workpiece. The wear modes and mechanisms in bandsaw cutting edges have been discussed. The results presented in this paper will be of interest to the design engineers and bandsaw end users.

Keywords: BANDSAW, BANDSAWING, CUTTING FORCE, SPECIFIC CUTTING ENERGY, WEAR

1. Introduction to Bandsawing

Bandsawing is the preferred method as primary machining operation in a variety of industries for cutting off raw materials into customer ordered pieces, in preparation for the secondary processes (e.g., turning) [1, 2]. Bandsawing offers the advantage of high automation possibilities, high metal removal rate, low kerf loss, straightness of cut, competitive surface finish and long tool life. The cutting edges of bandsaw are not infinitely sharp, but possess an edge radius even though they are produced by precision grinding operation. A smaller chip ratio in bandsawing (approximately 0.1) indicates that the cutting is not as efficient as cutting with nominally sharp tools at large feeds such as turning, where chip ratios can be more than 0.3. The bandsaw cutting action is intermittent and the number of active cutting edges in contact with the workpiece at any instant can vary depending on the shape and size of the workpieces. Today, most of the bandsaws used in the industry are of bimetal type (High Speed Steel tip with spring steel backing), though the demand for carbide tipped bandsaws is increasing.

Although much attention has been given to secondary machining operations (e.g., turning, milling, drilling etc.), very little attention has been given to primary machining operations (e.g., bandsawing). Thompson and Sarwar are among the earlier researchers [3-8], who have contributed to the fundamental understanding of cutting actions in sawing. Recent work undertaken by Sarwar et. al. [9-12] and other researchers [13-15] have led to a further understanding of the bandsawing process such as cutting forces and stress generated in the bandsaw teeth, chip formation mechanism, wear modes and mechanisms etc.

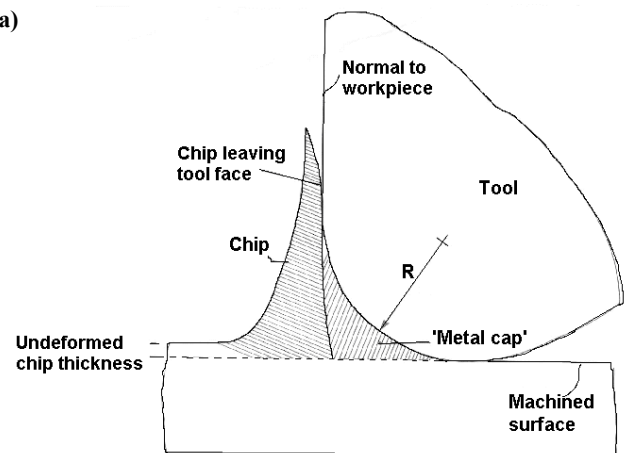
In order to have a better understanding of the mechanics of metal cutting in bandsawing operation and to improve the process and blade design, there is an urgent need to establish fundamental data associated with forces, metal removal rate and specific cutting energy. Owing to the technological development, new materials with improved physical and mechanical properties are constantly being developed. Production engineers face the challenge to cut-off to size the new difficult-to-cut materials. In order to cut these effectively and efficiently, knowledge of the cutting conditions (speed, feed, forces and specific cutting energy) are absolutely vital. Therefore, a basic understanding on the scientific evaluation of bandsawing efficiency would be beneficial for both bandsaw users and bandsaw providers for further development of band materials, tooth design and improved tooth precision.

2. Mechanics of Metal Cutting in Bandsawing

The distinctive characteristic of bandsawing process is that the layer of material removed per tooth ($5\ \mu\text{m}$ - $30\ \mu\text{m}$) is usually less than or equal to the cutting edge radius ($5\ \mu\text{m}$ - $15\ \mu\text{m}$). Furthermore, the chip formed in bandsawing has to be accommodated within the gullets of limited size compared to unrestricted chip flow in a single point cutting operation. This situation can lead to inefficient metal removal by a combination of

piling up, discontinuous chip formation and ploughing action in contrast to most of the single point cutting operations (e.g., turning). Fig. 1 illustrates chip formation mechanism in bandsawing.

(a)



(b)

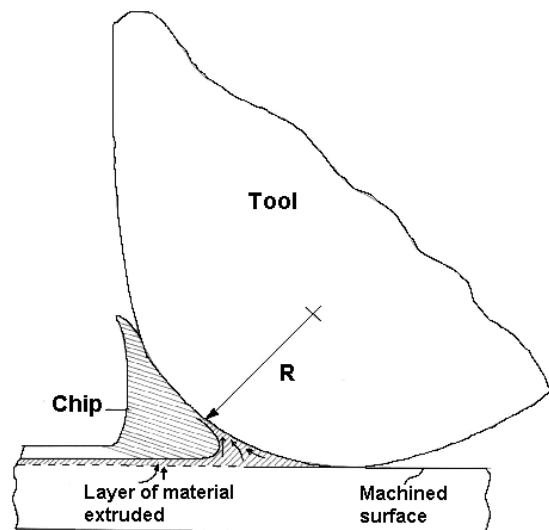


Fig. 1 (a) Metal cap chip formation and (b) Chip formation with extrusion in bandsawing.

Under the condition of cutting at smaller undeformed chip thickness with a blunt bandsaw tooth (i.e., higher edge radius), the tip of the cutting edge creates an apparent high negative rake angle with the workpiece surface. The material removal process starts with thin chip formation. With further advancement of the cutting edge, the material immediately ahead of the cutting edge becomes stagnant and forms a metal cap. This modifies the cutting edge giving metal to metal contact leading to increased friction and inefficient cutting with the chip increasing in thickness as the cut progresses. This situation continues until such time when the metal cap cannot sustain any further load and breaks down. After the

breakdown of the metal cap, the chip starts to flow again with a layer of material in front of the tool, extruding workpiece material to build a new metal cap. Similar to single point cutting, chips are also produced by shear type deformation during bandsawing. Chips could vary in size, shape and thickness. Continuous chips are produced when cutting soft material with bandsaw teeth having small edge radius (i.e., at the new condition of the tooth) compared to the depth of cut. Shorter and lumpy chips are formed by a combination of shearing and ploughing when the edge radius is higher than the undeformed chip thickness.

Fig. 2 presents a snapshot of the chip formation process at the extreme cutting edge of a bandsaw tooth taken with a high speed camera. At the beginning thin uniform chip is formed as the bandsaw tooth advances along the workpiece surface with a certain depth of cut. The workpiece material in front of the cutting edge is subsequently compressed and the chip thickness starts to increase. With further advancement of the bandsaw tooth, the workpiece material continues to build up until a lump is formed. Once the lump is fully formed the same process repeats again and again.

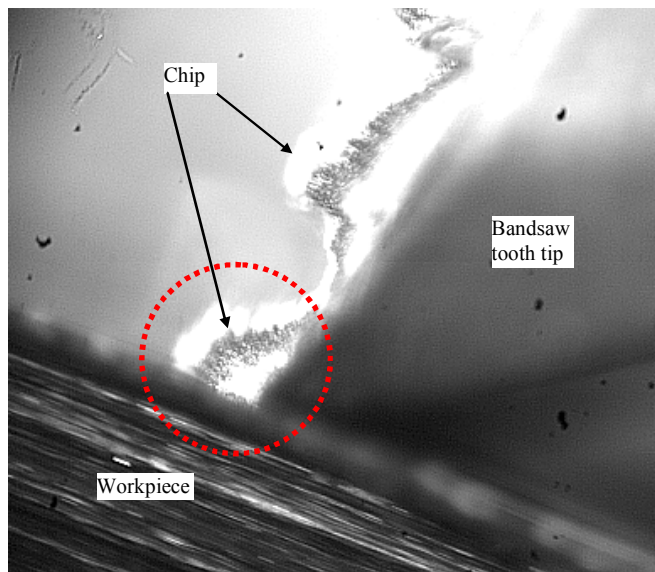


Fig. 2 Snapshots of chip formation in bandsawing as observed in High Speed Photography (bimetal bandsaw tooth machining steel workpiece).

3. Scientific Evaluation of Bandsawing Process

3.1. Full Product Testing

Traditionally, in order to evaluate the performance of bandsaw products it is necessary to carry out full-scale bandsaw tests, cutting a large number of sections of workpiece. Fig. 3 shows a fully instrumented vertical feed bandsaw machine (NC controlled, Behringer HBP650/850A/CNC) and a schematic diagram of cutting and feed directions during bandsawing. There are only two different parameters constituting the cutting data in bandsawing, namely cutting speed and feed rate.

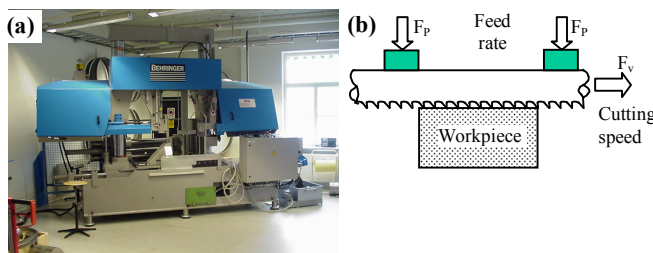


Fig. 3 (a) Experimental set-up used for bandsawing tests and (b) schematic diagram of thrust force (F_p) and cutting force (F_v) acting on the bandsaw.

The feed rate along with the choice of tooth pitch and cutting speed decides the depth of cut per cutting edge. The depth of cut affects the contact conditions at the edge, thereby having an effect on the thrust and cutting forces. The cutting speed governs the

sliding speed at the cutting edge and has a direct effect on temperature produced in cutting. The appropriate selection of cutting conditions is essential, as different workpiece materials require different settings. Cutting force and thrust force components are measured during the bandsawing tests using a 3-axis Kistler dynamometer. Fig. 4 shows the development of feed and cutting forces during the life of one bandsaw blade. The blade lasted for 950 cuts. The rapid increase of the cutting forces during the first few hundred cuts indicates a more rapid initial wear rate. This is followed by steady-state wear (secondary stage, main stage) until the cutting force component reaches a final accelerated stage of wear.

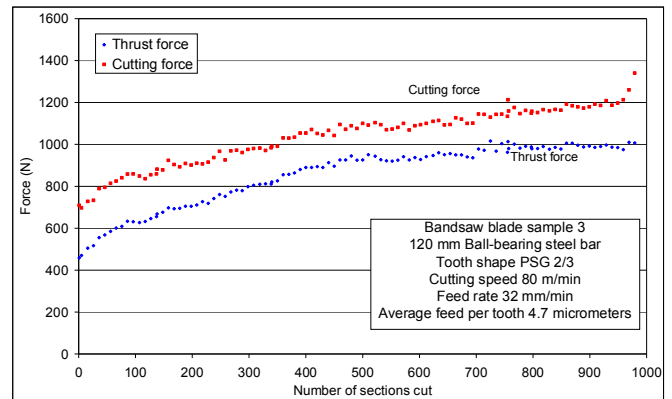


Fig. 4 Increase in force components with wear of the bandsaw blade in full product testing.

Specific cutting energy (E_{sp}) has been introduced as a parameter to quantitatively measure the efficiency of the bandsawing process. E_{sp} is a measure of the energy required to remove a unit volume of workpiece material. E_{sp} can assess products and process based on scientific values associated with both cutting forces (i.e., power) and material removal rate (feed, depth of cut and speed). Moreover, E_{sp} can be used to correlate various stages of tool wear to the performance of the bandsaw teeth, as it is more sensitive to low depths of cut, which is the case in bandsawing operation [16]. Fig. 5 shows the variation of E_{sp} with the number of cuts produced when cutting Ballbearing steel with three different bandsaw blades. For all three bandsaws, E_{sp} values for the sharp teeth are found to be approximately 5 GJ/m³, which become doubled as the bandsaws start cutting out of square cut (failure mode that indicates the end of bandsaw life). The variation of E_{sp} values also show the similar trend as the cutting forces.

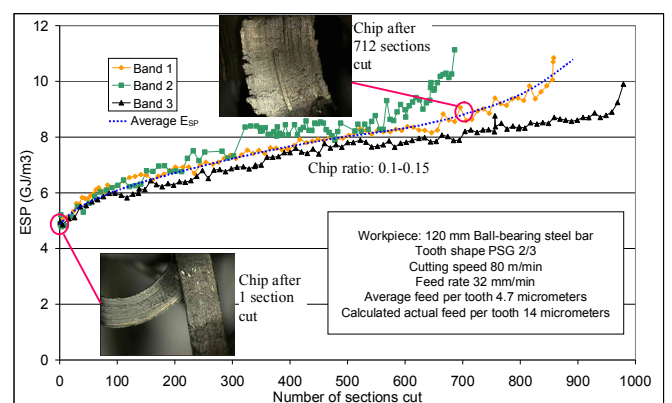


Fig. 5 Specific cutting energy (E_{sp}) during full bandsaw wear tests in Ballbearing steel workpiece.

It is interesting to note that all of the bandsaw samples have failed at approximately same level of E_{sp} (~10 GJ/m³). The variation in the bandsaw life could be explained by the variation of bandsaw tooth geometry (e.g., back to tip height, tooth tip condition, etc.), set geometry (e.g., set magnitude, set balance, set angle, etc.) and mechanical properties (e.g., hardness, toughness, etc.) in approximately 800 teeth of a particular band loop.

The other measurements and investigations such as wear land area, edge geometry, surface characteristics of cut-off workpieces (waviness), chip characteristics, out of square cutting, set width etc. need to be carried out to fully understand the bandsaw cutting characteristics. The full-scale testing activities can take several months of laboratory work.

3.2. Single Tooth Time Compression Testing

The bandsawing community faces one of the primary problems in quickly evaluating metal bandsaws in order to develop newer variants, comprising of new saw tooth materials, their heat treatment, or different tooth forms and quality. Furthermore, there are no simple ways of quantifying and evaluating the performance and life of these bands during sawing. Normally the time per cut as well as monitoring indirect parameters such as increase in cutting forces, or the amount of run-out of the saw kerf from the vertical plane are often used as performance criteria in full product testing. This only gives global data, which is difficult to apply to individual teeth. In addition, it is costly, complex and time-consuming to test the wear of full bandsaw products in full-scale bandsaw machines. Therefore, it is desirable to find a bandsaw simulation test or time-compression test that reduces the cost and the time consumption when performing bandsaw testing or adds further possibilities of investigating the cutting action. A time compression test also needs to be fully representative of the ordinary bandsaw product testing and give the fundamental data required for optimising the cutting conditions. The results that are produced need to be meaningful in order to replace the full bandsaw testing.

Single tooth time compression technique uses single bandsaw tooth to simulate the bandsawing process [4, 5, 17]. Intermittent cutting using the single tooth simulation method for different depths of cut ($2\mu\text{m}$ to $50\mu\text{m}$) proved successful in the study of specific cutting energy and the cutting forces. The cutting depth per tooth achieved was very similar to that found in actual bandsawing process. The large number of results obtained for different depths of cut per tooth show that the testing method adopted can be used to simulate an actual bandsawing process. Cutting force components of the time compression test (Fig. 6) give results, which are very closely related to the full product results. Hence, the time compression test can be effectively used with reliability in establishing useful data at a significantly reduced time.

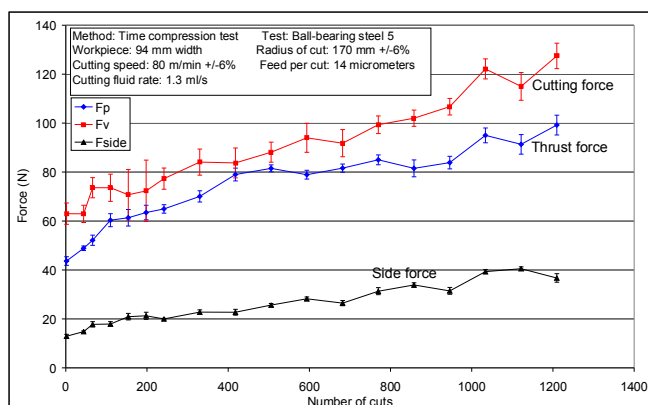


Fig. 6 Increase in force components with wear of the bandsaw tooth in time compression test.

The variation in specific cutting energy against depth of cut per tooth gives a typical exponential curve (Fig. 7). The effect of the edge radius of the cutting tool (saw tooth) is significant at lower depths of cut, giving an inefficient cutting action (higher specific cutting energy). When the depth of cut per tooth is increased, the edge radius effect decreases resulting in increased efficiency (lower specific cutting energy). The specific cutting energy reaches a steady state at 2 GJ/m^3 .

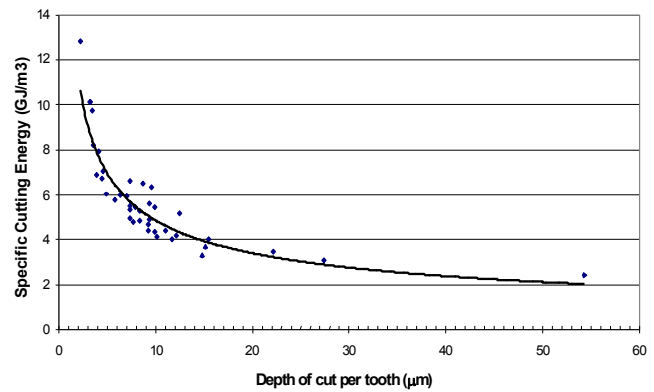


Fig. 7 Influence of depth of cut on specific cutting Energy during performance tests (Single tooth simulation test).

4. Failure Modes and Mechanisms in Bandsawing

4.1. Failure Modes

In general, bandsaws fail due to one or a combination of the followings: Out of square cutting, premature tooth failure, tooth wear or fatigue of backing metal as shown in Fig. 8 [18]. Out of square cutting is the most important reason for bimetal bandsaw failure. Out of square cut is caused due to the lateral displacement of band on a side. This could be related to instability in the band due to higher applied thrust force or unsymmetrical wear in the teeth. An incorrect choice of cutting data can result premature tooth failure due to the application of large forces. When the total wear in the bandsaw teeth reaches a critical value, a change in tooth geometry takes place (i.e., edge blunting). This can gradually lead to a higher cutting force, ultimately stopping the bandsaw from cutting any further, if the bandsaw has not failed in another mode at that point. The development of alternating stresses in the bandsaw loop from bending and twisting can generate fatigue cracks while the loop is circulating around wheels and guides. These cracks grow until the band loop is broken by fatigue failure.

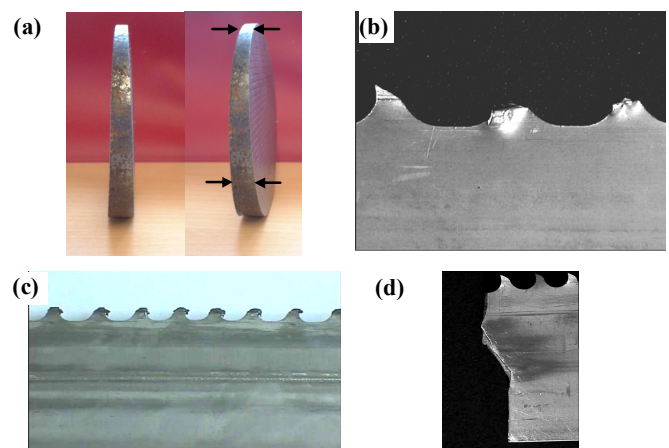


Fig. 8 Bandsaw failure modes: (a) out of square cut (b) tooth failure (c) tooth wear and (d) fatigue failure.

4.2. Wear Modes

The wear modes in bandsaw tooth depend on the work-piece material chosen, type of bandsaw tool material and the selection of cutting conditions. In general, the principal wear modes in any bandsaw tooth can be identified as flank wear, corner wear, rake face wear and edge rounding as shown in Fig. 9 [10-12]. Bandsaw teeth are worn in such a way that wear flat is produced at the tip of each tooth and the outer corners of the teeth are rounded. Rake face wear is generally not as severe as the flank wear. However, rake face wear can also contribute to a local change in cutting edge geometry. The change in edge geometry (edge rounding) will result inefficient chip formation due to an increase in the ratio of edge radius to depth of cut.

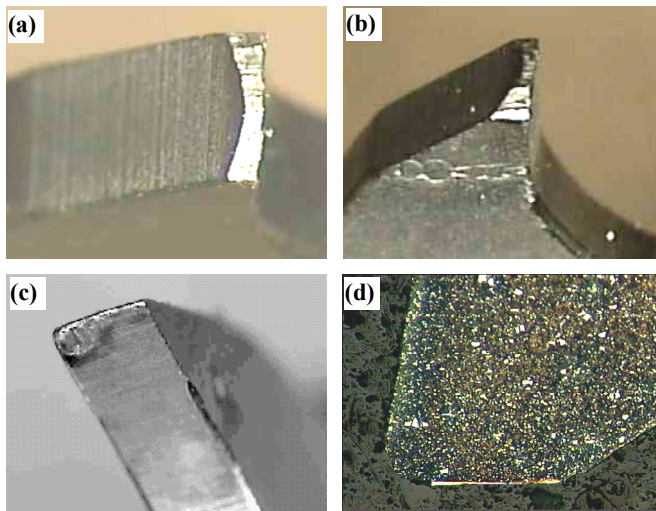


Fig. 9 Bandsaw wear modes: (a) flank wear (b) corner wear (c) rake face wear and (d) blunting or edge radius.

4.3. Wear Mechanisms

In High Speed Steel (HSS) bimetal bandsaw tooth, flank and corner wear are developed due to the abrasive action between the tooth and the machined workpiece with small to large amount of adhesive wear depending the properties of the workpiece materials [10, 11]. Metal cap or built-up edge is formed at the tooth edge and this could affect the cutting condition and tooth wear (Fig. 10). Plastic deformation, micro-chipping and thermal fatigue can also be observed in some cases.

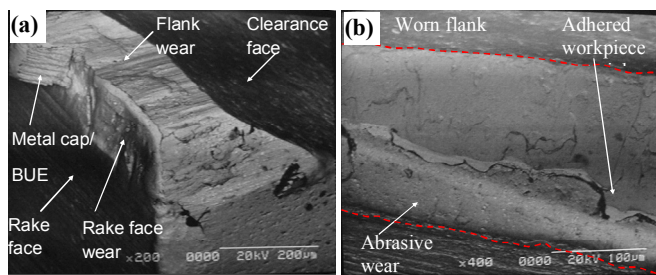


Fig. 10 Wear mechanisms in bandsaw teeth when cutting (a) ballbearing steel and (b) stainless steel.

5. Concluding Remarks

Although bandsawing process has been around for many years, very little research effort has been devoted to understand the mechanics of material removal, associated wear modes and mechanisms and scientific evaluation of the bandsaw products. Unlike other multipoint cutting tools (e.g., milling) the material removal process together with the wear and failure modes in bandsaw is far more complex. Although the method of manufacture of the cutting edges have been improved from milling to grinding (giving more uniformity and accuracy of cutting edges), the layer of material removed is still very small. This causes a complex combination of chip formation mechanisms (i.e., continuous chip, ploughing and fragmented chip). Flank and corner wear usually caused by abrasion and adhesion can alter the edge geometry (e.g., edge radius) and affect the chip formation mechanism.

Traditionally the performance of bandsaw is evaluated through full scale life testing, which is complex and time consuming. Single tooth time compression technique can be successfully employed to scientifically evaluate the bandsaw product in a representative way.

Specific cutting energy (E_{sp}) is an excellent parameter for assessing the tool/workpiece combination efficiency. The high value of E_{sp} (~10 GJ/m³) indicates that bandsawing is not as efficient as a single-point turning tool (~1.0-1.5 GJ/m³) where the chip is free to flow and the layer of metal removed is larger. The E_{sp}

also turns out to be a useful parameter to relate various stages of wear to the bandsaw performance.

6. Reference

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