INDUSTRIAL TRIALS OF LOW-EXPANSIVITY SAWBLADES

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ABSTRACT

Low-espansivity alloys have the potential to reduce thermal instability of sawblades during the sawing operation. In preliminary industrial trials of sawblades made of low-expansivity alloy, sawing accuracy was improved 22 to 38 percent during normal sawing. When saws made of a low-expansivity alloy were operated with a large temperature gradient across the blade, sawing accuracy was comparable to that of steel saws operated with little temperature gradient.

INTRODUCTION

The cost of logs typically ranges from 50 to 80 percent of the cost of manufacturing finished lumber in the United States. Lumber manufacturers are increasingly trying to offset the high cost of logs and improve profits by minimizing the total amount of wood fiber that is consumed in making a finished piece of lumber. This report addresses two factors in total wood fiber usage: saw kerf and allowance for variation in lumber sizing.

The saws most commonly used to manufacture lumber are generally made from high carbon alloy steels that have been cold worked, hardened, and tempered. During sawing, the rim of the saw heats while the body of the sawblade remains relatively cool. The heated rim expands while the cooler saw body does not. As a result, the tooth edge becomes longer so that it tends to weave or "snake? while cutting. The resulting inaccuracy in the lumber thickness must be accommodated by a larger target size, which increases the amount of wood fiber needed to make finished lumber.

Saw filers attempt to minimize the effects of expansion by tensioning. Tensioning puts the saw rim into an initial state of tension to offset the heat expansion that occurs during sawing and thereby keep the rim "tight." However, sawing lumber is seldom a steady-state process. In most sawmills. gaps in the material flow allow time for the saw to cool off between successive pieces. Therefore, tensioning is, at best, a compromise attempt to maintain saw stability under varying conditions.

Mote et al. (1981) showed that saw stability can be improved by heating the inner area of the saw, reducing the temperature gradient. Because both the rim and the saw body expand together, the rim remains tight. However. this thermal tensioning requires a complex electronic feedback control system.

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[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Worzala (1986) proposed using low-expansivity Invar[2] alloys as a sawblade material to minimize the degree of thermal expansion. Invar alloys are nickel–iron alloys. which typically exist in two electronic states (Weiss 1963): one ferromagnetic. the other antiferromagnetic. Both phases are face-centered cubic but have different lattice parameters. The antiferromagnetic phase. with the smaller lattice parameter, grows as temperature increases. causing a decrease in volume. This offsets the volume increase normally associated with increasing temperature.

The Invar alloy tested by Worzala and Danielson (1988) was Carpenter Steel (Reading, PA) LoEx43–PH. Saws made from this alloy appear to be more stable in operation than conventional steel saws. The LoEx43–PH alloy exhibited very poor wear resistance. After sawing 15 min at 120 ft/min (36.5 m/min), wear and rounding in the gullet were readily visible to the naked eye.

Two new low-expansivity alloys were developed by Inco Alloys International, Inc. (Huntington. WV), which show promise as sawblade material. These alloys. Inco 908 and 909, were developed for use in gas turbines and chip carriers in integrated circuits. Inco donated some 909 alloy plate to the Forest Products Laboratory for evaluating the feasibility of using these alloys as sawblades. This report discusses the results of preliminary industrial tests of sawblades made from Inco 909 alloy in two locations, the Hudson ICS pencil slat factory (San Leandro, CA) and the Summit Timber Company sawmill (Darrington, WA).

As happens in any tests in an industrial setting, our tests included many uncontrolled variables in equipment and raw material. Thus, conclusions cannot be based on side-by-side comparisons of low-expansivity and conventional steel saws, with all other factors held equal. Whenever possible, confounding factors, such as equipment malfunction or saw damage. were identified and their effect noted.

MATERIALS AND METHODS

Fabrication of Materials

Sawblades were fabricated from Inco 909 alloy plate. Table 1 shows the composition of Inco 909 alloy compared to that of Uddeholm proprietary saw steel. a steel representative of that commonly used in saws. Mechanical properties of Inco 909 are relatively similar to that of Uddeholm saw steel (Table 2). Thermal expansion of Inco 909 is approximately 55 percent that of Uddeholm saw steel throughout the temperature operating range.

The Inco 909 plate was fabricated into saws at California Saw and Knife Works. The plate was laser-cut into blades, ground to thickness, and treated at approximately l,000°F (555°C) to flatten and relieve stress. Parameters of the saws used at the two test locations are listed in Table 3.

Limitations of Materials

The Inco 909 plate was not stiff or hard enough to use as saw plate material. Saw filers at both test locations noted that the teeth bent easily during tipping and grinding. The teeth also bent while the saws were in service, which would be expected to negatively affect sawing variation.

The plate supplied by Inco was not as flat as that required for sawblades. Inco could not supply information on heat-treating requirements to flatten the plate. California Saw and Knife Works tried

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—Composition of alloys

Alloy	Weight of alloy addition (percent) Fe	Ni	Co	Ti	(Nb + Ta)	A1	Si	C	Mn
Inco 909	41.4	38.9	12.7	1.6	4.9	0.1	0.3	—	—
Uddeholm	Bal.	2.0	—	—	—	—	0.3	0.75	0.4

Table 2—Mechanical properties of alloys[a]

Alloy	Hardness (R_c)	Yield stress (x10^3 lb/in^2 (GPa))	Ultimate tensile stress (x10^3 lb/in^2 (GPa))	Elongation (percent)
Inco 909	43	153 (1.055)	192 (1.324)	16
Uddeholm	44	187 (1.290)	210 (1.450)	8

[a] Values are approximate.

Table 3—Saw parameters

Test location	Diameter (in. (mm))	Thickness (in. (mm))	Kerf width (in. (mm))	Tooth material
Hudson ICS	7 (178)	0.040 (1.02)	0.054 (1.37)	Carbide, brazed
Summit Timber Company	20 (508)	0.090 (2.29)	0.145 (3.68)	Stellite, welded

unsuccessfully to flatten the material by heating under restraint, as they do steel saws. The plate was still warped and had lumps when it was shipped to the saw filers.

The saw filers at Hudson ICS were able to hammer the Inco 909 plate flat. The saw filers at Summit Timber Company, working with 0.090-in. (2.29-mm) plate, were unable to flatten it to their satisfaction. The sawmill filers found that hammering on lumps only caused the lumps to move to another place on the saw plate, rather than to flatten; lumps on a conventional steel plate tend to flatten. Likewise, ridges could not be flattened totally. The saw filers generally do not use saws that are badly warped. We are not certain if the difficulty encountered in flattening the thicker plate was due to the thickness of the Inco 909 plate or related to its relative softness and low Young's modulus.

The application of saw teeth was also difficult. Because this was a new application for Inco, the manufacturers were unable to provide good guidelines. Much less heat transfer occurs within the Inco 909 alloy than within steel. The saw filers at Hudson ICS had to apply almost twice as much heat as usual to braze on the carbide teeth. At Summit Timber Company, the saw filer who tried to weld Stellite teeth found that so little heat was transferred through the Inco 909 alloy that a chill line developed immediately behind the teeth and the teeth could be pulled off by hand. The saw filer solved that problem by putting the hottest part of the torch flame directly on the tooth for a longer time than usual and using the highest heat setting possible to melt the Stellite.

At the end of the trials. the Inco 909 plate was not sufficiently age-hardened. Hardness was measured as R_c 37 rather than the expected & 43. This is likely to be one factor in the bending of teeth and plate.

Methods

The tests at Hudson ICS and Summit Timber Company were preliminary trials to determine if low-expansivity alloys could be made into sawblades. The tests were run under production conditions. so many variables that would usually be controlled under laboratory conditions were totally uncontrolled. At times, either the Inco 909 or the control steel saws were run with chipped teeth. which reduced sawing accuracy. In both sets of trials, the Inco 909 saws were run with bent teeth. At Summit Timber Company, the saws were not as flat as they should have been to give comparable results.

As a result of these uncontrolled conditions. many results reported here are somewhat subjective. The results are based on observation of saw performance. recognizing that the Inco 909 sawblades were not as well-manufactured and fitted as the steel saws.

Hudson ICS Trials

Hudson ICS manufactures pencil slats from kiln-dried incense cedar (*Libocedrus decurrens*) blocks. These slats are used in the manufacture of wooden pencils. The blocks are approximately 3 by 3 by 7-1/4 in. (76 by 76 by 184 mm). The pencil manufacturers groove the slats and glue a pair of slats together, sandwiching the graphite lead in the groove. The slats are not planed before gluing, so sawing accuracy and surface quality are critical.

Sawing is done on “tandem saws,” which consist of 13 modules of pairs of top and bottom saws in series. Each saw is mounted on an arm so that the saw can be retracted up or down out of the cut if force on the motor exceeds limits. Each successive pair of saws is offset from the previous pair by the thickness of a slat. Blocks are fed into the tandem saws end-to-end so that the saws are cutting continuously. As a result, the saws operate at a constant temperature to stabilize performance.

The Inco 909 saws were mounted top and bottom in two consecutive modules. The slat with both faces consisting of Inco 909 saws was selected as a sample. The slat from the same block that was sawn by the two consecutive steel saws was selected as a control. These two slats were selected as matched pairs from the same block to minimize variability caused by differences in the wood itself. Some variation in grain direction occurred within the blocks. which could affect sawing accuracy. but the variation occurred at random: nothing suggests that grain direction affected the two types of saws differently.

Two separate trials were made at Hudson ICS. In the first trial. slat thickness was measured at four locations, two on the top edge and two on the bottom. In the second trial. slat thickness was measured at six locations, three on the top edge and three on the bottom edge, to obtain a better measure of within-board sawing accuracy. Within-board. between-board. and total variation were calculated using the analysis of variance (ANOVA) method.

In the first trial, sawing variation with the Inco 909 saws was reduced significantly compared to that with the steel saws. The company improved their sawfiling practices in the 2 months between trials, which reduced the sawing variation before the second trial was conducted.

During the second trial, the saw lubrication system on the module mounted with one pair of Inco 909 saws became plugged with sawdust. During this trial, temperatures of the Inco 909 and control saws were read with a hand-held infrared pyrometer. The temperature was measured next to the saw collar and just beside the saw gullet as the saw left the cut. Distance between the two measurements was approximately l in. (25 mm). The pyrometer was roughly calibrated to read ambient temperature on the plates at approximately the same distance as the measurements taken during sawing. Emissivity of the Inco 909 and the steel saws was similar; the temperature was the same on both plates.

Temperature of the steel control saws was approximately 100°F (38°C) next to the collar and 110°F (43°C) behind the gullet. Before the lubrication system failed, temperature of the Inco 909 saws was 110°F (43°C) next to the collar and 130°F (54°C) behind the gullet, with the higher temperatures probably caused by the rubbing of the bent teeth against the wood. After the lubrication system failed. temperature of the Inco 909 saws was 110°F (43°C) next to the collar and 230°F (110°C) behind the gullet.

We recognize that **a** hand-held pyrometer is somewhat limited in accuracy, and the absolute values of the temperatures measured may be incorrect. The temperature was measured behind the gullet after the saw left the cut. so tooth temperatures were probably higher for both test and control saws. However, the large difference in temperature gradient after the lubrication system failed does indicate that the Inco 909 saws were running with a much larger temperature gradient.

Summit Timber Company Trials

The Summit Timber Company is a conventional sawmill that manufactures construction lumber from Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). The machine used for our trials was a standard 12-in. (305-mm) double-arbor gangsaw capable of sawing cants up to 12-in. (305-mm) thick into nominal 2-in. (38-mm) lumber. The Inco 909 saws were mounted only on the bottom arbor. The boards selected for measurement were 6-in. (152-mm) wide, so their entire width was sawn by the Inco saws. Board lengths were 16 to 20 ft (5 to 6 m).

When these trials were conducted, the arbor splines were worn and the company was waiting for a delivery of new splines. Grooves were worn in the splines, and the saws tended to shift from one groove to the next. This adversely affected sawing variation for both Inco 909 and steel saws.

Cants were not fed continuously into the double-arbor gangsaw as was the case at Hudson ICS. Space was allowed between consecutive cants so the operator could position the cants before feeding them into the gangsaw. This intermittent feed allowed the saws to cool between cants.

The Inco 909 saws were mounted in positions 5 and 6 on the arbor, with control saws in positions 7 and 8. for some trials. The order was reversed for the remaining trials to avoid biasing the data with a position effect. As was done at Hudson ICS, matched pairs of boards were selected from the same cant, with both faces sawn by either the Inco 909 saws or the steel control saws.

Board thickness was measured at eight locations. four on the top edge and four on the bottom. Top and bottom measurements were opposite each other so that top-to-bottom tapering could be identified.

Table 4–Resultsof Hudson ICS trials

Saw type and variation	Standard deviation (in. (mm))		
		Trial 2[a]	
	Trial 1	Before failure	After failure
Inco 909			
Within-board	0.0014 (0.0356)	0.0020 (0.0.508)	0.0034 (0.0864)
Between-board	0.0019 (0.0483)	0.0020 (0.0058)	0.0012 (0.0305)
Total	0.0024 (0.0610)	0.0028 (0.0711)	0.0036 (0.0914)
Steel			
Within-board	0.0038 (0.0963)	0.0027 (0.0686)	0.0027 (0.0686)
Between-board	0.0010 (0.0024)	0.0018 (0.0457)	0.0018 (0.0457)
Total	0.0039 (0.0991)	0.0033 (0.0838)	0.0033 (0.0838)
(Number of boards)	30	163	180

[a] Failure of lubrication system on module mounted with Inco 909 saws.

RESULTS

Hudson ICS Trials

Sawing variation measurements are summarized in Table 4. Sawing variation increased slightly after the lubrication system failed, but sawing accuracy was still within acceptable limits. Considering the large temperature gradient, we conclude that low-expansivity sawblades do have the potential to be more stable than steel saws.

The total variation between Inco 909 saws and steel saws was statistically significant at the 95-percent level for both trials before the lubrication system failed. There was no significant difference in total variation between the two saw types in Trial 2 after the lubrication system failed.

Summit Timber Company Trials

The Inco 909 saws were more accurate than steel saws in the trials at the Summit Timber Company. Overall sawing accuracy was deteriorated by the wear on the splined arbor. Table 5 compares the results for those trials with no apparent saw damage. The difference in total variation between the two saw types was statistically significant at the 93-percent level.

Subjectively, the Inco 909 saws were apparently more tolerant of tooth or plate damage than were steel saws. In several instances, the Inco 909 saws were run with damaged teeth, as evidenced by tooth marks on the boards. Although their sawing accuracy deteriorated, the Inco 909 saws were still acceptable by production criteria. Steel saws that had less tooth damage than the Inco 909 saws had to be removed from service because of poor sawing accuracy.

Six Inco 909 saws were mounted in matched pairs on the top and bottom arbors to determine if mis-match occurred. Mismatch was visible primarily on only one side of one of the two boards sawn by the six saws. A ridge around the eye in one saw of that pair apparently caused some instability.

Table 5–Results of Summit Timber Company trials

Variation	Standard deviation (in. (mm))	
	Inco 909	Steel
Within-board	0.0100 (0.2540)	0.0132 (0.3353)
Between-board	0.0061 (0.1549)	0.0084 (0.2134)
Total	0.0117 (0.2972)	0.0157 (0.3988)
(Number of boards)	63	63

Despite this mismatch, the Inco 909 saws met the production standards. Occasional mismatch occurred on the other sawn faces. In general, fewer mismatches occurred with the Inco 909 saws; Inco 909 mismatches were usually of smaller magnitude.

CONCLUSIONS

The trials indicated that low-expansivity sawblades do have the potential to improve sawing accuracy. Considering the softness of the plate used and the warped condition of the saws, the fact that the saws performed as well as they did strongly indicates that low-expansivity alloys can greatly improve saw stability, possibly with reduced saw kerf thickness. The next step is to learn more about the behavior of low-expansivity alloys as a saw plate material.

The trials will be repeated with the saw plate age-hardened to R_c 43 to determine if insufficient plate hardness caused the bent teeth and plate warpage noted in the trials reported here. Damping characteristics and resonant frequencies will be analyzed to better understand the reason for the improved stability. Other low-expansivity alloys will also be tested to determine if they are more stable than the Inco 909. Further research is needed to develop methods for applying saw teeth by welding or brazing that overcome the heat transmission problems encountered in our trials.

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