Modelling of Frame Saw Blade Abrasion in the Kerf in Sawing Softwood Logs

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Abstract

The effect of friction and abrasion of frame saw blades side planes in a kerf when sawing pine and spruce sawlogs in the top end diameter classes' interval 18-40 cm was modelled accordingly to resultant saw blade thickness and surface hardness. Gradually diminishing saw blade thickness eliminates initial surface hardness of cold rolled strip steel. Hardness and thickness of new and used frame saw blades interrelationships on the abrasion zone of frame saw blades were discussed. Phenomena's of thickness diminution were established showing good correlation between thickness and surface hardness. The effect of asymptotic stabilization of hardness after certain depth of wear on saw blade side planes has been stated. Further recovery of surface hardness alongside the blade length seemed to be related to the typical sawlog diameter classes' distribution (18-40 cm) at the Lithuanian frame sawmills.

Key words: modelling saw blade, abrasion, wear, hardness, sawlog

Introduction

Leading sawmilling industry countries for more than two decades experience consistent expand and evolution of strip steel saw blade applications and developments. Rapid transition from frame sawmills to band and circular sawing during the last decade is in progress also in Lithuanian sawmill industry. However many experts foretell renaissance and emerge of the frame saw blades with new competitive performances! Still proper tool design, selection and especially saw blade maintenance needs to be enhanced considerably. Distribution of costs in an efficient sawmills shows that wood saw blades accounts for only 0.02% of total costs while tool maintenance reaches some 1% or more (Production…2006, Uddeholm…2006). Saw blade service time depends on various factors and it is expected to be as long as possible.

Frame and band saw blades are strips of cold rolled, hardened and tempered steel. Surface hardness (HRC - Rockwell hardness scale) varies considerably from 38 HRC for teeth swaging to 49 HRC for spring-setting (Production…2006, Williston 1989, Wood …2004). For each single blade surface hardness have to be as uniform as possible to facilitate swaging and setting accuracy, proper tensioning, steady wear and impact resistance as well as fatigue strength. Best saw blade steel distinguishes by hardness tolerance ±1 HRC but some manufacturers are content with ±2 HRC or even larger hardness spread (Gang…2002, Morozov 1988, Uddeholm…2006, Wood…2006,). Therefore, industry regularly experience considerable variation in the hardness properties within each individual steel coil as well between different deliveries and manufacturers. That makes life difficult for saw-doctors to correctly carryout the blade maintenance (Production…2006; Wood…2004).

Uniformity of surface hardness is not the only reason to explore steel quality or select optimal supplier of saw blades. During saw body friction in the kerf some surface abrasion occurs and its hardened layer starts gradually wear up affecting blade thickness (Ukvalbergienė *et al*. 2006). Relatively high temperatures, particularly at the edges of the teeth reaching 600-700 ^{o}C, create thermal stresses which also affect the steel properties (Grigaras and Baltrušaitis 2006). Such process is under the influence of wood species, moisture content, sawing speed, feed speed, setting or swaging side clearance, etc (Williston 1989, Wood… 2004, Production… 2006).

The process of stress corrosion cracking was studied for standard types of sawblade steel (Krilov 1986). The combined effects of corrosion and wear of these steels produced an average loss of material of 5 g/m^2/h in weight and 0.001 mm/h in thickness. Such a classification of sawblade steels and timbers processed has an immediate applied use.

Surface finish of frame and band saw blades for swage-setting is polished non-chromium plated. During swaging tooth breast is additionally cold rolled and its hardness increases up to 52 HRC. Saw blades for spring-setting are made polished or chromium plated for longer life (Gang…2002, Wood…2004). Chromium plating reduces friction and abrasion of blade body in the kerf and increases wear resistance at the edges of the teeth (Uddeholm…2006).

Hypothetically saw blade thickness and hardness has to diminish with abrasion of saw blade side surfaces caused by corrosion and friction of saw body with wood in the kerf. Together with high temperatures it has in turn to accelerate hardness decrease and subsequently steel wear resistance taper (Astakhov 2004). This probably might also be quantifiably estimated by changing of saw blade thickness. Obviously for frame saw blades the configuration of these phenomena may be expected to be more intensive in the lower part of the saw body (Lee *et al.* 1994).

The objectives of this research were to test surface hardness distribution of new and used frame saw blades; establish possible hardness regularities along and across saw blade; investigate alterations in body thicknesses of used saws and their possible relations with surface hardness changes. If hypothesis proves–out the aim was to reveal mechanism and regularities of such process.

Materials and methods

Sawlog abrasion and wear model

For description saw blade side plate's abrasion process in the kerf the following model was proposed (Figure 1).

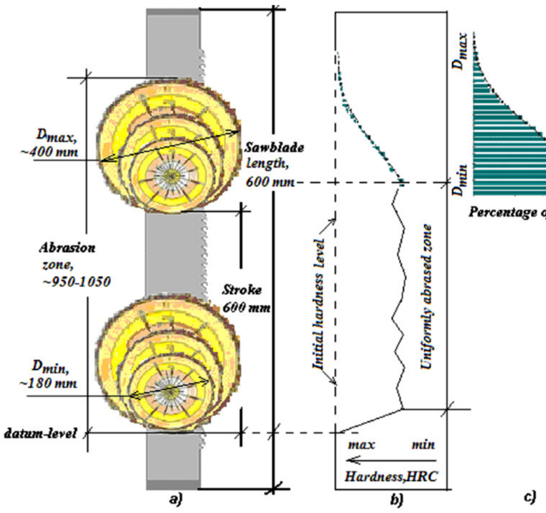

Figure 1. Modelling of saw blade abrasion in the kerf within logs contact zone during one frame stroke: a)-location of logs D_{min}-D_{max} at the upper and lower dead-points of the saw blade stroke; b)-uniformly abraded zone; c)-typical sawlog size distribution

Our hypothesis was that approximately constant saw blade abrasion and therefore thickness and hardness have to remain on contact zone of log with diameter D_{min} within reach of one stroke, Figure 1, *a* (also see *uniformly abraded zone* in Figure 1, *b*). After that initial thickness of saw blade and therefore surface hardness begins to recover due to less intensive abrasion of decreasing number of logs with bigger diameters (according to the model showed in the upper right zone, Figure 1, *c*) (Baltrušaitis and Pranckevičienė 2003). Surface hardness within entire contact zone for sawlog diameters D_{min}-D_{max} hypothetically follows regularity described in Figure 1, *b* (Baltrušaitis and Pranckevičienė 2001).

Experimental

Serial measurement of saw blade thickness and hardness has been planned and focused on validation hypothesis of blade body thickness-hardness interrelationships under abrasion in the kerf. Surface hardness and thickness of two samples of frame saw blades each consisting of 5 new and 5 used to different extent pieces was tested (Table 1).

Table 1. Characteristics of tested saw blades

Saw blade samples	Characteristics (average)
Used frame saw blades:	Nominal thickness: 2.2-2.3 mm
(non-chromium plated)	Width: 86-118 mm (used)
	Length: 1600 mm
New frame saw blades:	Nominal thickness: 2.2 mm;
(chromium plated and non plated)	Width: 160 mm
	Length: 1600 mm

Used frame saw blades have been selected after their width reached approximately half of the initial standard value. It corresponds to manufacturer's recommendations on ultimate service life. Five used and three new frame saw blades were manufactured in Russia (Gorky IZ, chrome-vanadium steel mark 9XŌ, polished non-chromium plated). Two more new chromium plated saw blades manufactured in Poland (GASS) and Germany (Carl RÖNTGEN GmbH) have been added for using as model if testing comply with the conformity declared by manufacturers ±1 HRC hardness tolerance. All used saw blades have been selected from softwood (Scots pine *Pinus sylvestris* and Norway spruce *Picea abies*) sawmills. The range of log top end diameters classes at sawmills was 18-40 cm.

New saw blades were used for referent data to compare initial spread of thickness and hardness properties with the results obtained on used to the ultimate service life saw blades. Testing procedure was in accordance with our earlier experiments (Timofejev and Baltrušaitis 2003).

Side surface area on the abrasion zone of every single saw blade within reach of D_{min}-D_{max} (Figure 1, *c*, respective log diameters 18-40 cm) was divided into separate small rectangular zones 30-50 mm in length and 20-30 mm in width. Apparent length of this zone on the tested saw blades varied between 950-1050 mm but measurements were pursued on the 1200 mm range starting from datum-level at the lower end of every blade (corresponding with the initial sawlog contact and abrasion in the kerf on the upper dead-point of the frame stroke, Figure 1). Hardness and thickness were measured at the junctions of lines separating zones. This way from 120 to 180 measuring points has been received for every saw blade at one side. At these points thickness was measured with accuracy ±0.01 mm using calibrated micrometer. Hardness measuring was carried out with accuracy ±0.5 HRC using portable hardness tester *Instrumatic* (CV Instruments Limited, England).

Measuring data were statistically computed with dual purpose: to obtain the relationships of saw blade surface hardness and thickness distribution on side planes; and to lay down results sequentially from the non-abraded upper end downward to check likelihood of possible hardness-thickness regularities (the last procedure only for used frame saw blades). In order to reveal phenomena's of saw plate surface wear-thickness-hardness mechanism new and used saw blades were tested and compared. Values, standard deviations and distribution of saw blade strip thickness and surface hardness were compared within and between blades and with allowable tolerances declared by manufacturers.

Results and discussion

New chrome-vanadium (steel mark 9ХФ) frame saw blades made in Gorky IZ showed up wide divergences of hardness reaching in separate cases up to ±2.5 HRC (requirements in Russia according to GOST standards ±2 HRC). New saw blades (GASS and Carl RÖNTGEN) not exceeded deviation of ±1.2 HRC and could be therefore considered as of satisfactory quality.

Figure 2 provides typical surface hardness distribution pattern for new frame saw blade.

Evident in Figure 2 even (within 44-46 HRC) distribution of surface hardness of the new saw is convincingly transformed to gradual hardness diminution from 51 HRC to 45 HRC towards lower end in used saw (Figure 3).

This tapering pattern was characteristic of all five tested saw blades.

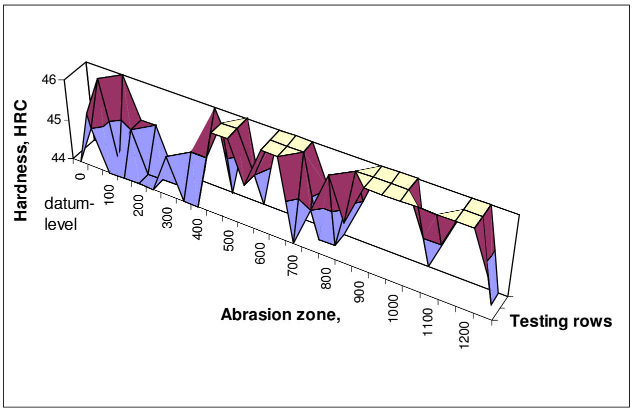

Figure 2. Typical pattern of surface hardness on new frame saw side plane

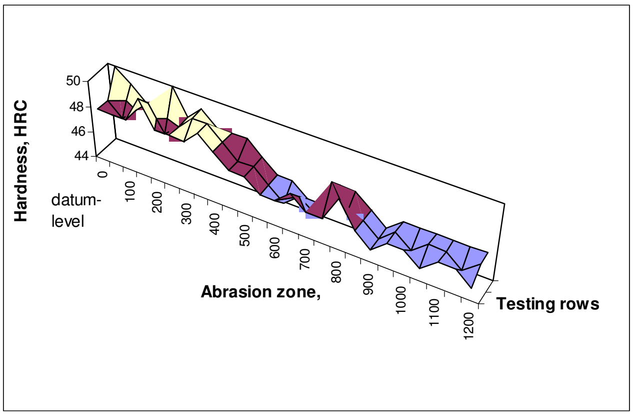

Figure 3. Typical pattern of surface hardness on used frame saw side plane

Moreover, all Gorky IZ frame saw blades being in use up to the allowed width limit of 85 mm exhibited features confirming our hypothesis of interdependence of saw blade surface hardness and gradual diminution of thickness caused by body abrasion (Figures 4 and 5).

Consequential thickness diminution phenomena downwards saw blade butt end was expectant and

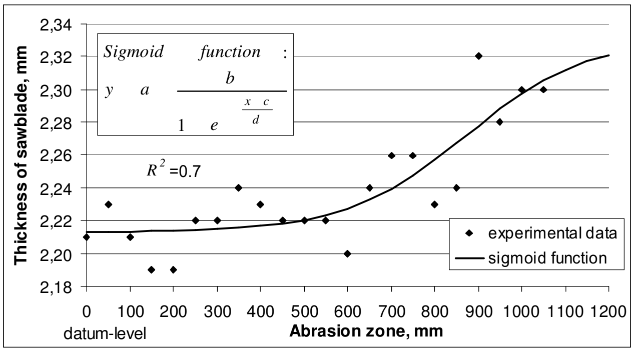

Figure 4. Change of frame saw blade thickness upwards to the top end (sigmoid function coefficients: *a*=2.2129; *b*=0.1182; *c*=872.677; *d*=138.8371)

rationale having in minds that lower part of frame saw blade body and teeth always participate in sawing experiencing permanent friction in the kerf. With the increase in diameter of processed sawlogs the zone of permanent friction also increases. Median thickness reduction from about 2.31 mm at top end of saw blade to 2.21 mm in the abraded lower part (Figure 4) correspond to median hardness drop from 50 HRC to 45 HRC according to the same model (Figure 4).

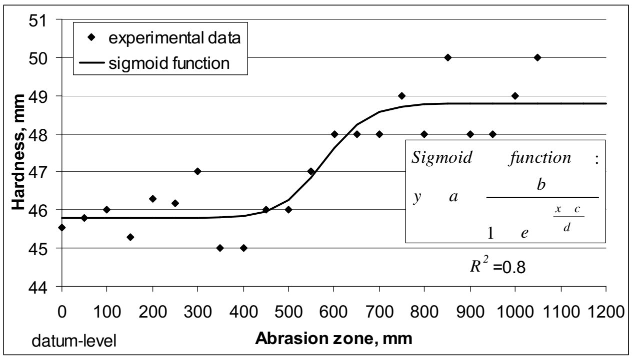

Figure 5. Change of frame saw blade side plane hardness upwards to the top end (sigmoid function coefficients: *a*=45.7765; *b*=3.0248; *c*=578.9751; *d*=47.5412)

Similar abrasion caused thickness-hardness relationships have been observed for all significantly used frame saw blades. The decrease in thickness on tested frame saw blades was 0.07-0.11 mm (average per five tested saws 0.081 mm) while the corresponding median hardness decrease range was 3.5-5.5 HRC.

Reference-tested new frame saw blades showed discrete surface hardness distribution varying within and between separate blades ±1 HRC without notably consistent pattern and no longitudinal-transverse regularity of thickness changes has been observed.

Almost identical results (rather than moderate differences) could be explained by natural species and diameter classes' variety of processed saw logs during service life of all tested frame saw blades (Figure 6).

The character and models of thickness-hardness exchange in all observed cases as seen in Figure 6 were convincingly comparable. The intensity of abrasion is evidently similar.

Dependence of surface hardness on depth of wear on saw blade side plate is shown in Figure 7.

The models of surface hardness and depth of wear (Figure 7) could be modeled by equations with significant coefficients of determination (for surface hardness model R^2=0.54, for depth of wear model R^2=0.89). Depth of wear remains high (about 0.025 mm) within first 350 mm of abrasion zone; consequential decrease is observed when approaching less intensive friction zone with the end of saw blade stroke (600 mm). At

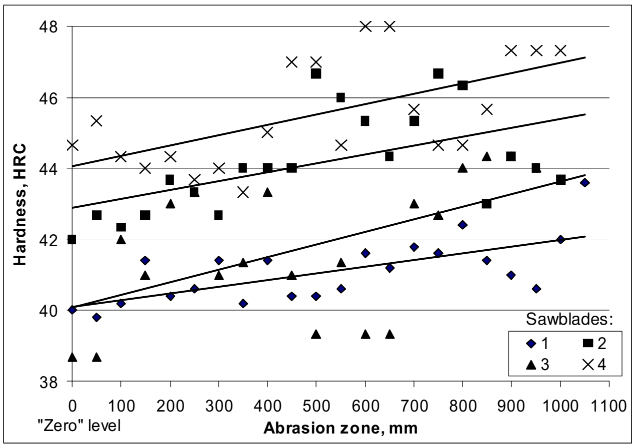

Figure 6. Change of surface hardness within abrasion zone of four tested saw blades

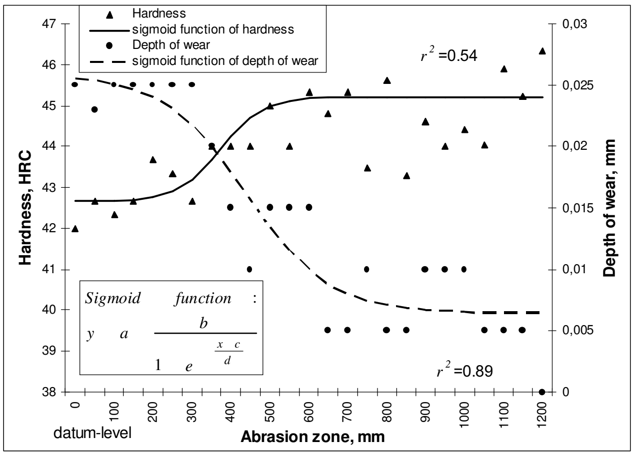

Figure 7. Interrelations of hardness-wear on saw blade side plates within abrasion zone (hardness sigmoid function coefficients: *a*=42.6530; *b*=2.5587; *c*=372.5658; *d*=55.2834; depth of wear sigmoid function coefficients: *a*=0.00643; *b*=0.0194; *c*=438.6372; *d*=-106.8771)

the beginning of abrasion zone the lowest hardness 42 HRC is observed corresponding to the highest depth of wear (more than 0.025 mm). Surface hardness stabilizes at the depth of wear 0.018 mm and then starts to grow-up when depth decreases to approximately 0.008 mm (values calculated using depth of wear model, Figure 7). It is clearly evident recovery of surface hardness to initial 46 HRC starting from approximately 44 HRC at 850 mm from the beginning of the abrasion zone.

Conclusions

During sawing all saw blade contact surfaces with wood are subjected by normal and tangential stresses causing various dimension forces resistant to saw blade movement. Highest values and therefore most intensive temperatures evidence within direct cutting zone close to the saw teeth tips. Resulting heating and temperature gradients cause stresses within whole saw blade body and due to lasting character gradually affects steel structure and properties. Additional friction and abrasion in the kerf accelerates diminution of saw blade plate thickness; resulting surface hardness reduction adequately reflects the mechanism of wear.

Polished non-chromium plated frame saw blades undergo considerable changes in thickness exceeding in size hardened during steel coil manufacturing surface layer. Change in saw blade thickness is strongly related to the change of surface hardness. Asymptotic decrease of hardness towards lower end of the saw blade follows tapering wear-up of hardened layer of saw blade. Surface hardness stabilizes at depth of wear 0.017 mm notwithstanding to further decrease of saw blade thickness and begins to grow when depth falls lower 0.01 mm. Thickness diminution has pronounced asymptotic regularity towards lower end of the saw blade; predominant and apparent explanation could be alterations in abrasion zones of side planes undergoing due to gradually changing diameters of processed sawlogs.

The results obtained here support the hypothesis that decreases of saw blade thickness and hardness during exploitation depends on diameter classes of processed at the sawmill sawlogs. More experiments are needed to relate finally sawlog diameter class distribution (see model for typical Lithuanian sawmill, Figure 1, *c*) with the recovery of surface hardness after abrasion zone reaches 800 mm and more (Figure 7, hardness model); nevertheless both models are clearly sigmoid functions and adequately changing.

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МОДЕЛИРОВАНИЕ АБРАЗИВНОГО ИЗНОСА ЛЕНТЫ РАМНОЙ ПИЛЫ В ПРОПИЛЕ ПРИ ПИЛЕНИИ БРЕВЕН

А. Балтрушайтис

Резюме

По результатам измерения результирующей толщины и твердости моделировалось абразивный износ боковых граней рамной пилы в пропиле при распилке сосновых и еловых бревен диаметром в верхнем конце 18-40 см. Установлено, что постепенное уменьшение толщины ленты элиминирует начальную твердость холоднокатаной стали пильной ленты.

Рассматривалась взаимосвязь твердости и толщины новых и отработанных пильных лент в зоне, по длине соответствующей размерам контакта в пропиле различных диаметров распиливаемых бревен за один ход пильной рамы. Установленные закономерности снижения толщины ленты отмечались хорошей корреляцией с результирующей твердостью изношенной поверхности. Отмечена асимптотическая стабилизация твердости по достижении определенной глубины износа поверхностного слоя пильной ленты. Дальнейшее последующее восстановление поверхностной твердости по длине полотна пилы, вероятно происходит соответственно закономерностям распределения диаметров бревен, поступающих в типичные лесопильные заводы Литвы.

Ключевые слова: моделирование, полотно пилы, износ, твердость, бревно.