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EVALUATION OF BARRIER MATERIALS: METAL ALLOYS, FIBERS, AND PLAT--ETC(U)
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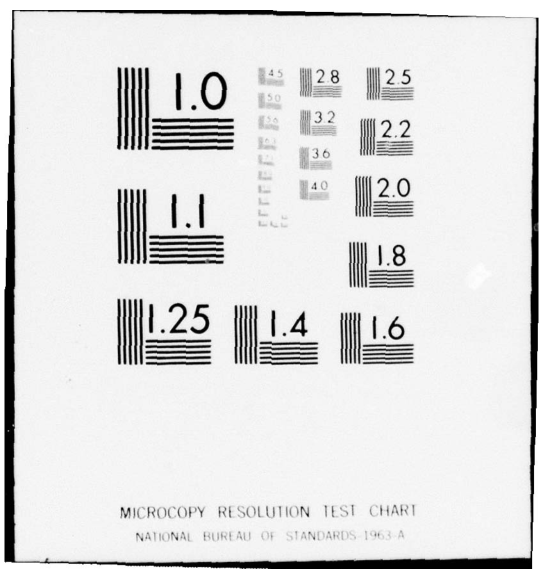
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EVALUATION OF BARRIER MATERIALS: METAL ALLOYS, FIBERS, AND PLATES

by

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January 1977

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The resistance of various commercially available lightweight materials to CO_2 laser damage was examined. Five samples were supplied for laser evaluation: (1) D242, a needle punched and rolled alloy fiber, (2) 304SS stainless steel fibers web sintered and rolled, (3) 430SS, a stainless steel sinter on hard backing, (4) FM515 with Inconel 600 backing, and (5) a graphite woven cloth. A 100 W CO_2 laser beam was focused to provide

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20. ABSTRACT (continued)

various irradiance levels up to 6.7 KW/cm^2. These samples may be exposed safely at about 20 watts/cm^2. For kilowatt level exposures, dark finished samples are more robust than bright finished samples of the same material. At 6.7 KW/cm^2, all materials are penetrated in less than one second with the exception of 430SS and DH242 wet with water.

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INTRODUCTION

The development of the CO_2 laser presents a variety of problems in laser protective shielding, including materials for routine laboratory baffles. There are potentially useful lightweight materials commercially available which can be easily cut and formed into any desired shape. The purpose of this study is to determine whether several commercially available shielding materials hold promise for protection against high energy laser radiation.

MATERIALS TESTED

Experimental studies were conducted on a number of commercially available metal fiber materials to determine the feasibility of their use as high energy laser barriers. The materials were obtained from the Brunswick Corporation, Sugar Grove, Virginia. The company furnished a woven graphite cloth and four sets of paired samples. Within each pair the sample designation is the same except for the surface appearance, that is, one is dark and the other is bright. The dark finishes were obtained by preoxidizing bright samples. A summary of their physical properties is included in Table I. These materials vary in texture from the soft matted DH242 and 304SS to the platelike FM515. The matted cloth, DH242, is made up of very fine metal fibers rendering it flexible, soft, and spongy. Because of these qualities, it can be impregnated with laser attenuating materials, such as water for absorbing the CO_2 laser, to further attenuate the laser beam. The 304SS, which is made of stainless steel fibers, is not as flexible as the DH242 because its fibers are more closely woven, thus rendering it not as spongy. The other samples are composed of large fibers that are solidly compressed into a rigid metal board (430SS) or onto a metal plate (FM515). The latter resembles a granular surface. The graphite sample consists of spun fibers woven into a black cloth.

PROCEDURE

The experimental setup is shown in Figure 1. The laser is a Coherent Radiation, Model 40, single mode, CO_2 laser. The laser output beam was used at full width, 1.905 cm, for irradiances between 1.75 to 35 watts/cm^2; and focused down with a water cooled germanium lens to obtain a 0.137 cm diameter spot for higher irradiances. The irradiances were determined by first measuring the energy output of the laser with a Coherent Radiation Laboratory, Model 203, thermopile detector and dividing it by the burn spot area and the time of incidence on the detector (H = joules/cm^2 sec). In the diagram, M is a 100% mirror, used to deflect the laser beam into the thermopile. The helium-neon laser is necessary to align the sample to the CO_2 laser in order to assure that a different area of each sample was used for each exposure. The conditions of the exposures are given in Tables II and III.

Table I. Properties of Lightweight Materials Tested

SAMPLE #	ALLOY	FIBER DIA. (microns)	DENSITY (lbs/ft.^{2})	TENSILE STRENGTH (PSI)	THICKNESS (in.)	OTHER PROPERTIES
1	DH242	8.0	.205	---	.400	Needle punches and rolled to final density
2	304SS	8.0	.219	---	.220	Stainless-steel web, sintered and rolled to final density
3	430SS/ FM1311	46.1-62.0	1.97	---	--- ±.015	No tensile strength specification, ±2% tolerance on density, ±.015 tolerance on thickness
4	FM515 with Inconel 600	6.0	---	950-2,800	.250	.190" FM515 - backed with .060" Inconel 600
5	Graphite	---	.063	360,000	---	Modulus → 34 x 10^6 lbs/in^2, Breaking Strength → 13.5 lbs, % Elongation → 1.1%, Specific Heat → 1.7

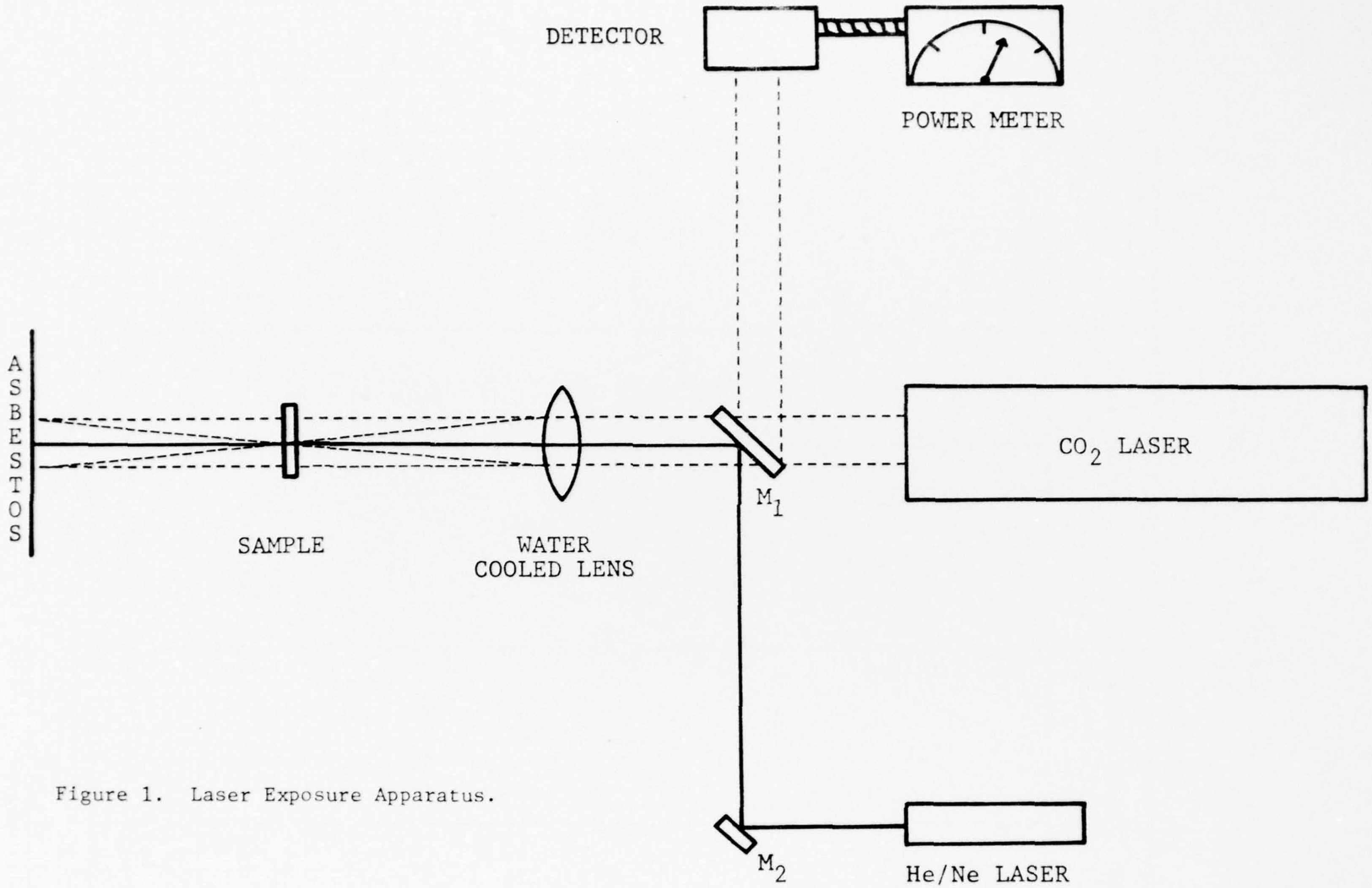


Figure 1. Laser Exposure Apparatus.

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2) †	TIME (sec)	REMARKS
#1 DH242 Needled Web	5	1.75	1	No visible change
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	2	" " "
			4	Glowing begins
			8	" " (red)
			16	Glows red
			32	Reaches & stays at red glow
			64	" " " " " "
	20	7.0	1	Immediately glows dark red. Starts bright red & in 2 sec reaches
			64	Orange & stays orange
	50	17.5	1	Starts bright orange & goes to yellow
			2	" " " " "

*The wattage meter was fluctuating through the tests. The indicated wattage is estimated to be at the center of the fluctuation.

†Irradiance was determined by dividing the indicated wattage* by the area of the beam. $r = 3/8'' = 0.95$ cm. $A = \pi r^2 = 2.85$ cm^2.

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
			4	Starts bright orange & goes to yellow
			8	Discoloring & very little smoke
			16	Discoloring increases (no smoke)
			32	Further discoloration, same as 16 sec
			64	" " "
	100	35.	1	Starts orange glow & goes to bright yellow; larger area of glowing. Extreme orange & bright yellow at center
			2	Discoloration, surface damage
			4	Damage increases, same as 2 sec
			8	" " " " "
			16	" " " " "
			32	" " " " "
			64	" " " " "
#2 304 Stainless Steel Sintered Web Preoxidized	5	1.75	1	No visible change
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	64	" " "
	20	7.0	1	" " "

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
#2 (cont'd)	20	7.0	2	No visible change
			4	" " "
			8	Discoloring begins, loose fibers glow
			16	Discoloring increased, red glow very faint
			32	Further discoloration, dark red glow
			64	" " "
	50	17.5	1	Orange, almost yellow glow, discoloring, slight surface damage
			2	*Same as 1 sec. (Larger area)*
			4	" " " " " "
			8	" " " " " "
			16	" " " " " "
			32	" " "
			64	" " "
	100	35.	1	Very bright orange to yellow, discolorations, damage to outer layer.
			2	Very bright orange to yellow, discolorations, damage in center.
			4	Extremely bright orange to yellow to white, discolorations, extensive damage to large portion of area exposed. Glow remains after beam.

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO^2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRAD. (Watts/cm^2)	TIME (sec)	REMARKS
#2 (cont'd)			8	Same as 4 sec. + discoloring on back increases, increasing damage, glow remains after beam.
	100	35.	16	" " " "
			32	" " " "
			64	Extensive damage to back of sample, cracks where beam nearly penetrated.
#3 430 Stainless Steel Preoxidized FM1311	5	1.75	1	No visible change.
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	16	" " "
			32	" " "
			64	" " "
	20	7.0	16	" " "
			32	" " "
			64	" " "
	50	17.5	16	" " "
			32	Deep red glow, discoloration at 20 seconds.
			64	Deep red glow, constant, discoloration is dark.
	100	35.	2	No visible change.
			4	Begins to glow light red.
			8	Orange glow & discoloration begins.
			16	Orange glow lingers after beam, discoloration increases.

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
#3 (cont'd)	100	35.	32	Same as 16 sec. + some fibers are blue and white.
			64	Same as 32 sec., more fibers are white.
#4 FM515 with .060" Inconel backing.	5	1.75	64	No visible change.
	10	3.5	64	" " "
	20	7.0	64	" " "
	50	17.5	8	" " "
			16	Light red glow begins.
			32	Deep red glow.
			64	Orange glow.
	100	35.	< 1	No visible change.
			1	Begins orange glow.
			2	Orange glow.
			4	Orange glow, very slight discoloration.
			8	" (yellow at center, discoloration increases).
			16	" " "
			32	" " "
			64	" " " + discoloration , damage to surface (cracks), vaporization.
#5 Graphite Cloth	10	3.5	1	No visible change.
			2	" " "
			4	" " "
			8	" " "
			16	" " "

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
#5 (cont'd)	10	3.5	32	No visible change.
			64	" " "
	20	7.0	1	" " "
			2	" " "
			4	" " "
			8	Discoloring begins, faint red to orange glow.
			16	Discoloring increases, light orange glow.
			32	" ", dark orange glow, initial smoke.
			64	Same as 32 sec.
	50	17.5	1	Begins to glow orange, odor.
			2	" " " " "
			4	Orange glow, odor.
			8	Discoloration begins, initial smoke, odor.
			16	Increasing discoloration & damage + same as 8 seconds.
			32	" " "
			64	" " "
	100	35.	1	Orange glow (glows through to back), odor.
			2	Bright orange glow, smoke, odor.
			4	" " ", no smoke, odor, damage and discoloring begins.
			8	Bright orange to yellow glow, odor, and increasing damage + discoloration.
			16	Same as 8 secs. + initial smoke.
			32	Same as 16 secs.

Table II. Results of Exposure of Dark Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts*)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
#5 (cont'd)	100	35.	64	Same as 16 secs. Increasing glow through to back and increasing damage and discoloring throughout.
DH242 (dry)	100	6.7×10^3	< 2	Complete penetration.
(wet)	100	6.7×10^3	80	Minimal surface damage.
304 SS	100	6.7×10^3	< 1	Complete penetration
430 SS/ FM1311	100	6.7×10^3	22	90% penetration and discolored back.
FM515	100	6.7×10^3	1	Penetrated to plate backing.
Graphite Cloth	100	6.7×10^3	< 1	Complete penetration.

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
DH242 (dry)	5	1.75	1	No visible change.
			2	" " "
			4	" " "
			8	Discoloring begins.
			16	Discoloration increases.
			32	" "
			64	" "
	10	3.5	1	No visible change.
			2	" " "
			4	" " "
			8	Discoloring begins.
			16	Discoloration increases.
			32	" "
			64	" "
	20	7.0	1	No visible change.
			2	" " "
			4	Discoloring begins.
			8	" " and surface damage.
			16	Discoloration & surface damage increases.
			32	" " "
			64	" " "

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm²)	TIME (sec)	REMARKS
DH242 (dry)	50	17.5	1	Orange glow, surface damage & discoloration.
			2	Same as 1 sec., increasing brightness and discoloring size.
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	100	35	1	Orange-yellow glow, discoloration & surface damage.
			2	Same as 1 sec. with increasing glow, discolorings & damage.
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	100	1,000	< 1	Glows white, burns deep.
			1	" " " through.
DH242 (wet)	100	1,000	1	Glows white, hisses as water evaporates, some surface damage.
			2	Glows white through to back, hisses as water evaporates, burns ∿ 1/2 way through.

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
DH242 (wet)	100	1,000	4	Same as 2 sec. except burns deeper.
			8	Same as 4 sec. except beam begins to come through back.
			16	Same as 8 sec., steam is seen during and after exposure, more beam getting out of back.
			32	Burns completely through.
304 SS	5	1.75	1	No visible change.
			2	Discoloration begins.
			4	Discoloration gradually increases.
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	1	Discoloration begins.
			2	Discoloration gradually increases.
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
304 SS	20	7.0	1	Discoloration begins.
			2	Discoloration increases and red glow begins.
			4	Discoloration gradually increases and orange glow.
			8	Increasing discoloration and glow.
			16	" " "
			32	" " "
			64	" " "
	50	17.5	1	Glows orange and discolors.
			2	Increasing discoloration and orange glow.
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	100	35	1	Glows bright yellow, discolors.
			2	" " " surface damage.
			4	" " "
			8	Glows yellow, discolors, glows brighter yellow as surface burns and spreads, discolors on back; glow remains after exposure.

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
304 SS	100	35	16	Same as 8 sec. except discolors on back also.
			32	Same as 16 sec. except burned hole through back and more discoloration on back.
			64	Same as 32 sec. but more intense.
	100	~1,000	< 1	Glows white, completely burns through.
430SS/ FM1311	5	1.75	1	No visible change.
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	1	" " "
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	20	7.0	1	" " "
			2	" " "
			4	" " "

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADINACE (Watts/cm^2)	TIME (sec)	REMARKS
430SS/ FM1311 (cont'd)	20	7.0	8	No visible change.
			16	" " "
			32	" " "
			64	" " "
	50	17.5	1	" " "
			2	" " "
			4	Discoloration begins.
			8	Discoloration gradually increases.
			16	" " "
			32	" " "
			64	" " "
	100	35	1	Discoloration begins.
			2	Discoloration increases and red glow begins.
			4	Same as 2 sec. but orange glow.
			8	" " " " "
			16	" " " " "
			32	" " " " "
			64	Glow remains after exposure.
	100	∿1,000	< 1	Glows orange and damages surface.
			1	Glows orange and surface damage increases.
			2	" " " " and glows red on back.
			4	Same as 2 sec. and starts to burn through back.

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
430SS/ FM1311 (cont'd)	100	1,000	8	Same as 4 sec. and burns partially through back.
			16	Same as 8 sec. but burns completely through.
FM515	5	1.75	1	No visible change.
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	10	3.5	1	" " "
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "
	20	7.0	1	" " "
			2	" " "
			4	" " "
			8	" " "
			16	" " "
			32	" " "
			64	" " "

Table III. Results of Exposure of Bright Finish Lightweight Materials to CO_2 Laser Radiation (cont'd)

SAMPLE #	BEAM POWER (Watts)	POWER IRRADIANCE (Watts/cm^2)	TIME (sec)	REMARKS
FM515	50	17.5	1	Discoloration begins.
			2	" " increases and orange-red glow.
			4	Same as 2 sec.
			8	" " " "
			16	" " " "
			32	" " " "
			64	" " " "
	100	35	1	Discoloring, red-orange
			2	Increasing discoloring and glow.
			4	" " "
			8	Same as 2 sec. and glow lingers after exposure.
			16	Same as 8 sec.
			32	" " " "
			64	" " " "
	100	1,000	1	Glows yellow to white, burns deep hole to backing.
			2	Brighter glow, hole larger.
			4	" " " "
			8	Glow lingers after beam and hole larger.

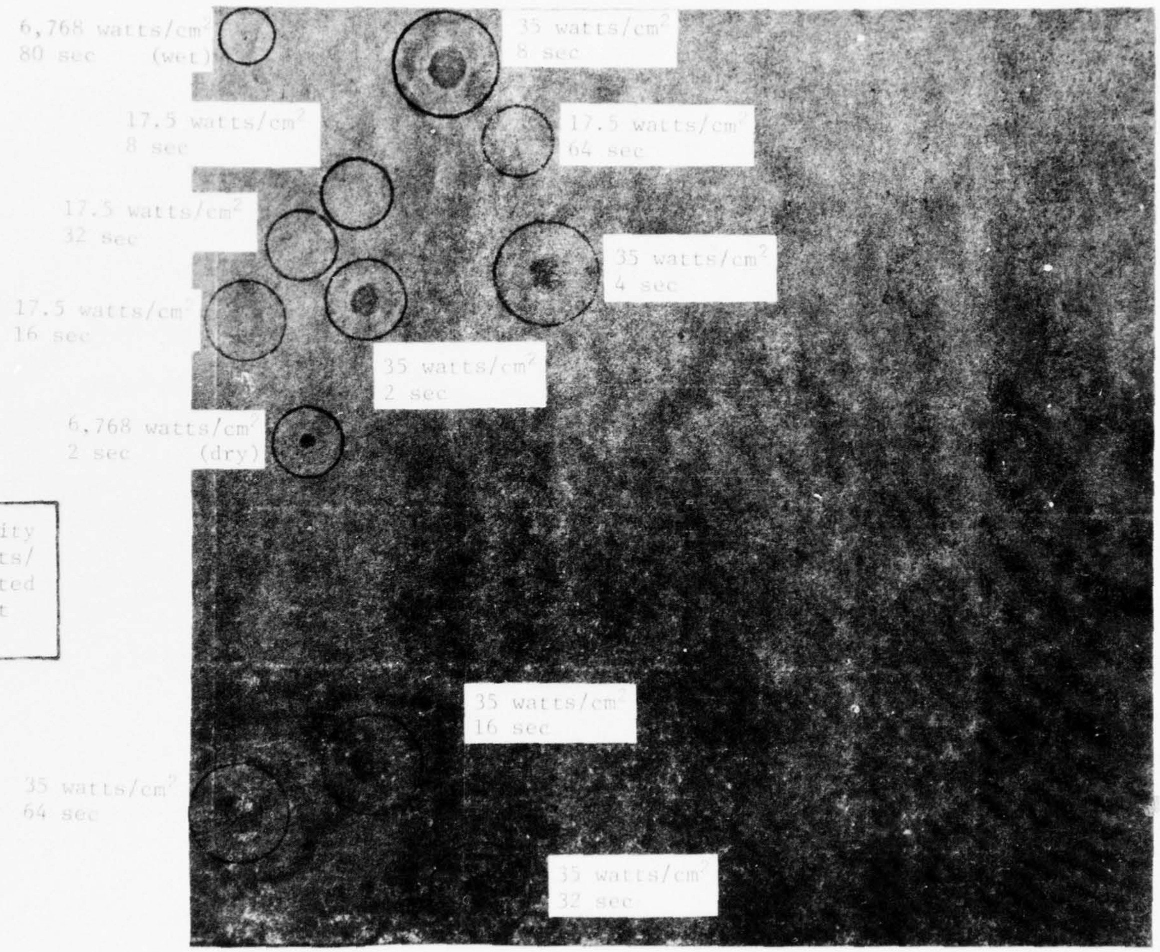
RESULTS

The observed behavior of each sample under test is described in Tables II and III, and the damage sustained by each sample is shown in Figures 2 through 10.

The results for the darkly finished samples are presented in Table II. With increasing irradiance, all samples sustained surface discoloration before exhibiting further damage or penetration. The onset of surface burns and penetration damage was preceded by incandescence of the fibers which varied in intensity with the laser power output. The samples 430SS and FM515 showed appreciable resistance to the unfocused CO_2 laser for a time duration of a little over one minute. The irradiance thresholds of the materials for damage exceeding mere discoloration, an excerpt of Table II, are shown in Table IV. All of the samples were also subjected to 6.8 KW/cm^2, whereupon most suffered complete penetration in less than one second. The exceptions are DH242 which took nearly two seconds to damage, and sample 430SS which underwent complete penetration damage in twenty-two seconds. Taking advantage of the spongy quality of DH242, it was soaked with water and then exposed to the 6.8 KW/cm^2 beam. After eighty seconds the wet DH242 sample had sustained only minimal surface damage.

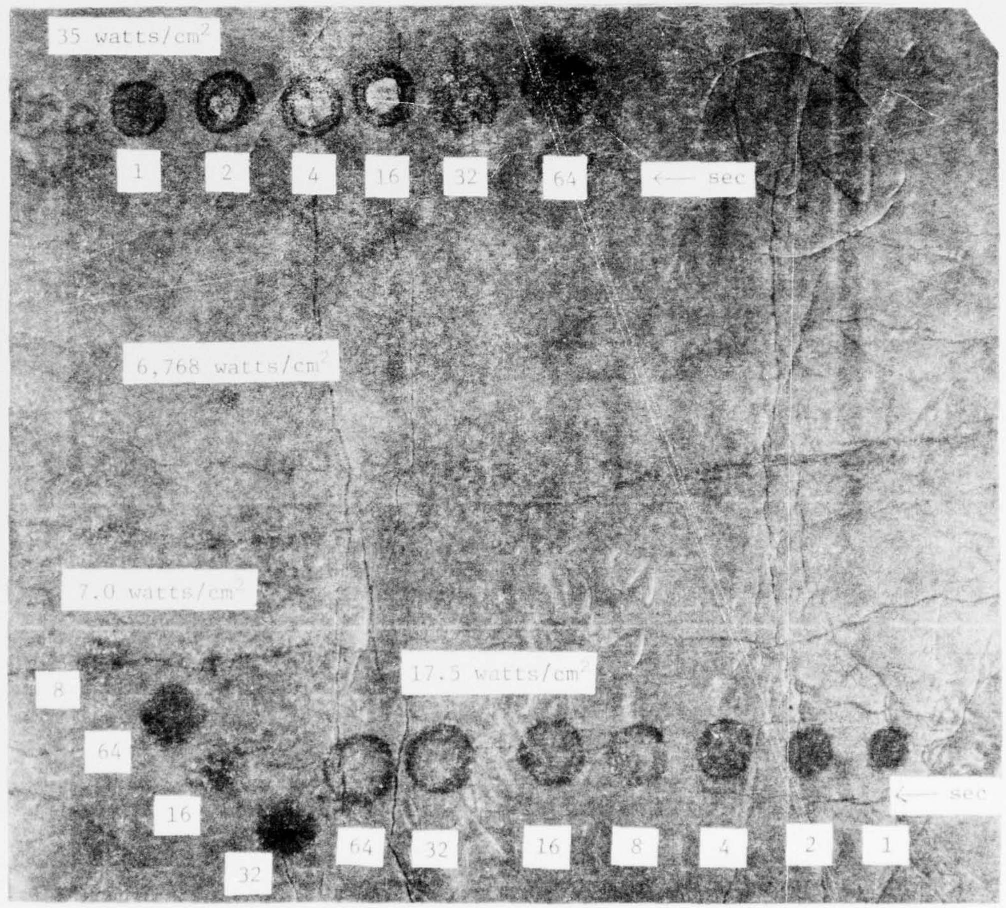
The brightly finished samples show lower damage thresholds than the dark ones discussed above. These results are detailed in Table III, and damage thresholds are summarized in Table V. Again the samples 430SS and the FM515 have little damage at 35 W/cm^2. At an irradiance of 1.0 KW/cm^2, all samples were completely penetrated by the CO_2 laser beam within one second except the 430SS metal fiber board which was damaged within this period but not completely penetrated. Penetration of this sample occurred sixteen seconds later. The bright sample of DH242 is also spongy and was also soaked with water to determine its barrier properties at higher power irradiance. Using the laser beam at 1.0 KW/cm^2, this sample was penetrated in eight seconds, therefore this material is not as good as its dark counterpart when treated similarly.

It must be pointed out that for both FM515 samples (dark and bright), which have an Inconel backing, complete penetration involves penetration of the fiber cover only. It could not be determined whether the Inconel backing was damaged, since the samples were not cut out to determine if any damage occurred there. However, at all the laser power ranges used, no complete penetration of the metal backing was observed.



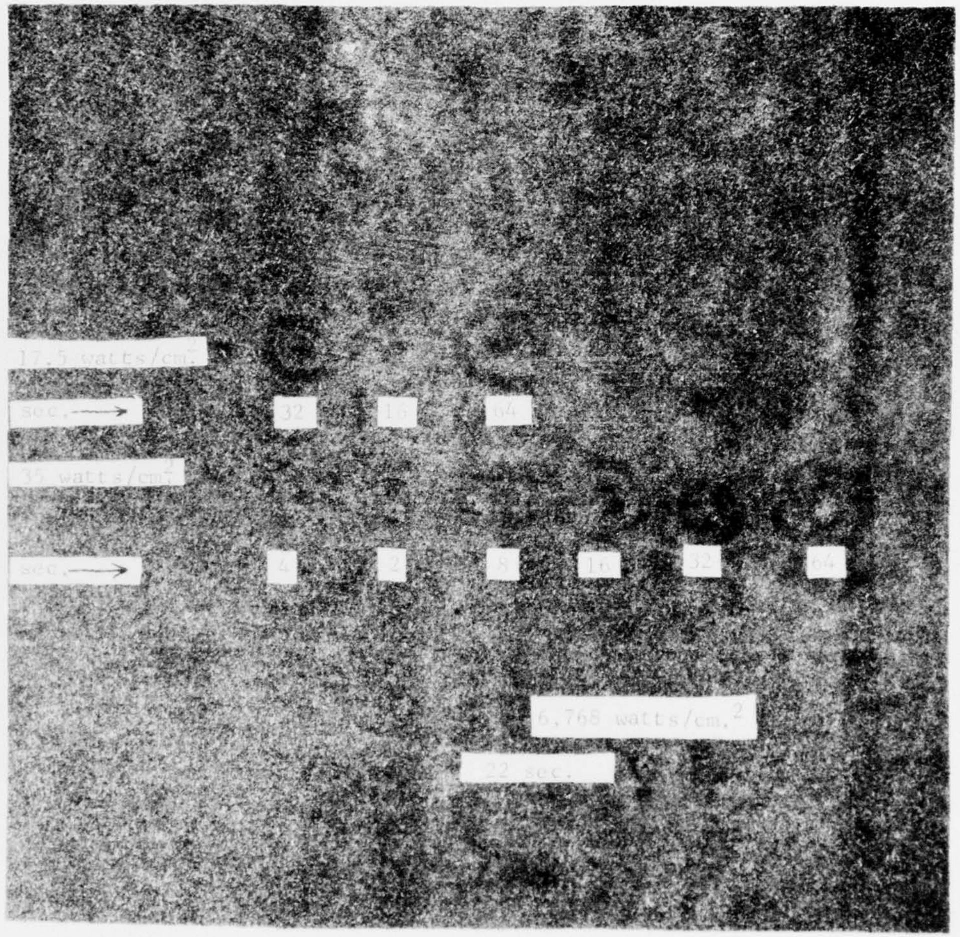
NOTE: High power density exposures at 6,768 watts/cm^2 completely penetrated for dry sample, but not for wet sample.

Figure 2. DH242 After Exposure to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2, and times (sec)



NOTE: High power density exposure at 6,768 watts/cm² resulted in complete penetration in < 1 sec.

Figure 3. 304 Stainless Steel After Exposure to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2), and Times (sec)



NOTE: High power density exposure at 6,768 watts/cm² resulted in 90% penetration.

Figure 4. 430 Stainless Steel After Exposure to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2), and Times (sec)

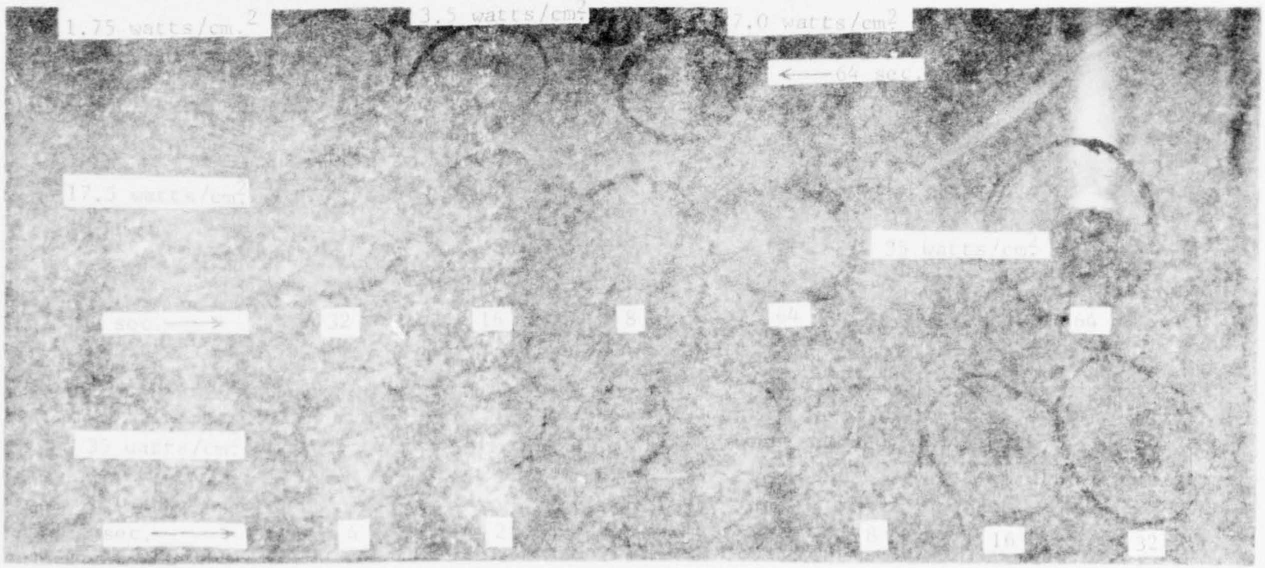
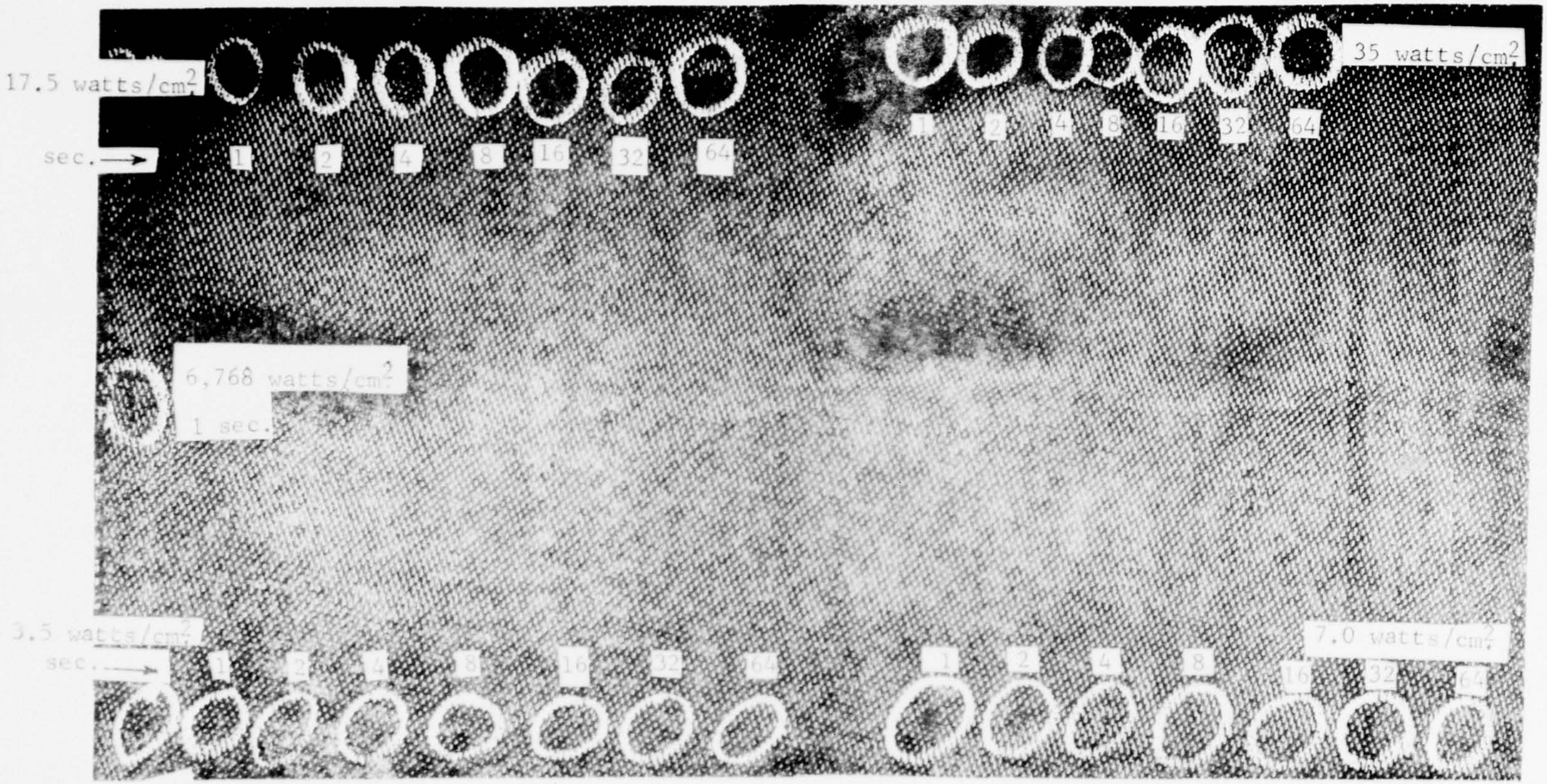


Figure 5. FM515 After Exposures to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2), and Times (sec)



NOTE: High power density exposure at 6,768 watts/cm^2 resulted in complete penetration.

Figure 6. Graphite Cloth After Exposure to CO_2 Laser Radiation at Indicated Power Densities (watts/cm^2) and Times (sec)

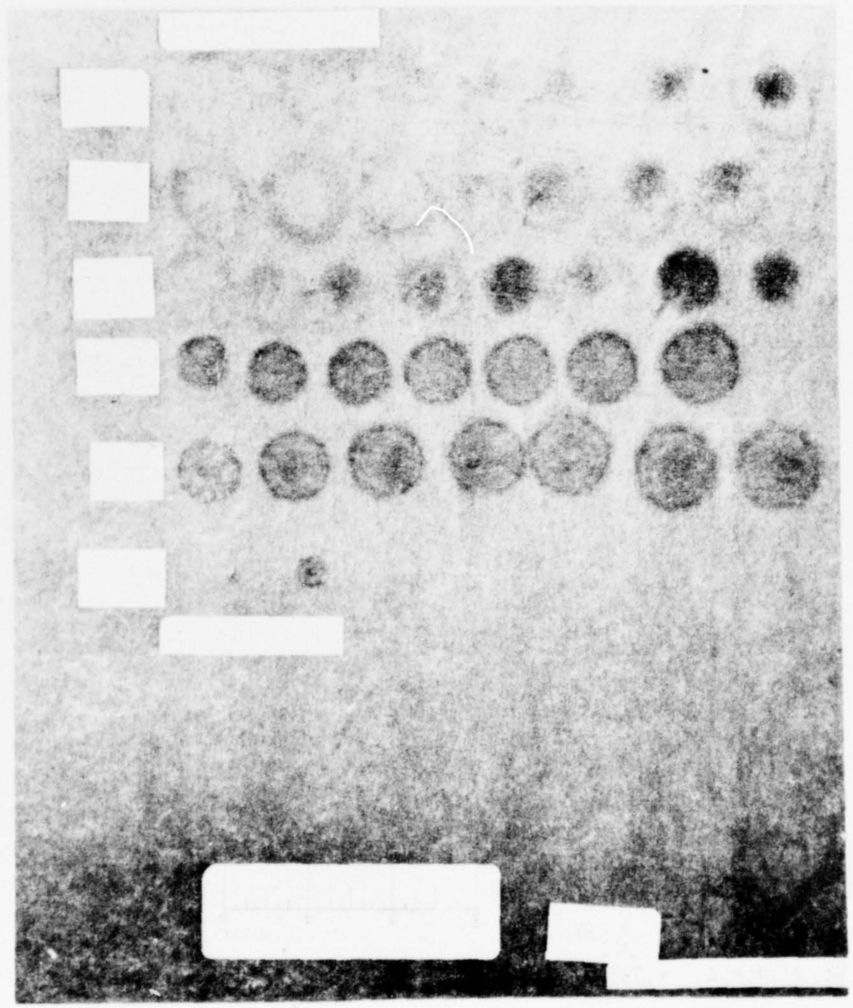


Figure 7. DH242 After Exposures to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2) and Times (sec)

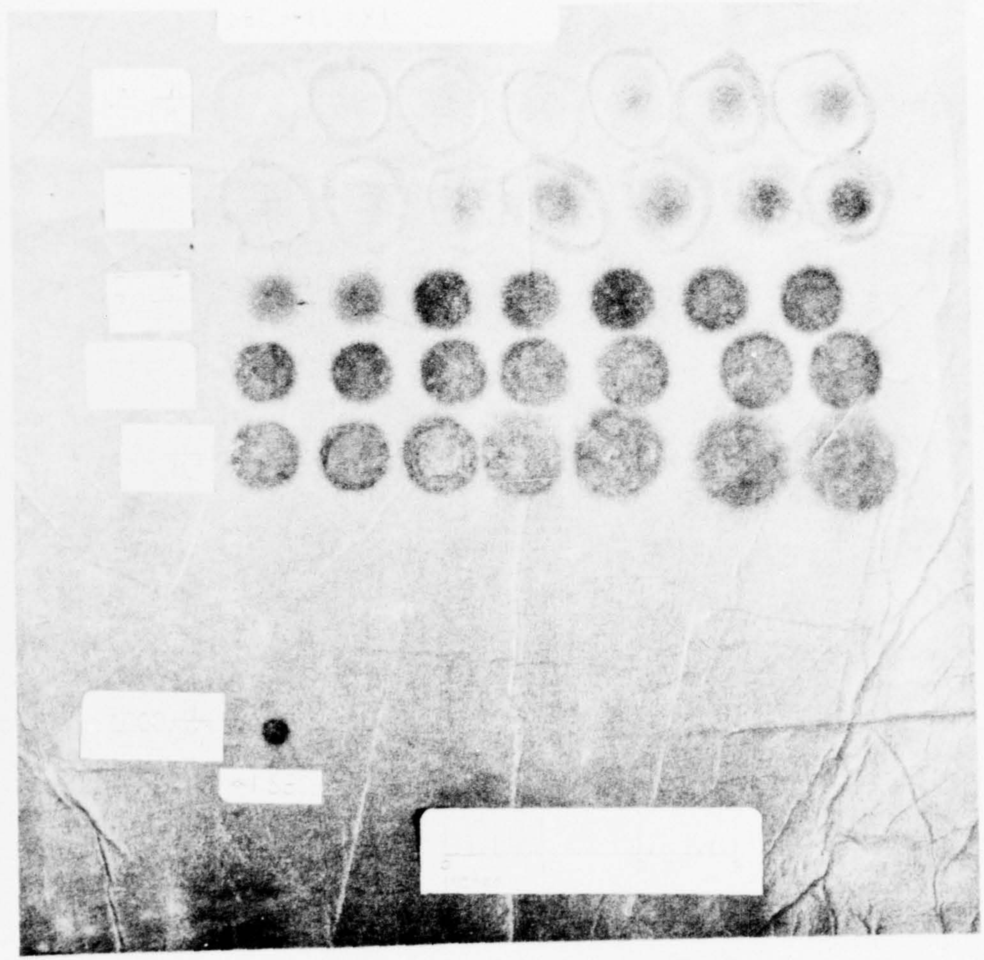


Figure 8. 304 Stainless Steel After Exposures to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2) and Times (sec)

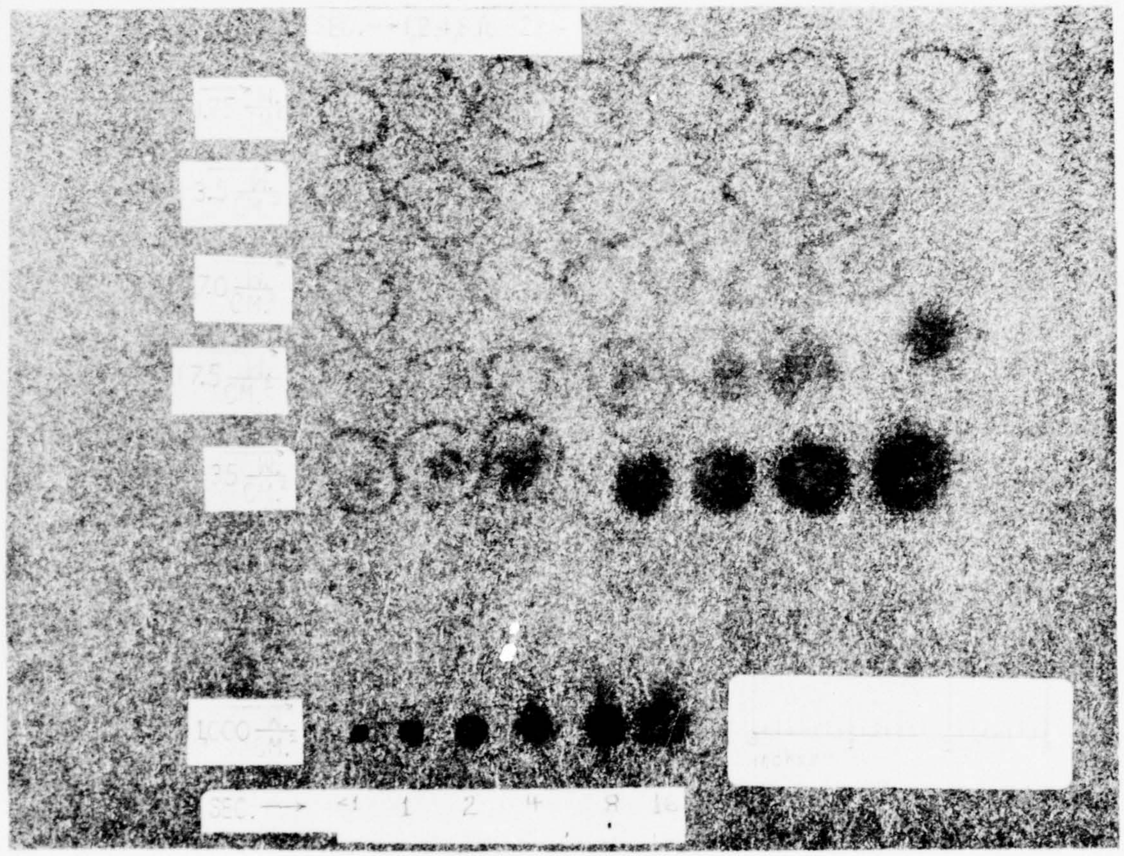


Figure 9. 430 Stainless Steel After Exposures to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2) and Times (sec)

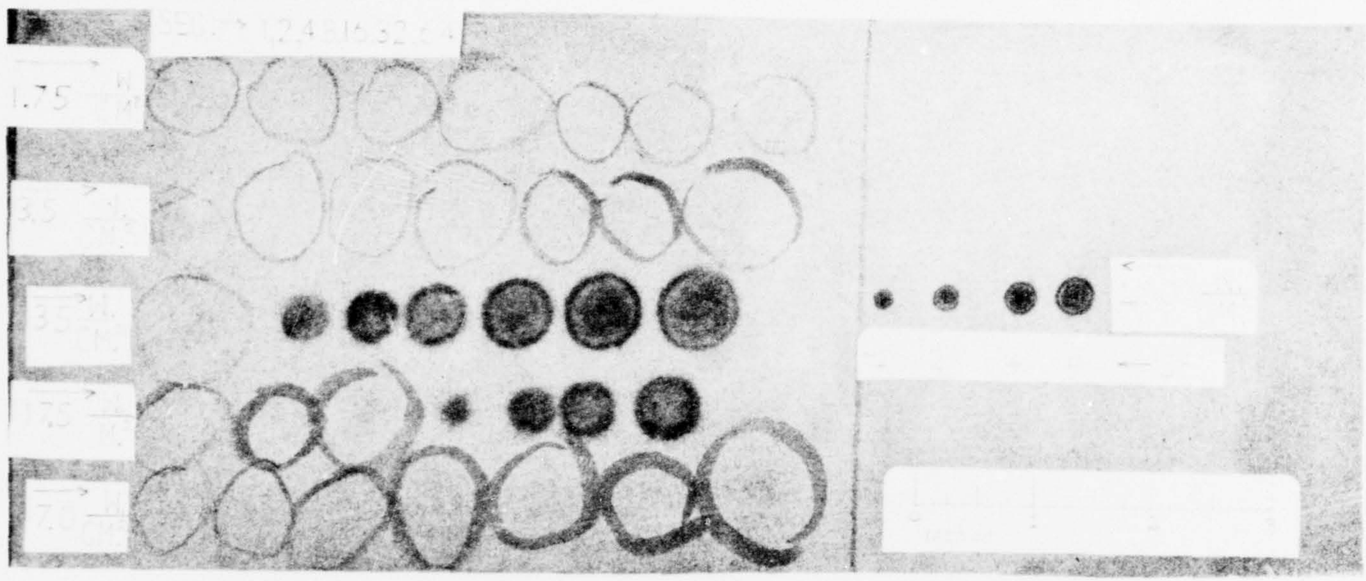


Figure 10. FM515 After Exposures to CO_2 Laser Radiation at Indicated Irradiances (watts/cm^2) and Times (sec)

Table IV. CO_2 Laser Irradiance Damage Threshold of Dark Finished Lightweight Materials

SAMPLE #	TIME (sec)	POWER IRRADIANCE (Watts/cm^2)	DESCRIPTION OF DAMAGE
DH242 (dry)	2	35	Surface
304 $S_\lambda S_\lambda$	1	35	Penetration begins
430SS/ FM1311	64	35	Superficial
FM515	64	35	Discoloration and surface cracks
Graphite Cloth	16	17.5	Surface
DH242 (wet)	80	6,768.00	Superficial

Table V. CO_2 Laser Irradiance Damage Threshold of Bright Finished Lightweight Materials

SAMPLE #	TIME (sec)	POWER IRRADIANCE (Watts/cm^2)	DESCRIPTION OF DAMAGE
DH242 (dry)	8	7.0	Surface
304 $S_\lambda S_\lambda$	2	35.0	Surface
430SS/ FM131	4	17.5	Surface
FM515	4	17.5	Surface
DH242 (wet)	2	1,000.00	Penetration

CONCLUSIONS AND RECOMMENDATIONS

The above results illustrate that these metal-fiber materials offer very little protection against CO_2 laser damage. The only exception is the water impregnated dark DH242 which sustained minimal surface damage at power densities of 6.8 KW/cm^2. This capability renders this sample useful as a probable barrier material to CO_2 laser radiation.

Further investigations of the DH242 (dark, water impregnated) sample are recommended to determine the extent of its usefulness as a CO_2 laser barrier. Studies should be conducted to find out the temperature gradients through and across the sample when the material is irradiated by the laser. Laser damage threshold should be determined. Since the metal fiber of this sample is steel, environmental studies should be conducted to assess corrosion and its effects on the CO_2 laser barrier properties of the material. For this reason, water impregnation may be impractical. A search of other impregnating materials should also be conducted.

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