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LASER CUTTING OF KEVLAR LAMINATES

By R. A. VanCleave
Department 861

Published September 1977

Topical Report on PDO 6985051
G. W. Edman, Project Leader

Prepared for the United States Energy Research and Development Administration Under Contract Number EY-76-C-04-0613 USERDA

Bendix Kansas City Division

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LASER CUTTING OF KEVLAR LAMINATES

BDX-613-1877, UNCLASSIFIED Topical Report, Published September 1977

Prepared by R. A. VanCleave, D/861, under PDO 6985051

An investigation has been conducted of the use of laser energy for cutting contours, diameters, and holes in flat and shaped Kevlar 49 fiber-reinforced epoxy laminates as an alternate to conventional machining. The investigation has shown that flat laminates 6.35 mm thick may be cut without backup by using a high-powered (1000-watt) continuous wave CO_2 laser at high feedrates (33.87 mm per second). The cut produced was free of the burrs and delaminations resulting from conventional machining methods without intimate contact backup. In addition, the process cycle time was greatly reduced.

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ILLUSTRATIONS

SUMMARY

A 1000 watt CO_2 laser system, with a numerically-controlled (NC) table, was used to evaluate laser cutting of Kevlar 49 (registered trademark of E. I. duPont de Nemours and Company, Inc.) and epoxy resin laminates, ranging in thickness from 1.0 to 14.7 mm. Use of a high-powered laser for this application was investigated because of the difficulties usually experienced with conventional machining methods.

Laminates measuring 1.0, 3.56, and 6.35 mm in thickness were cut successfully in an unrestrained state, using 125, 300, and 450 watts, respectively, at a feedrate of 33.87 mm per second (mm/s). Edge taper of approximately 0.08 mm, caused by decreasing power density through the thickness, resulted in the 6.35 mm laminates. Laminates 13.0- and 14.7-mm-thick were cut through, but a layer of 1.0- to 1.5-mm-thick char and a rough edge resulted. Maximum penetration without this excessive layer of char is 7.6 mm. Holes 5.0 mm in diameter can be cut in the 6.35-mm-thick laminate; but tapered and elongated holes result when using present techniques.

Laser cutting produces both edge and surface carbon deposits as well as a large amount of fumes and smoke. Surface carbon deposit can be reduced by covering the surface with adhesive-backed tape, and edge deposits can be removed by alcohol wiping followed by a vapor blast. Fumes and smoke should be exhausted from the work area. The NC system used provides repeatable contouring work in the horizontal plane.

It was concluded that the 1000-watt laser is an effective tool for cutting Kevlar/epoxy laminates up to 7.6 mm thick. The cut produced is of better quality than that of a machined cut in that it is free of burrs and delaminations, and the cycle time is greatly reduced.

Additional work is planned to refine current processes and to further define effects of variables on cutting performance and quality.

DISCUSSION

SCOPE AND PURPOSE

Laser energy has been evaluated as an effective technique for cutting Kevlar 49/epoxy laminates. The laser energy techniques developed for current products designed by Lawrence Livermore Laboratories (LLL) and Sandia Laboratories will serve as a base for the general advancement of laser cutting of Kevlar/epoxy laminates at Bendix. Previous machining experience with Kevlar/epoxy laminates produced frayed or burred edges and delaminations. Acceptable edges could be obtained using conventional tools and techniques when the laminate was sandwiched tightly between disposable backups, but this process is too slow for flat laminates and is impractical for surface contoured laminates.

Early efforts with a 1000-watt laser showed that Kevlar/epoxy laminates can be cut at high speed (33.87 mm/s) without burrs or delaminations. Development activities were directed toward laser cutting those products within existing requirements.

PRIOR WORK

A 50-watt, continuous wave CO_2 laser was used to remove fuzz or burrs from conventionally machined slots. Attempts had been made to cut 3.17-mm Kevlar 49/epoxy laminates with the 50-watt laser, but the equipment proved to be underpowered.

ACTIVITY

A Model 1000 Continuous Wave CO_2 Laser, made by Photon Sources, Inc. (Figure 1) was evaluated for laser cutting of Kevlar 49/epoxy laminates. The power of this laser is adjustable from 50 to 1000 watts while the beam has a gaussion energy distribution across its diameter and is focused to a single spot approximately 0.25-mm in diameter by a 127-mm (5-inch) focal length objective lens made of zinc selenide.

The beam is delivered vertically to the work with a coaxial Argon gas flow to keep the focusing lens clear of smoke given off during cutting and to aid in beam penetration and cutting.

The work station contains a 330-mm-square table controlled with a two-axis Icon System, Model 380C-5, continuous path numerical control (NC) system capable of straight line and arc movements up to 33.87 mm/s depending on the contour (Figure 2). Input resolution of the system is 0.025 mm.

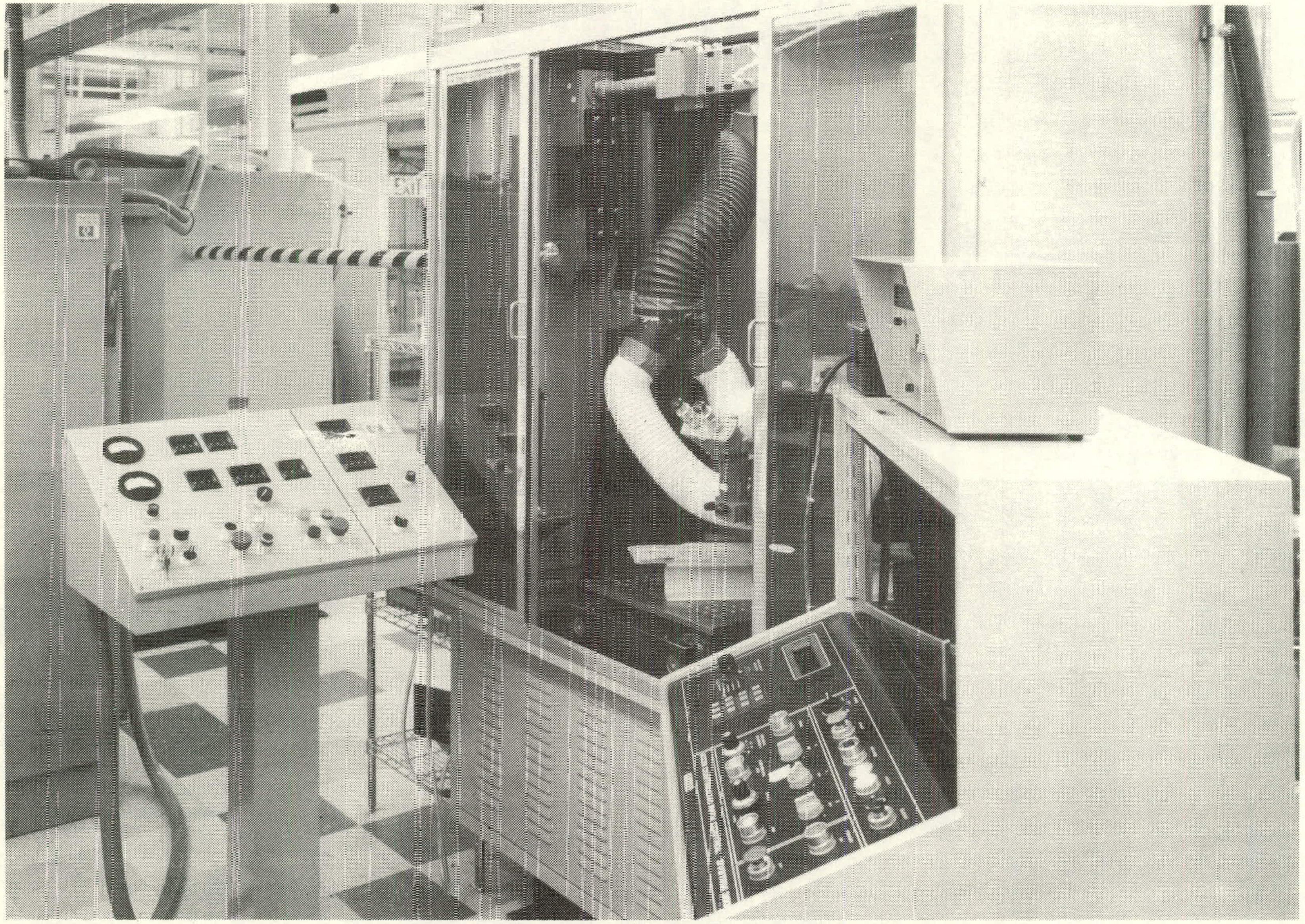

Figure 1. Model 1000 Continuous Wave CO_2 Laser System

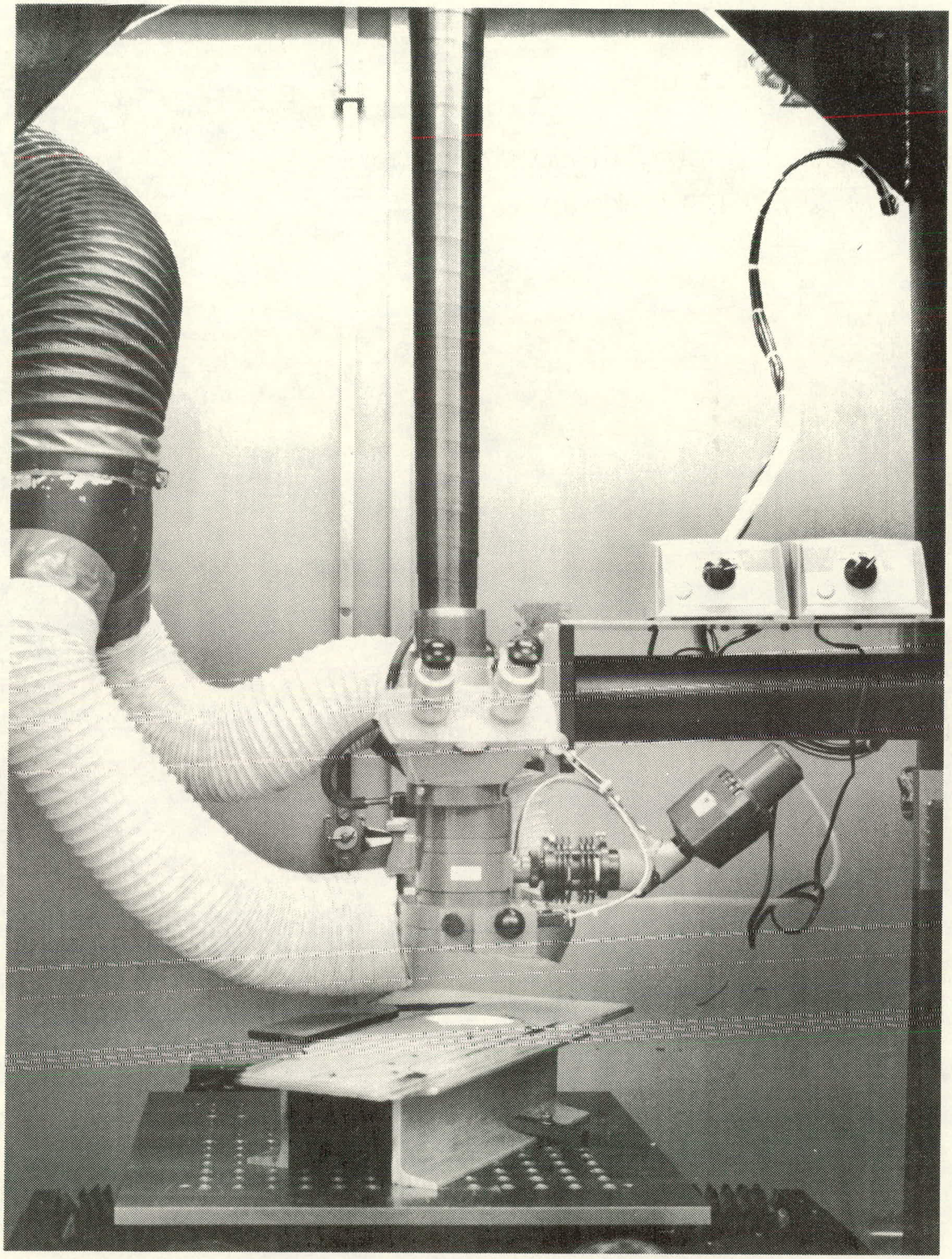

Figure 2. Laser Work Station

A microscope optics system enables tooling or workpiece to be located by means of aligning reference points with crosshairs in the optics system. The objective lens is manually positioned to change focal point.

The laser system was used to cut both flat and non-flat laminates. The first non-flat laminate required a 9.27-mm-wide slot be cut in a thickness ranging from approximately 1.0 mm to 3.56 mm.

Material varied from 5 to 16 layers of number 181 fabric and DER 332 resin (Dow Chemical Co.) and T403 (Jefferson Chemical Co.) hardener. A portion of the slot was to be cut in a surface which deviated from a flat plane by approximately 6.0 mm. Power for the cut was 175 watts with the object lens focused halfway into the profile. Cutting speed was 33.87 mm/s with a cycle time of 4.0 seconds per slot. The effective beam diameter (kerf) was approximately 0.20 mm.

The remainder of the slot was cut with a thickness ranging from 2.0 mm to 5.0 mm and an out-of-flatness of 5.0 mm. Power required was 400 watts with lens focus halfway into the profile and speed was 33.87 mm/s. Based on initial cuts the tolerance of the slot width will be plus or minus 0.13 mm or better.

A second non-flat laminate required cutting of 19.05 mm holes in a 1.0-mm-thick laminate made from five layers of Kevlar cloth and DER 332/T403 resin system. The surface varied from a flat plane by approximately 7.0 mm. The holes were cut using 125 watts at 33.87 mm/s with a kerf of 0.20 mm and a beam focus halfway into the profile. Even though the surface varied from the focus point by as much as 2.5 mm, the holes were round within 0.05 mm.

Parts have been laser-cut from flat Kevlar/epoxy laminates. The first part is made from 31 layers of Kevlar prepreg, style 181 using the E781 (U.S. Polymeric) resin system, for a thickness of 6.35 mm (Figure 3). The power required to cut the contour and holes was 450 watts focused at the top surface. The cutting speed was 33.87 mm/s (Figure 4). Kerf was 0.05 at the bottom and 0.25 mm at the top, tapering the part 0.10 mm per side. This taper occurs because, as power is consumed in vaporizing the material, less power is available at the bottom of the cut and a narrower cut results. The holes averaged 5.74 mm at the top and 5.5 mm at the bottom.

The hole was jagged. Steps in the cut approximately 0.1 mm in size were evident in both the edge of the contour and the body of the holes (Figure 5). These steps result from inaccuracies in the table movements at these high cutting speeds. It is believed that the 0.001 input resolution of the NC system contributed to these errors. A second part was cut from the same 6.35 mm thick laminate (Figure 6). Again, the stepping problem is evident in the edge of the part.

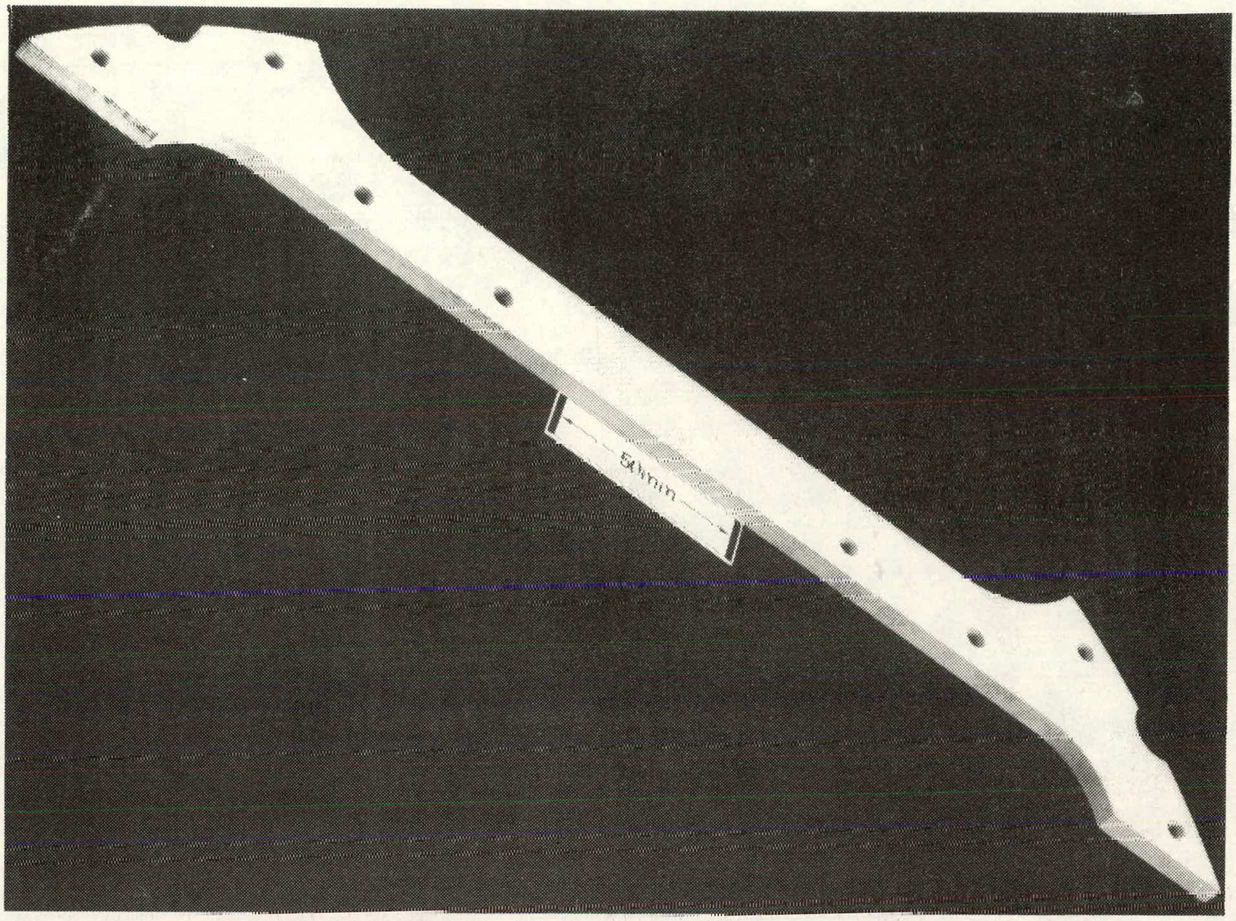

Figure 3. Contour Laser Cut in 6.35-mm-Thick Kevlar/Epoxy Laminate

Figure 4. Laser Cutting Contour and Holes in 6.35-mm-Thick Kevlar/Epoxy Laminate (Cycle Time = 75.0 Seconds Per Part)

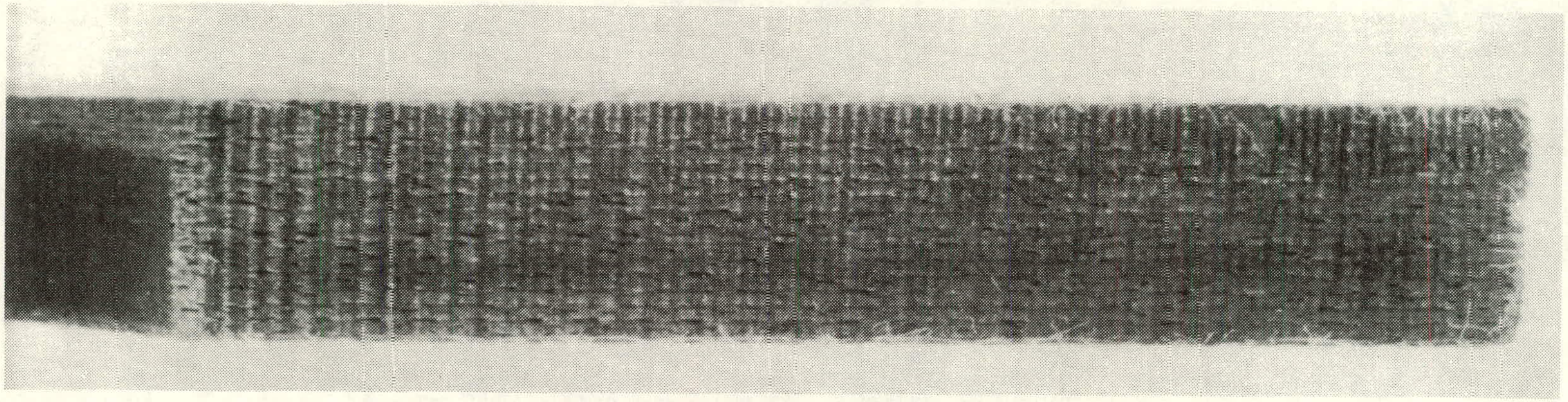

Figure 5. Contour Stepping Problem with 0.0254-mm Input Resolution

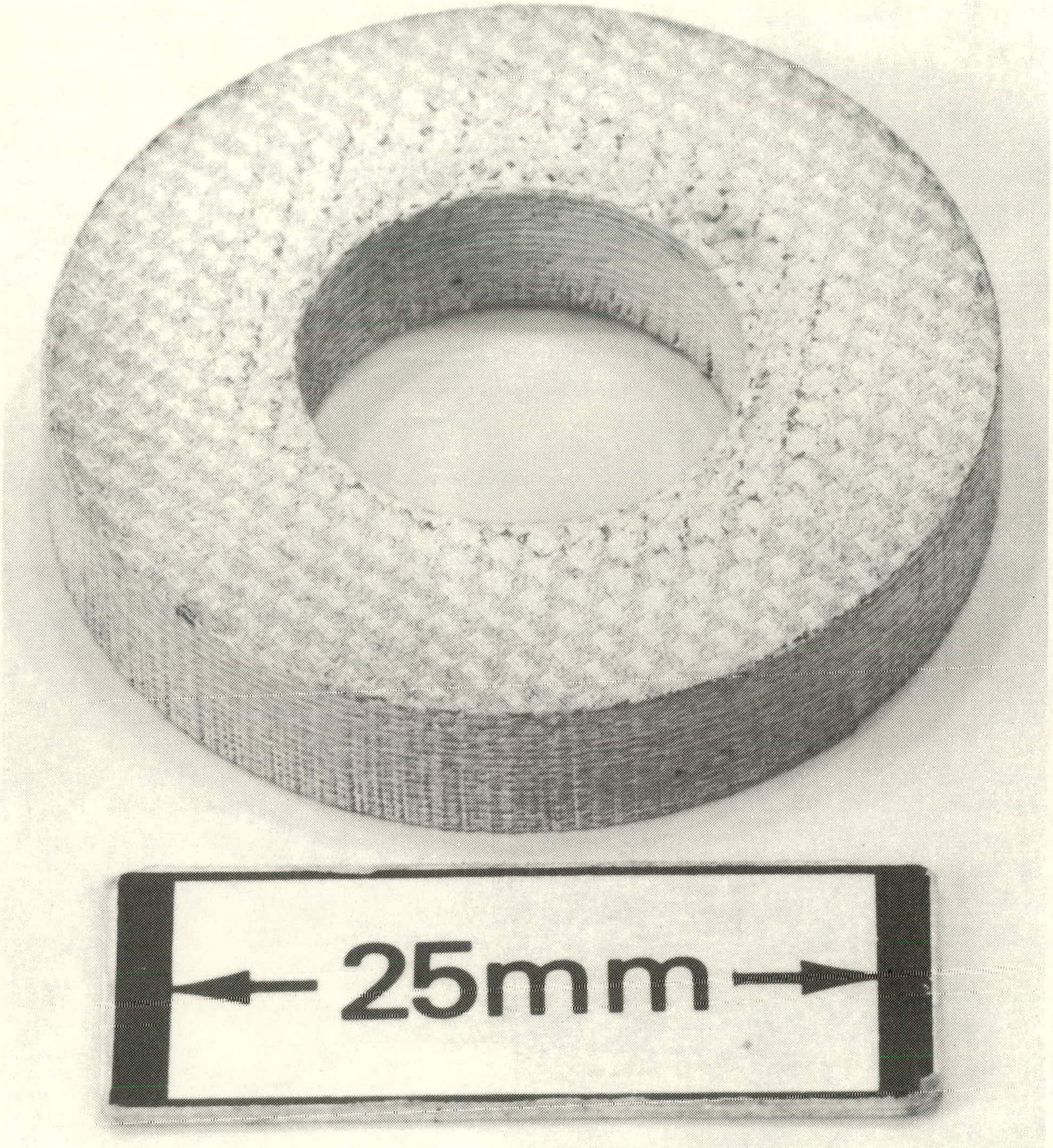

Figure 6. Contour Laser Cut in 6.35-mm-Thick Kevlar/Epoxy Laminate (Cycle Time = 16.0 Seconds Per Part)

Another part is a 3.56-mm-thick disk with a 73.2 mm outer diameter (OD) from a flat laminate. Material is 18 layers of Kevlar prepeg 181 fabric, and E781 resin. The part has a 4.93 and a 1.8 mm through-hole. These parts have been cut with 200 watts focused at the top surface (Figure 7). The OD was cut at 33.87 mm/s with a 0.05 mm kerf. The 4.93 mm hole was cut at 25.4 mm/s with a 0.20 mm kerf and the 1.8 mm hole was cut at 16.93 mm/s with a 0.40 mm beam diameter (cycle time of 13.0 seconds per part). The smaller circles require slower feed rates to prevent motor stalling or jerking and the slower feeds produce larger kerfs.

Tests were run to check the laser beam's ability to penetrate thick Kevlar/epoxy laminates. Laminates 13.97 mm thick were cut in two steps with the 1000-watt laser. The first cut was actually five passes at 800 watts (maximum power at that time) and 21.17 mm/s spaced 0.254 mm apart to "V" out the cut to a depth of 7.62 mm. This was followed by one pass centered in the "V" at the same power and feed to cut through the remainder of the laminate.

The cut produced was layered with char material approximately 0.50 mm thick with a rough textured edge. A 254.0 mm length focal length lens did not improve the depth of cut.

Tests were then conducted at Photon Sources Inc., Livonia, Michigan, using a higher power laser. Laminates 13.0 mm thick were cut. Power (1000 watts) was focused at 5.0 mm below the top surface through a 127-mm lens with a feedrate of 3.39 mm/s for one pass with an argon cover gas. An 11.4 mm penetration and a relatively smooth edge resulted. This surface was charred material about 1.5 mm thick and was easily removed. The Kevlar laminate under this char was rough in texture and concaved about 1.0 mm deeper at the middle than near the top and bottom surfaces (Figure 8). The same settings, except an increase in power to 1350 watts, produced a through-cut with a similar surface and texture (Figure 9). A 14.7-mm-thick laminate was cut at Photon with 1,350 watts power at 3.39 mm/s and a similar textured edge was produced (Figure 10).

Test samples cut on a GTE-Sylvania laser at GTE-Sylvania, Mountain View, CA, using a 127 mm lens, 1,500 watts of power, an argon cover gas and feed rate of 63.5 mm/s produced a smooth straight-lined cut in 6.35-mm-thick Kevlar/epoxy laminate. (The increased speed may have produced a more carbon-free cut, but the edge was still black with carbon.) Even higher feedrates are anticipated, but none have been attempted.

Approximately 30 percent of the carbon deposited on the edge and surface of the laser-cut Kevlar/epoxy laminates may be removed by hand wiping or with an alcohol-soaked paper wiper. Remaining carbon can be removed using vapor blast of 1000 grit glass beads

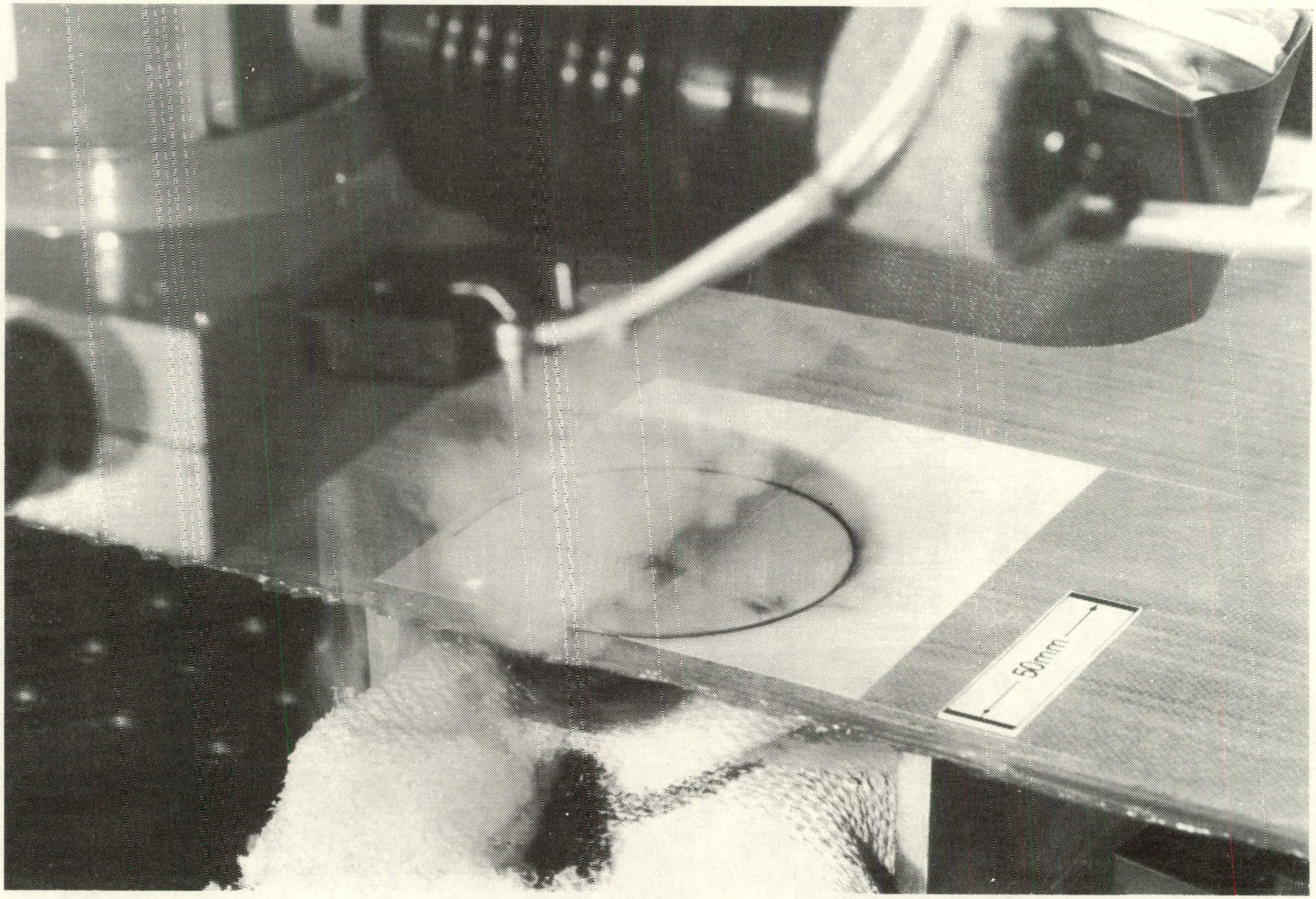

Figure 7. Laser Cutting 3.56-mm-Thick Kevlar/Epoxy Laminate
(Cycle Time = 13.0 Seconds Per Part)

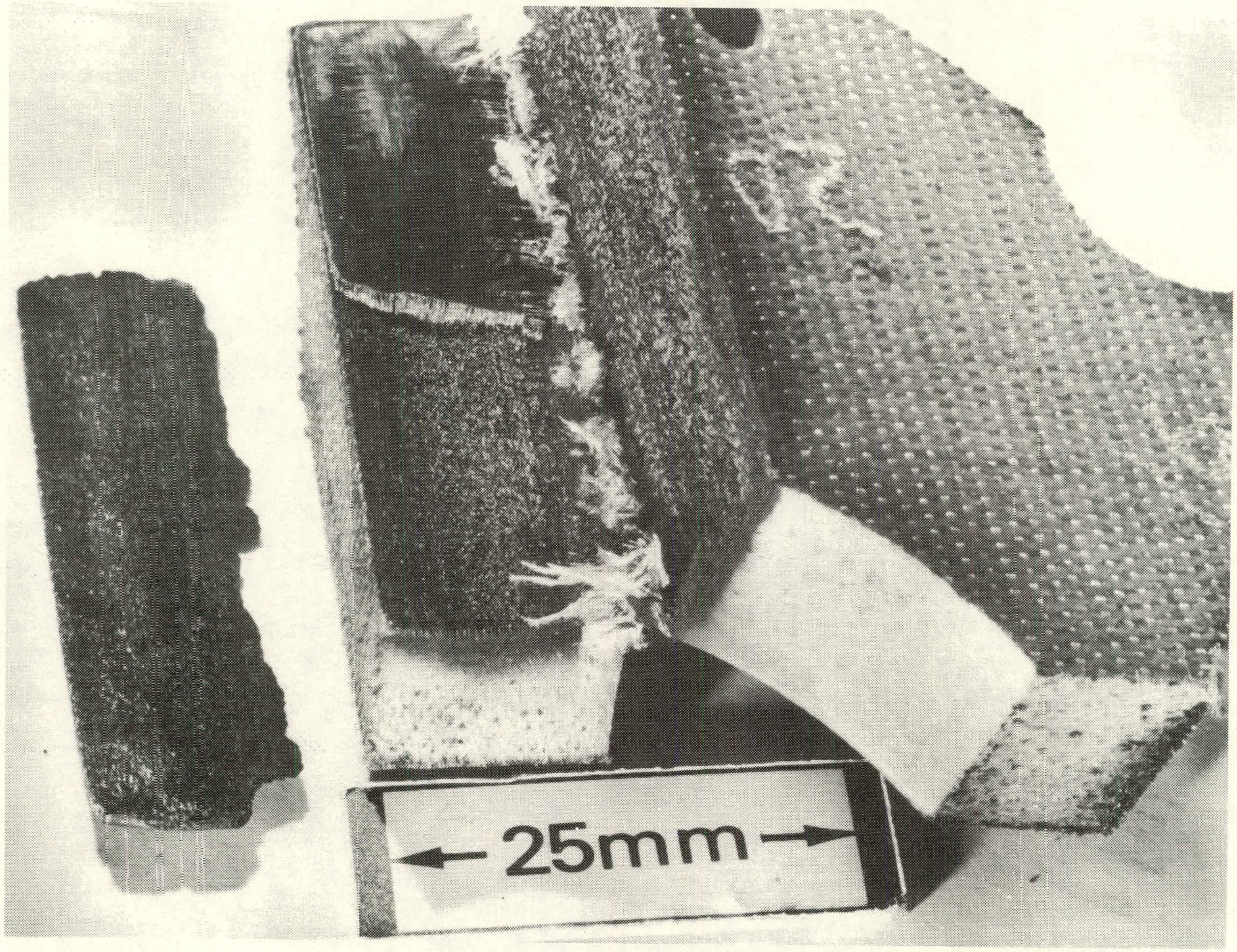

Figure 8. Single-Pass Laser Cut in 13.0-mm-Thick Kevlar/Epoxy Laminate at 1000 Watts

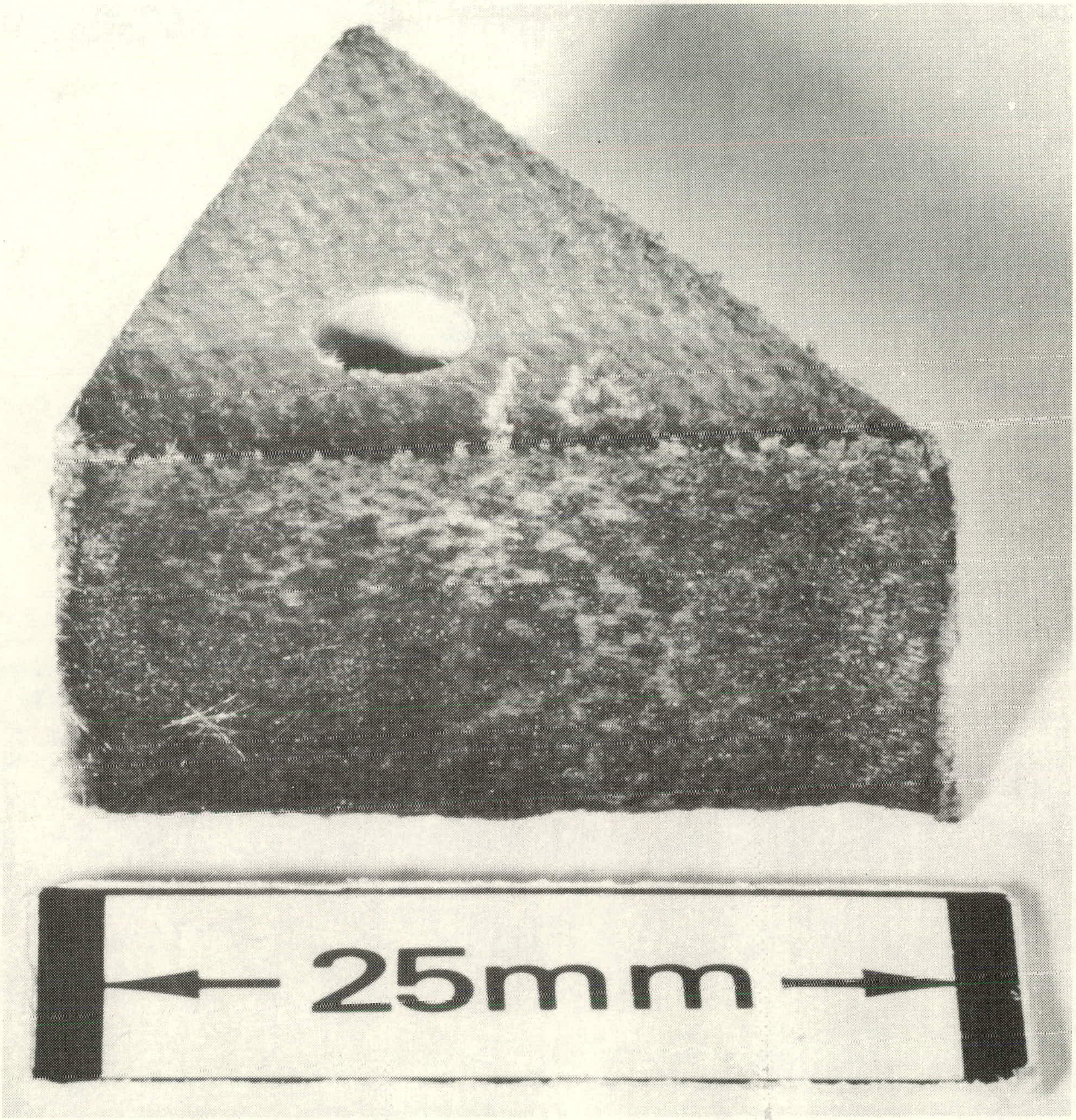

Figure 9. Single-Pass Laser Cut in 13.0-mm-Thick Kevlar/Epoxy Laminate at 1350 Watts

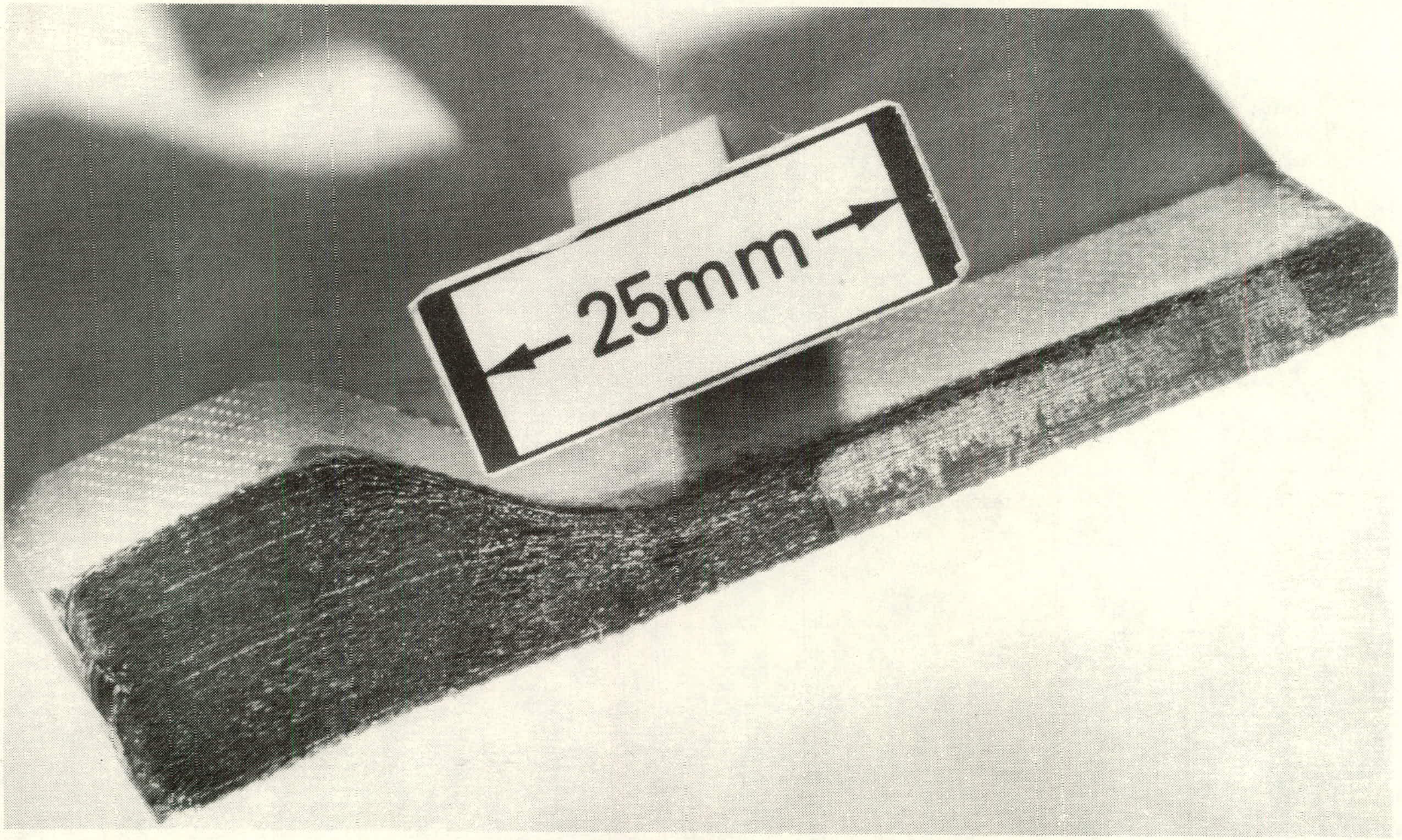

Figure 10. Single-Pass Laser Cut in 14.7-mm-Thick Kevlar/Epoxy Laminate

(Figure 11). Carbon deposits on the top laminate surface can be reduced greatly by masking the area to be cut with tape and cutting through the tape. It also was observed that the flame produced during cutting was greatly reduced when the part was masked with tape.

Layers of dry Kevlar fabric have been cut with the laser. Distortion to the weave and pattern and excessive time required to cut contoured patterns using scissors or power shears makes fabrication of laminates by NC laser cutting of dry cloth very attractive. Twelve layers of cloth rings have been cut using 130 watts at 33.87 mm/s (cycle time of 14.0 seconds) but excessive carbon deposit on the cloth occurred. One layer and four layers have been cut using 40 watts, but again excessive carbon deposits occurred.

Laser cutting of Kevlar cloth and Kevlar/epoxy laminates produces a light-colored odorous smoke. Care should be taken to exhaust the work area. The cutting also produces a flame approximately 75 mm long. The flame tails in the same direction as the table movement, or away from the uncut surface. Precautions should be taken to avoid fire.

ACCOMPLISHMENTS

The 1000 watt CO_2 laser was proven to be an effective tool in cutting Kevlar 49/epoxy resin laminates. A process has been established which replaces conventional machining of non-flat laminates with laser cutting and reduces cutting time while improving edge quality. Kevlar/epoxy laminates 6.35 and 3.56 mm thick can be laser cut to given contours.

Limitations of using the laser as a Kevlar laminate cutting tool are the laminate thickness, the resulting edge taper, the material charring, and the effects on the material. Maximum thickness is near 7.6 mm before excess charring and poor edge definition occur. Edge taper caused by decreasing power density through the thickness is approximately 0.10 mm for a 6.35-mm-thick laminate. This taper is evident in the form of conical holes. The laser cut produces carbon deposits even in the thinner laminates. Approximately 30 percent of this carbon can be wiped off, but the remaining carbon requires blasting or some similar method for complete removal. The effects of the laser cut on the parent material are not known at this time. Width of the heat-affected zone and effects on material properties adjacent to the cut are also unknown.

It was observed that the open looped NC system (no feedback from motors which control table movement and positioning to confirm table movement) used on the existing laser allowed for incorrect

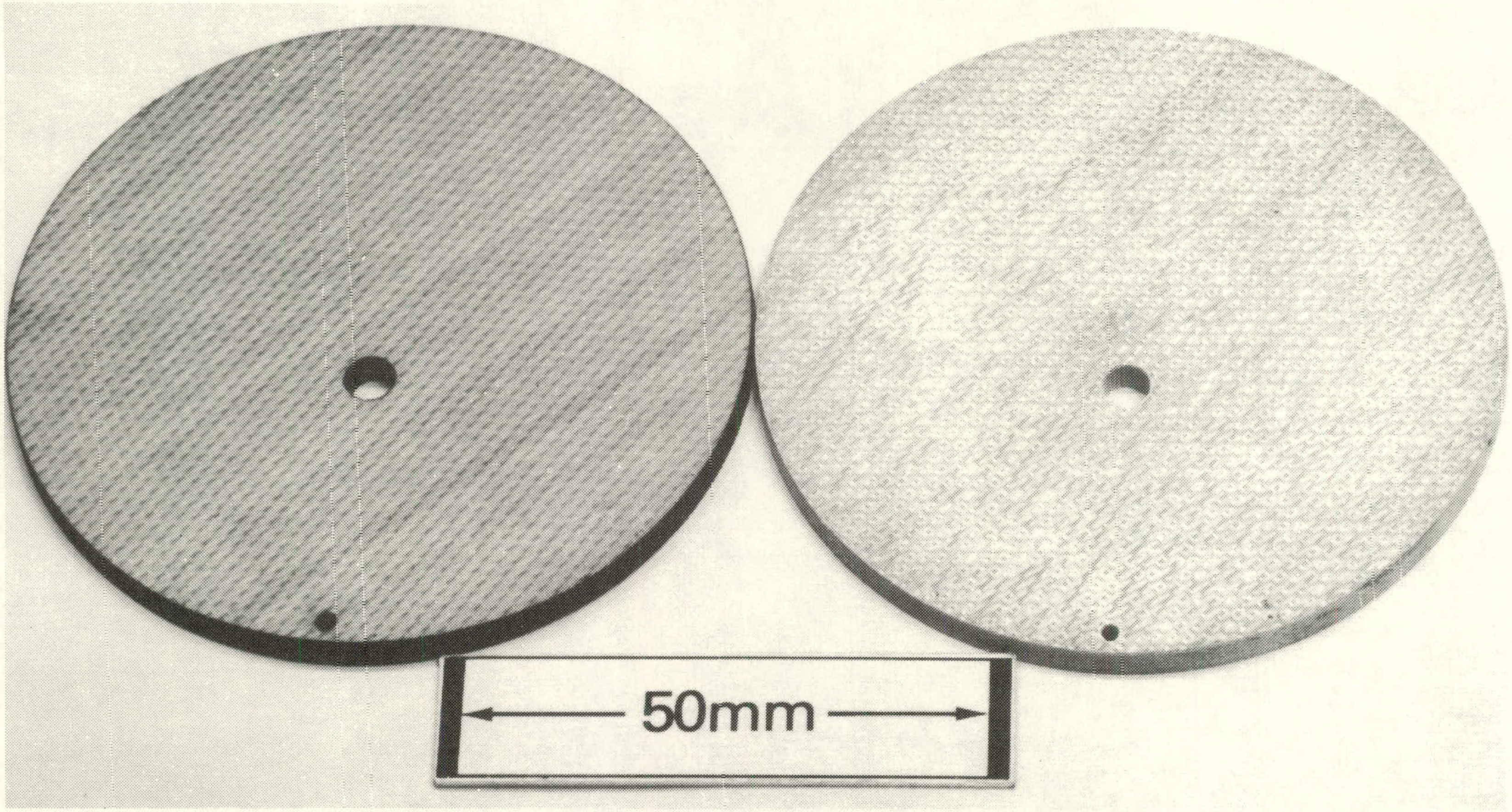

Figure 11. Kevlar/Epoxy Laminate (3.56-mm-Thick) Before and After Vapor Blast

positioning, especially when axis reversal movement occurs. To improve this situation any axis reversal should have a program hold of about 0.5 second to assure correct movement in one direction before movement reverses.

Position readout numbers are not necessarily a true reading of table movement with this system and set positions should be confirmed periodically during a production run. Lack of cutter compensation on the existing NC control caused a delay in development, since correction in beam size for different thicknesses and cutting speeds required Mylar tape changes.

The laser is a useful tool in cutting Kevlar laminates within given thickness limits. The edge fuzzing problem with conventional cutting techniques does not exist. The need for cutting tools is eliminated; and cutting time is reduced significantly. Applications also are probable in the cutting of plastics in general.

Any new laser system considered for this type of work should have a closed loop feedback NC system to better control accuracy and reliability. Direct numerical control rather than numerical control or some other form of cutter compensation should also be considered. A third axis (focus position) numerical control would greatly increase the flexibility of the system for cutting non-flat laminates and for reducing cycle time.

FUTURE WORK

Additional work is planned for CO_2 laser cutting of Kevlar/epoxy laminates. The following activities are planned.

- Study the effects of feed rate (cutting speed), power level (wattage), material thickness, Kevlar/epoxy ratio, focal point location and beam size (kerf) on cutting performance so that cutting parameters are better defined for future Kevlar/epoxy products to reduce startup time.

- Determine more accurately the maximum material thickness which can be cut.

- Increase maximum cutting thickness possible by using higher power, faster feedrates, or pulsed mode cutting instead of continuous wave.

- Establish processes for cutting test samples of various shapes to support material property testing.

- Determine effects of laser cut on material properties.

- Determine the heat-affected zone for various thicknesses and power levels.

- Improve the technique for cutting holes ranging from 1.5 to 13 mm in diameter to reduce tapered sides and out of roundness in laminates which range in thickness from 1.0 mm to the maximum cutting thickness available from the laser.

- Investigate the practicality of laser cutting pockets (cuts not completely through) in Kevlar/epoxy laminates.

- Continue the study of Kevlar cloth cutting.

- Determine the nature of the byproducts produced by laser cutting Kevlar/epoxy laminates and their effects.

- Study effect on the cut of clipping (masking the beam to remove the fringe area power and use only the higher power, center portion of the beam).

- Study the effect on the cut in laminates made with different fiber orientations.

- Determine how to dissipate excess energy below the laminate and establish minimum fixture heights to prevent damage to the part which might be caused by beam reflection of fixture compounds.

- Investigate the effect on charring and carbon deposits when the laminate is cut in a vacuum or under water.

- Investigate the effect of a gas jet assist on cutting performance.

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