Laser Machining

Of Southern Pine

Charles W. McMillin

John E. Harry

The authors are, respectively, Principal Wood Scientist, USDA Forest Service, Southern Forest Experiment Station, Alexandria, La., and Senior Development Engineer, Welding and Cutting Fundamentals Section, British Oxygen Co., Ltd., London, England. This paper was presented at Session 28 — Noise Pollution — of the 25th Annual Meeting of the Forest Products Research Society, July 1, 1971, in Pittsburgh, Pa. It was received for publication in July 1971.

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Abstract

When cutting with an air-jet-assisted carbon-dioxide laser of 240 watts output power, maximum feed speed at the point of full penetration of the beam decreased with increasing workpiece thickness in both wet and dry samples; the trend was curvilinear. Feed speeds averaged 99.1 and 14.6 inches per minute for samples 0.25 and 1.00 inch thick, respectively. Somewhat slower feed speeds were required for wet than for dry wood. In wet wood, maximum feed speed was unrelated to specific gravity. In dry wood, slightly slower speeds were required when wood density was high than when it was low. The laser cut along and across the grain with equal speed. Scanning electron micrographs showed that the laser-cut surfaces, while blackened, were far smoother than sawn surfaces. There was little damage to wood structure, but some carbon deposits were evident on cell walls and in lumen cavities.

THE LASER (an acronym for light amplification by stimulated emission of radiation) provides a source of intense optical radiation. Details of laser physics are available from other sources, and it is sufficient to state here that lasers emit a coherent beam of highly collimated monochromatic light that can be focused to very small diameters. At even moderate output levels, the power density at the focal point is sufficient to vaporize most materials.

The use of a laser for cutting wood offers a number of advantages over conventional machining processes:

- No sawdust is created.
- The kerf is narrow.
- Complicated profiles can be cut easily.
- Cut surfaces are smooth.
- No reaction forces are exerted on the workpiece.
- There is no tool wear.
- Noise is minimal.

Bryan (1963) investigated the feasibility of machining wood with light emitted from a pulsed ruby laser. Because of the low power output and the short-duration pulsed nature of this type of laser, cutting was limited to holes about 0.030 inch in diameter and 0.060 inch deep.

A greater potential for cutting was realized with the development of the carbon-dioxide molecular gas laser. Output is continuous, and powers in excess of 1,000 watts are possible at efficiencies of about 18 percent. The cutting action can be further improved by using a co-axial jet of gas, usually air, to assist in removal of vapor and particles from the cut region and to cool the top surface (Lunau and Paine 1969; Harry and Lunau 1971). With a gas jet, it is possible to produce deep, uniform-width cuts with square edges in a variety of materials.

Lunau and Paine (1969) proposed industrial application of an air-jet-assisted carbon-dioxide laser as a line profile cutting machine. Such machines have recently been developed (Anonymous 1970ab; Doxey 1970; March 1970) to prepare steel-rule die blocks of the type used for cutting or creasing paper cartons, gaskets, and cloth. In this application, an intricate and accurate pattern of narrow slots is required in 3/4-inch-thick plywood.

Most experiments in cutting wood with lasers have been demonstrative in nature, and none of the data are specific to southern pine. The principal objective in the research reported here was to establish interrelationships between maximum cutting rate and workpiece thickness, specific gravity, moisture content, and direction of cutting when southern pine is machined with an air-jet-assisted, carbon-dioxide laser. A further objective was to characterize the topography of laser-cut surfaces.

Experimental Design and Procedure

A factorial experiment with two replications was designed as follows:

Wood moisture content, percent (Dry, Wet)
Wood specific gravity (Low, High)
Direction of cutting (Along the grain, Across the grain)
Workpiece thickness, inches (0.25, 0.50, 1.00)

By visual inspection of latewood content, 24 rough, kiln-dried, 8-foot-long southern pine (*Pinus* spp.) boards were selected so that 12 were of low and 12 were of high specific gravity. All had about 6 rings per inch and were flat-sawn and defect-free. The boards in each specific gravity class were then cross-cut to 2-foot lengths, and a sufficient number were randomly assigned to the factorial combinations of moisture content, cutting direction, thickness, and replication.

After they had been conditioned to 12-percent moisture content, the boards were planed to thickness and a 6-inch-square cutting specimen accurately sawn from each. The specific gravity of each sample was computed from its volume at 12-percent moisture content and calculated ovendry weight. Samples of low specific gravity averaged 0.45 while those of high specific gravity averaged 0.54. Samples designated as dry were retained at 12-percent moisture content. Those

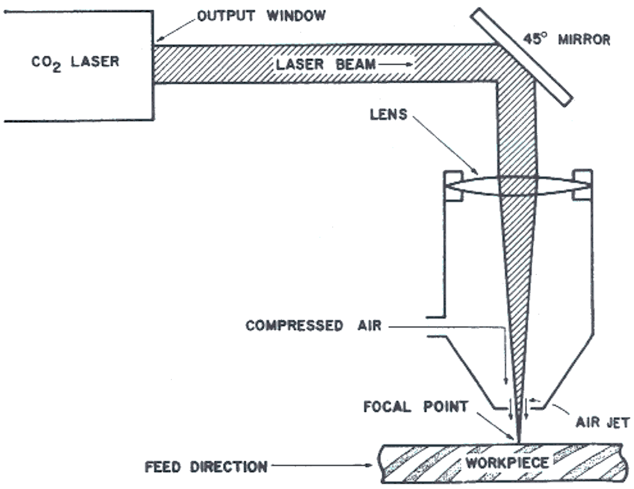

Figure 1. — Diagram of experimental air-jet-assisted, carbon-dioxide, laser-cutting device.

designated as green were saturated under a vacuum; the resulting average moisture content was 70 percent.

Samples were cut in random order with a carbon-dioxide laser which emitted radiation at a wavelength of 10.6 μm. All cuts were made at 240 watts of output power. The beam emerged horizontally from the output window and was deflected downwards by a 45° mirror (Fig. 1). It then passed through a sodium chloride lens having a focal length of 8 inches; the lens also formed the upper sealing surface of an air-jet nozzle. The focused beam passed concentrically down the axis of the nozzle and was at minimum diameter of about 0.010 inch at 0.040 inch outside the nozzle.

An air-hydraulic, variable-speed feed system traversed the workpiece through the focused beam. The maximum feed speed at full penetration of the laser beam was determined for each sample. First, the sample was positioned in the feedworks and an initial pass made at a speed estimated to be too high to allow complete penetration. The specimen was then indexed 1/4-inch and a second parallel cut made at a slightly slower speed. This procedure was repeated until the entire thickness of the sample was penetrated. The feed rate in inches per minute and the kerf width at mid-thickness were recorded.

Topography and cellular characteristics of both laser and conventionally cut surfaces were examined with a scanning electron microscope.

Results

By analysis of variance (0.01 level), the maximum feed speed at full penetration of the laser beam differed with workpiece thickness, wood specific gravity, and moisture content. Feed speed along the grain did not differ from speed across the grain. Thus, when cutting complicated line profiles or holes, the feed speed need not be varied with changes in cutting direction.

As indicated by the tabulation below, the maximum feed speed decreased with increasing workpiece thickness in both wet and dry samples; the trend was curvilinear. For a given thickness, slower speeds were required for wet than for dry wood. The magnitude of the difference increased as the thickness of the workpiece decreased.

Moisture content (percent)	Workpiece thickness (inches)		
	0.25	0.50	1.00
	- - - - Inches/minute - - - -		
Dry	111.0	46.4	17.2
Wet	87.1	36.1	12.0

In wet wood, maximum speed was unrelated to specific gravity. For dry wood, speeds were slower in wood of high density than in wood of low density.

Specific gravity (green volume and ovendry weight)	Workpiece thickness (inches)		
	0.25	0.50	1.00
	- - - - Inches/minute - - - -		
Low	123.9	49.9	22.0
High	98.2	42.9	12.5

The kerf produced by the laser beam is narrow (avg. 0.012 inch) in comparison to that of conventional saws (about 0.1 inch in 1-inch stock). Kerf width was unrelated to cutting direction, moisture content, and specific gravity, but it increased with increasing workpiece thickness. Widths were respectively 0.009, 0.012, and 0.015 inch for samples 0.25, 0.50, and 1.00 inch thick. The leading edge of the cut was extremely sharp. The faces of the cut were blackened, but there was virtually no char on either the top or bottom surface.

Scanning electron micrographs show that laser-cut surfaces are far smoother than sawn surfaces (Fig. 2). Band and circular saws leave bundles of tracheids protruding from the surface. Because saw teeth require set or side clearance, the feed per tooth is also visible. On laser-cut surfaces, there is little damage to wood structure; some carbon deposits, however, are evident on cell walls and in lumen cavities (Fig. 3). In cuts made along the grain, the depth of char appeared about equal to the width of an individual tracheid (30 to 60 μm). When cutting was done across the grain, the ends of tracheids looked melted, and the char extended about 50 μm in a direction perpendicular to the cut surface. Visual inspection indicated that the degree of charring increased with increasing workpiece thickness and was slightly greater for dry than for wet wood. While surfaces remained blackened, loose char was easily removed with compressed air or by light brushing.

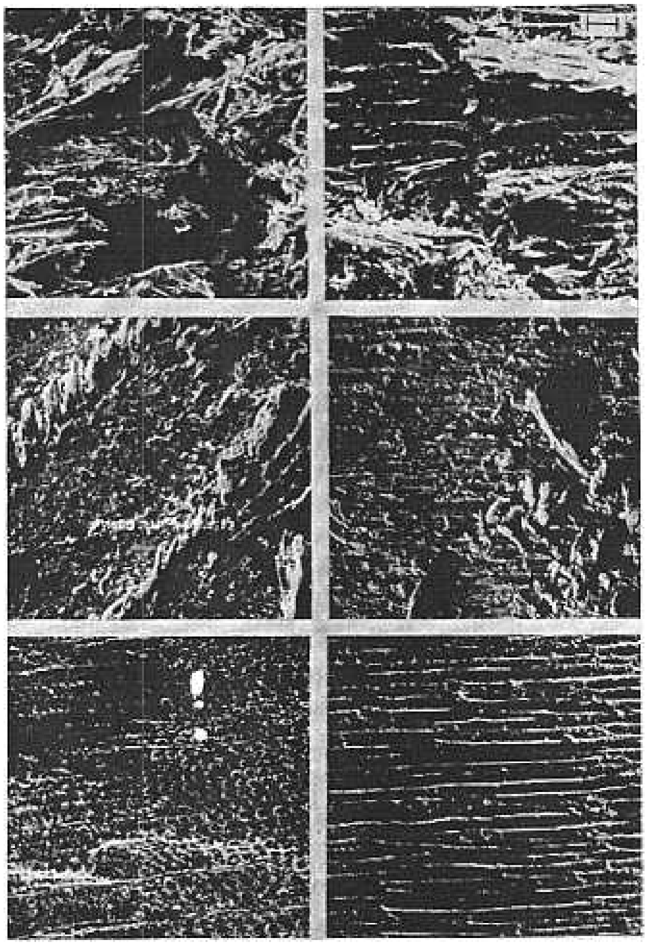

Figure 2. — Scanning electron micrographs of surfaces cut across the grain (left column) and along the grain (right column) by (from top to bottom) bandsawing, circular sawing, and laser cutting. Scale mark shows 0.1 inch.

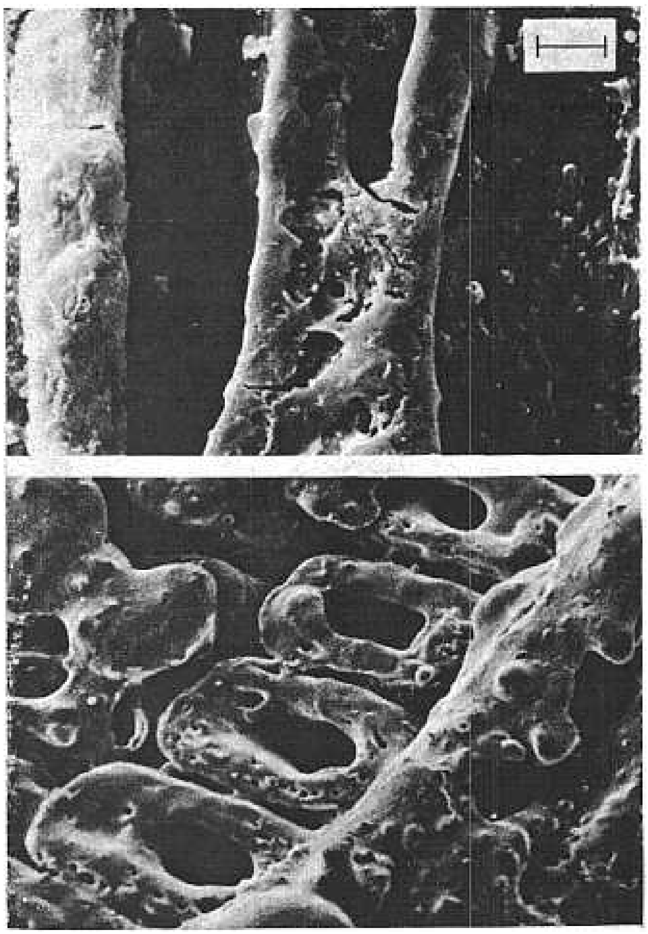

Figure 3. — Scanning electron micrographs of southern pine surfaces cut with a carbon-dioxide laser along the grain (top) and across the grain (bottom). Scale mark shows 10 μm.

In the course of the present study, several other wood-based materials were also cut. The tabulation below provides a few examples. The speeds shown are not necessarily maximum.

Material	Thickness (Inch)	Power (Watts)	Feed speed (Inches/minute)
Southern pine plywood (phenol formaldehyde glue line)		240	20
Southern pine particleboard	.50	240	16
Hardboard	.25	180	12
Tempered hardboard	.25	240	13
Fiber insulation board	.50	180	14
Corrugated boxboard	.17	180	236
Illustration board	.10	180	91
Kraft linerboard	.02	180	207

Discussion

With a laser beam the energy available for cutting is related to the thermal and optical properties of the material. When the beam strikes the surface of the work, reflection of photons causes loss of energy. While metals may reflect over 90 percent of the energy, losses for wood are relatively small. After energy has been absorbed, further losses accrue from conduction of heat into the bulk of the material. Again, wood has low thermal conductivity by comparison with metals.

Although wood has basic properties which permit high quantities of energy to be concentrated at the point of incidence, conductivity losses may explain a portion of the effect of specific gravity and moisture content on feed speed observed in this study. MacLean (1941) and others have shown that the thermal conductivity of wood increases with both moisture content and specific gravity. As thermal conductivity increases, less energy is concentrated at the point of incidence, and feed speeds must be reduced to vaporize a given volume of material per unit time. Furthermore, with wood at high moisture content or high specific gravity, there is more material per unit volume to vaporize per unit time.

Specific cutting energy is a measure of efficiency and is usually expressed in terms of kilowatt hours per cubic inch of material removed. Most carbon dioxide lasers having outputs of 240 watts require about 5 kilowatts of input energy. If a 1-inch-thick workpiece is fed at 15 inches per minute with a 0.015-inch kerf, the volume of wood removed per hour is 13.5 cubic inches and the specific cutting energy is 0.37 kilowatt hour per cubic inch. When southern pine is bored with a 1-inch-diameter, double-spur, double-twist machine bit rotated at 1800 rpm and 0.020-inch-thick chips are removed, the specific cutting energy is about 0.0004 kilowatt hour per cubic inch (Woodson and McMillin 1971). A 38-tooth, 48-inch-diameter, 700 rpm, inserted-tooth circular saw cutting 2-inch-thick lumber with a 9/32-inch kerf and 0.077-inch feed per tooth would require about 0.0002 kilowatt hour per cubic inch (specific cutting energy estimated for southern pine from data of Andrews 1955).

Other considerations, however, offset the laser's low efficiency. For example, at a cutting speed of 8 inches per minute, the laser preparation of die blocks discussed earlier is reported to be 10 times faster than by conventional methods, and also is more accurate (March 1970).

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