A Study on the Destruction of Ceramic Filters When Bludgeoned

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Goal:

The purpose of this project is to attempt to obtain photographs of the progression of cracks through ceramic filters and to analyze these photographs to better understand the event. We will discover the force placed upon the filter the instant before it is shattered and find the speed of the bludgeoning tool. We will also compare our findings to the modulus of rupture testing which Selee Corporation performs on its filters.

Theory:

In the analysis of the photographs, we found the force and impulse with which the ramrod struck the filters. This was done using pictures cer30154ed and cer30155ed. In these two photos, we used four flashes of different colors: blue, red, orange, and green. We adjusted the timing so that the first two flashes, blue and red, were set off before the ramrod broke the filter and the last two flashes, orange and green, were set off during the collision. As it turned out, it appears that the orange flash went off just as the rod made contact and the green was set off right as it left the surface of the filter. Using basic d-v-a-t and impulse-momentum theory physics, we were able to roughly calculated the velocities of the rod, the force with which it struck the filter, and the impulse of the collision.

The formulas used and the methods described in the analysis are excerpts from the Cutnell and Johnson as presented in Dr. Kolena's Physics with Topics class at the North Carolina School of Science and Mathematics.

*These equations calculate average velocity over the time period and use net force, not applied force. This will introduce a small amount of error into our calculations, but should not skew the overall results very much. The accuracy should be good enough for our purposes.

Equipment and Techniques: *(See diagram below)*

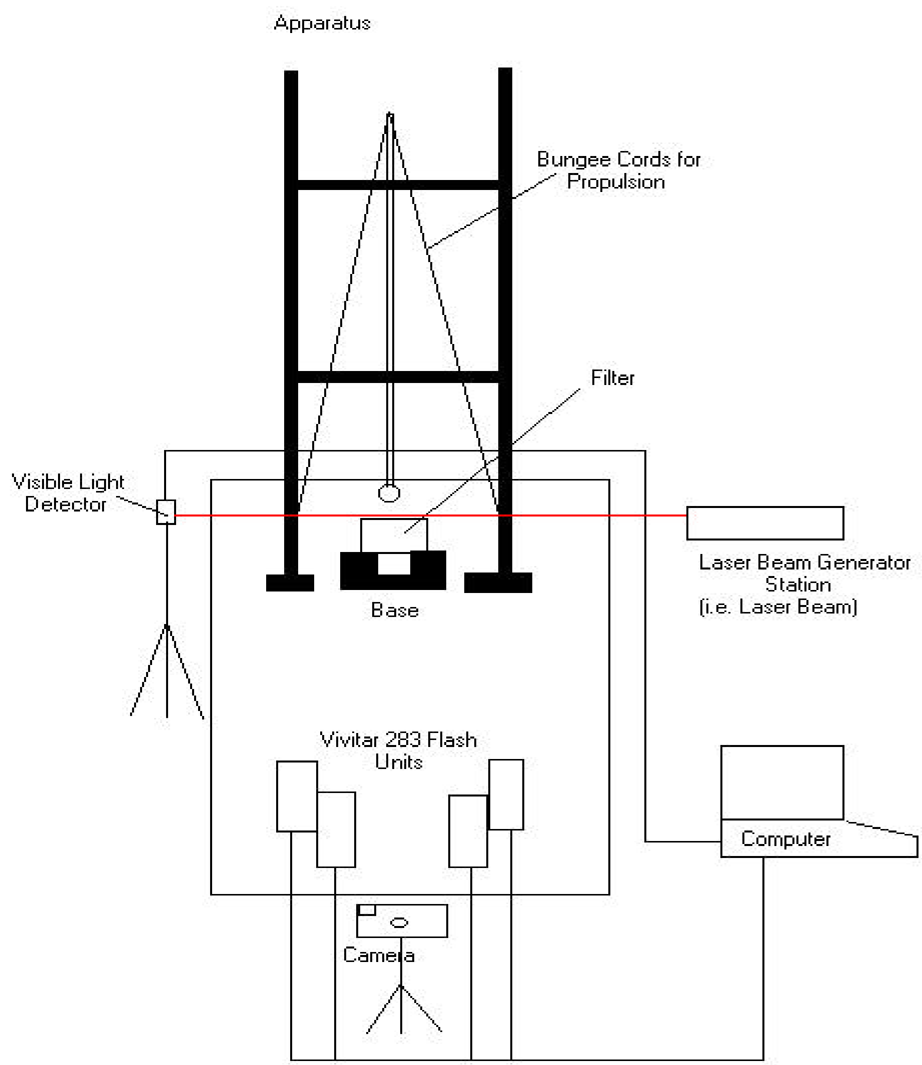
The cracking of ceramic filters is a fine art. These filters (see appendix) are designed to do their job (see appendix) on molten metal, so they are strong. It takes a very specific amount of force to crack each and every one of our test subjects. We discovered that a device that uses a ramrod with a blunt object upon the end would do nicely (see diagram below – section apparatus). The device that is affectionately known as "the Cracker" was built. Essentially it is two 2"x4" boards that are approximately 1.6 meters tall standing vertically with two 2"x4" boards that are 0.3 meters long placed between them horizontally in the middle of the framework 0.25 meters apart. This frame was then nailed to two 2"x4" feet that were 0.25 meters long and used to provide stability for the entire apparatus. A hole was drilled through each of the horizontal 2x4 boards in order to provide a guide for the ramrod. In order to keep the holes on center, a 1x4 board was nailed diagonally to the frame. This also made the entire apparatus rigid and the force behind the ramrod more reproducible. The ramrod is composed of a 3/8 inch threaded rod with a cut off mop handle as the actual contact object. The power behind this rod was a bungee cord wrapped around the base of the frame with a cotton pouch sewn in the middle. In order to increase the tension on the cord, two nails were used to place the cord lower on the frame, thus producing a greater downward force. The arming mechanism was a High-Speed Imaging student by the name of Alex Crouse whose responsibility was to set the ramrod to a height that was standard throughout the experiment. During the experiment, we changed the placement of the bungee cords but not the height from which it dropped to greatly increase the force applied to the filters. The velocity of the ramrod was roughly consistent when the setup was unchanged as demonstrated by the 4% difference in initial velocities of the ramrod analyzed below.

The apparatus was then placed on a countertop, which was its home for the next two weeks. The trigger was a laser-based photogate (Laser Beam Generator) aimed so that the leading edge of the bludgeon would break the beam, sending a signal to the computer to tell to begin its flash sequence. An Apple II+ computer was used to control the flashes during the experiment. Intervalometer 2 was the program used to control the initial delay of the flashes and the intervals between each flash. The 4 Vivitar-283 flash units were placed along an arc 1.0 meter in front of the apparatus. Each of these units had a different color filter to distinguish the progression of the crack along the side of the filter. The flash duration was 1/30,000 s, so that there was no blur in the pictures. Throughout the experiment, we tested the use of a different number of flashes just to see what results we could achieve.

The Nikon 990 digital still camera (diagram – camera) was then placed 1.25 meters away from the crack site on a tripod. From here, the camera was safe and still able to produce quality photos. The focus, shutter speed, ISO setting, f/stop, and zoom were all set manually in order to achieve the images that were needed.

The crash deck was originally two 2”x4” boards with a 1x4 board placed between them. The filters were then placed upon the deck and sacrificed before the bludgeoning tool. The filters did not have enough room to complete their break so a higher crash deck was constructed by hammering another board to each side of the deck. Our assumption was correct so the new deck was instituted throughout the rest of our picture taking. A meter stick was placed next to the boards in order to scale the photograph.

The Portrait of the Cracker



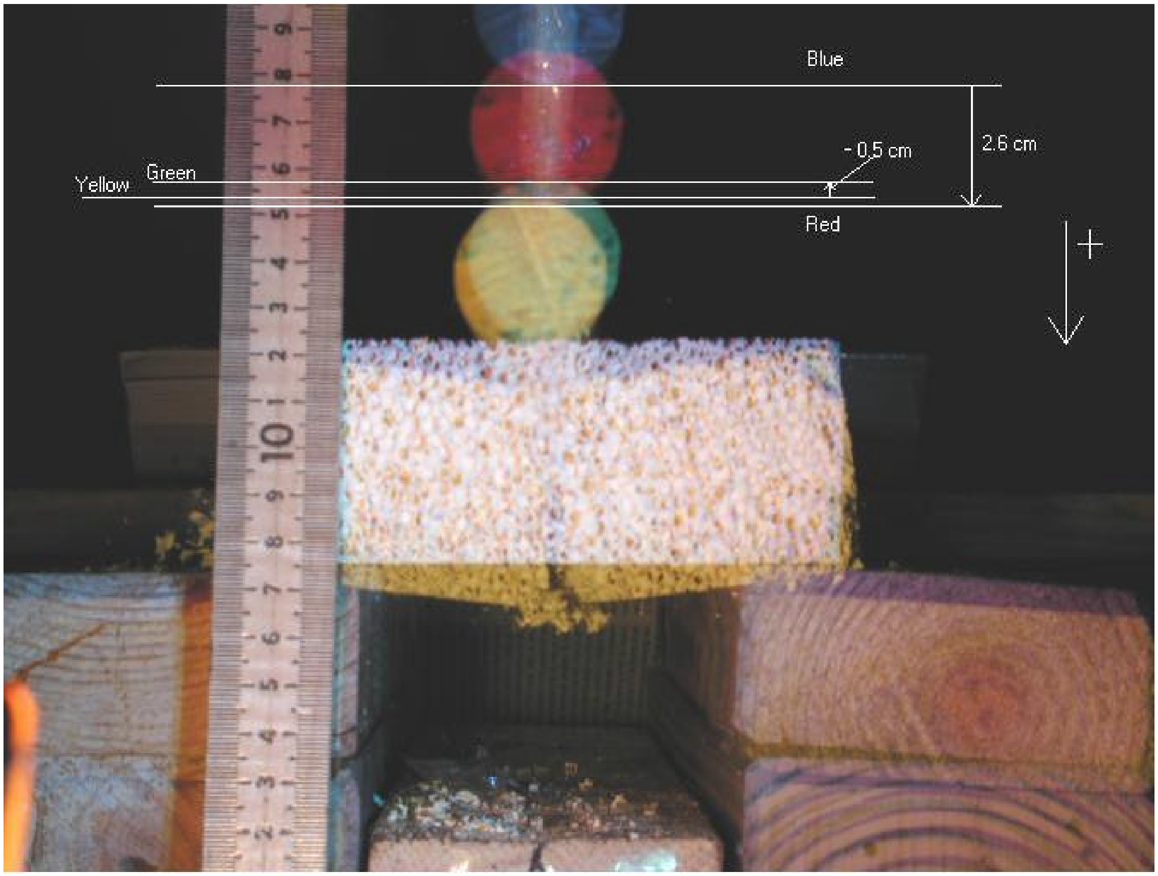
Data and Analysis:

The following settings did not change: ISO setting was 400. Distances from subject: to camera 1.0 m, to flash 0.5m, to trigger 0m. The values that changed between frames are included on the following page.

Frame	f-stop	Image Resolution	Delay Time (ms)	Interval Time (ms)	Filename	Subject Description
1	8.9	XGA Fine	0.02	50	cer10102.jpg	Dud
2	8.9	XGA Fine	0.02	50	cer10103.jpg	Dud
3	8.9	XGA Fine	0.02	50	cer10104.jpg	Dud
4	8.9	XGA Fine	0.2	10	cer10105.jpg	Pic taken, timing off
5	8.9	XGA Fine	0.1	5	cer10106.jpg	Delay testing, wood
6	8.9	XGA Fine	0.15	5	cer10107.jpg	Delay testing, wood
7	8.9	XGA Fine	0.2	5	cer10108.jpg	Delay testing, wood
8	8.9	XGA Fine	0.3	15	cer10109.jpg	Delay testing, wood
9	8.9	XGA Fine	1	15	cer10110.jpg	Delay testing, wood
10	8.9	XGA Fine	5	15	cer10111.jpg	Delay testing, wood
11	8.9	XGA Fine	5	15	cer10112.jpg	Delay testing, wood
12	8.9	XGA Fine	5	15	cer10113.jpg	Final Delay, wood
13	8.9	XGA Fine	5	15	cer10114.jpg	No break
14	8.9	XGA Fine	5	15	cer10115.jpg	very good
15	8.9	XGA Fine	5	12	cer10116.jpg	bad trigger, nothing interesting
16	8.9	XGA Fine	5	12	cer10117.jpg	very good
17	8.9	Hi	5	12	cer10118.jpg	3 flashes, Camera flash went off
18	8.9	Hi	0.02	12	cer10119.jpg	Flash Test
19	8.9	Hi	5	12	cer10120.jpg	3 Flashes, good
20	8.9	XGA Fine	5	1	cer20125.jpg	Setup Changed, delay off 3 flash
21	8.9	XGA Fine	2	12	cer20126.jpg	Good Break, bad delay
22	8.9	XGA Fine	3	7	cer20127.jpg	2 Flash, dud
23	8.9	XGA Fine	3	7	cer20128.jpg	2 Flash, blue green, good
24	8.9	XGA Fine	3	7	cer20129.jpg	2 flashes, orange and green
25	8.9	XGA Fine	3	N/A	cer20130.jpg	1 flash, orange
26	8.9	XGA Fine	3	12	cer20131.jpg	2 filters, 2 flashes, o-g, no break
27	8.9	XGA Fine	3	12	cer20132.jpg	Big filter, 2 flash, gg
28	8.9	XGA Fine	3	35	cer20133.jpg	Speed and Acceleration Testing
29	8.9	XGA Fine	3	15	cer20134.jpg	no flash
30	8.9	XGA Fine	3	10	cer20135.jpg	good - 3 images speed measurement
31	8.9	XGA Fine	2	7	cer20136.jpg	speed, frame-changed setup, 2 images
32	8.9	XGA Fine	2	4	cer20137.jpg	only 2
33	8.9	XGA Fine	2	2	cer20138.jpg	Acceleration
34	8.9	XGA Fine	2	2.5	cer20139.jpg	Speed 3 flashes dim
35	8.9	XGA Fine	2	2.5	cer20140.jpg	dim
36	8.9	XGA Fine	2	3	cer20141.jpg	no good
37	8.9	XGA Fine	3	4	cer20142.jpg	good
38	8.9	XGA Fine	3	7	cer20143.jpg	big filter 3 flashes o-g-b
39	7.9	XGA Fine	3	7	cer20144.jpg	2 flash o-g good but dim
40	7.0	XGA Fine	3	7	cer20145.jpg	big 2 flash o-g
41	7.0	XGA Fine	3	7	cer20146.jpg	2 small no flash
42	7.0	XGA Fine	3	7	cer20147.jpg	2 small w/spacers
43	7.0	XGA Fine	3	7	cer20148.jpg	through vertical, diagonal trigger setup
44	7.0	XGA Fine	3	7	cer20150.jpg	same no flash
45	7.0	XGA Fine	3	7	cer20151.jpg	same
46	6.3	XGA Fine	3	3	cer30152.jpg	b-r-o-g 4 flash, delay test
47	6.3	XGA Fine	3	3	cer30153.jpg	b-r-o-g with big filter good
48	6.3	XGA Fine	3	3	cer30154.jpg	b-r-o-g with big filter good
49	6.3	XGA Fine	1	3	cer30155.jpg	with small filter good
50	6.3	XGA Fine	1	3	cer30156.jpg	all flashes above
51	6.3	Hi	1	3	cer30157.jpg	all flashes above

Results and Analysis:

Cer30154ed



m=0.660 kg

Blue ⇒ Red $\Delta t = 0.00300s$ $\Delta d = 0.0260m$

Orange ⇒ Green $\Delta t = 0.00300s$ $\Delta d = 0.00500m$

initial velocity (blue - red) = d/ Δt
= 0.0260m/0.00300s
= 8.67 m/s

final velocity (orange – green) = d/ Δt
= -0.00500m/0.00300s
= -1.67 m/s

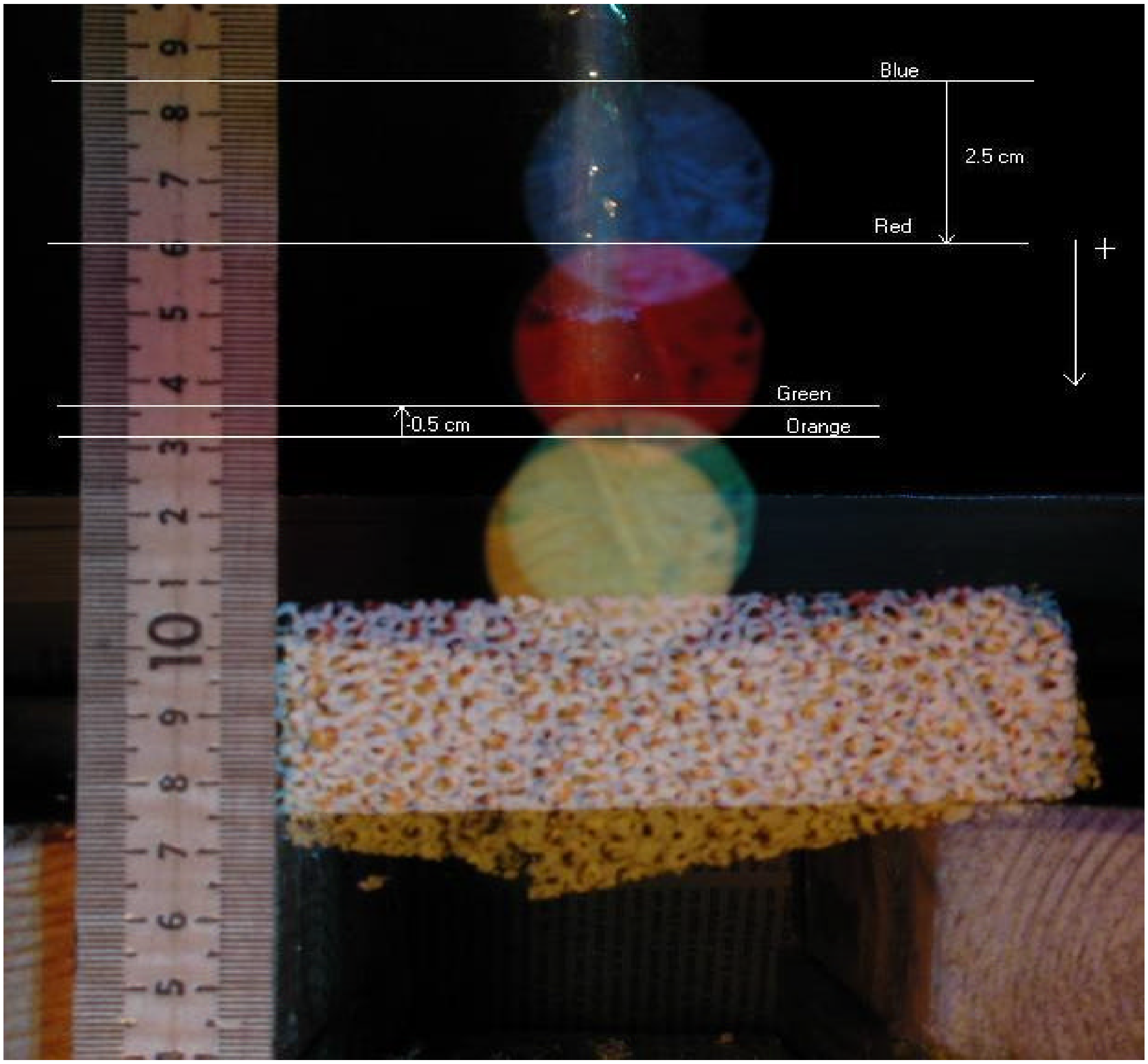
I = F Δt = Δp = final mv – initial mv

F= (final mv – initial mv)/ Δt
F = ((0.660 kg * -1.67 m/s)-(0.660 kg * 8.67 m/s))/0.006s
F = -1200 N

I = F Δt
I = 1200N * 0.003s
I = 3.6 Ns

m=mass Δt=change in time v=velocity I=impulse F=force

Cer30155ed



m=0.660 kg

Blue ⇒ Red $\Delta t = 0.00300s$ $\Delta d = 0.0250m$

Orange ⇒ Green $\Delta t = 0.00300s$ $\Delta d = 0.00500m$

initial velocity (blue - red) = d/ Δt
= 0.0250m/0.00300s
= 8.33 m/s

final velocity (orange – green) = d/ Δt
= -0.00500m/0.00300s
= -1.67 m/s

I = F Δt = Δp = final mv – initial mv

F= (final mv – initial mv)/ Δt
F = ((0.660 kg * -1.67 m/s)-(0.660 kg * 8.33 m/s))/0.006s
F = -1100 N

I = F Δt
I = 1100N * 0.003s
I = 3.3 Ns

To carry out this analysis, we used the formulas described in the theory section of this report.

Using printed photographs, we measured displacement. Change in time we knew from the interval times inputted into the computer. Those measurements were used to calculate initial and final velocities of the rod. The velocities were in turn used to calculate force. The force found was the net force of the filter on the rod, which is negative since we defined positive as down. From Newton's third law, we know that the magnitude of the force of the rod on the filter is equal to that of the force of the filter on the rod, but opposite in direction. The force was used to determine impulse. Also, these formulas refer to net force, not force applied. This takes into account the force of the earth's gravitational field on the filter. For these calculations, we assumed that this force was negligible, at least in comparison to the force we applied. A small error could have been introduced because of this. Another assumption used to simplify analysis was that the velocity that we calculated was the velocity with which the rod struck the filter. Since the rod was accelerating, this was not quite true. The actual velocity would be slightly faster than the velocities that we calculated. This should be safe to assume because the time interval between when our velocities were calculated and when the rod came into contact with the filter is somewhere between .006 and .003 seconds.

We found that the speed of the rod was very consistent, with initial velocities of 8.33 m/s and 8.67 m/s in the two photographs analyzed. This worked out to give us applied forces of 1200 N and 1100 N and impulses of 3.6 Ns and 3.3 Ns. This force can be converted to kilograms and then to pounds to show that the rod applied a force of approximately 247 pounds in cer30154ed and 269 pounds in photograph cer30155ed.

The conversion from newtons to pounds was carried out so that we could more easily compare our data to that collected by Selee Co., the source of the filters. In order to evaluate strength, Selee uses a three-point break method. This is what we modeled our breaking apparatus after. The sample is placed on a base (two support points) and a measured force is applied to the center of the top of the filter (the third point). The magnitude of the force applied is then used to calculate the MOR, or modulus of rupture of the filter. The equation for the modulus of rupture is shown below:

$$MOR = (3/2)\,(FS)/(WT^2)$$

Where: MOR is modulus of rupture in psi
F is the breaking force in pounds
S is the span between two bottom supports in inches
W is the width of the sample in inches
T is the thickness of the sample in inches

(the force applied was applied slowly, gradually increasing until the filter breaks)

For filters like the ones supplied to us, Selee Co. found average MORs of around 300psi to 400psi. However, they found a range of about 100psi to 600psi was not unusual for these silica filters. In order to compare our force calculations with these measurements, we converted our Newton force calculations to pounds and plugged them into the MOR formula. The span was four inches, the width of the filters was five inches, and the thickness of the filters was 1.22 inches for the small and 1.85 inches for the large filters. Our MOR calculations gave us values of 200psi for photograph cer30155ed and 94psi for cer30154ed. Given the range found by Selee Co., our data agrees very well with theirs. However, both are fairly low compared to even the middle of the range of given MORs. This could possibly be partly due to the many assumptions that we made in our calculations. These errors were discussed in this section.

Discussion

Through the analysis, we learned the force that we applied to break the filters. With the aid of picture editing software, mainly Paint Shop Pro 5 and Photoshop 5, we were able to observe cracks traveling through the filters. This is shown clearly when pictures with multiple flashes are split into several photos, each showing a different color. When separated into black, yellow, magenta, and cyan, we obtained the best photographs. These are shown at the end of the report within the appendix. An example of this is included using photograph cer20143. The original photograph and the split color photographs are included for comparison.

The photographs described above, along with several others show the path taken by the cracks in the filters. In a discussion with the instructor, the question of where the crack originates was posed. We believe that the cracks begin at the bottom of the filter, directly across from where the ramrod struck. It is unlikely that a small crack goes through from top to bottom first because of the state of the broken filters. When the halves of the filters are placed back together, it is easy to tell where the ramrod struck. With this side facing up, it is possible to hold the filter horizontally by one half without the other falling off. If the sample is turned over, this test does not work. So, the crack must originate at the bottom.

Conclusions:

During the course of this project, we discovered that the impact with the bludgeon on the ceramic filters caused the break to start from the bottom with a slight indentation where initial contact took place. The apparatus also hits harder than we thought considering it split the 1x4 board down its length after going through a filter.

We found that it is possible to observe the progression of cracks in porous ceramic material, as we had hoped. In this way, we have met our goals. We found the force that we used to break the filters (approximately 1200 N) and that the cracks originate in the bottom of the filter.

In the analysis of our photographs, we calculated the force applied to the filters and calculated the associated modulus of rupture. These results were compared to those in standard tests done by the supply company and found to be reasonable. This showed us that both our apparatus and our calculations were fitting to this situation.

References:

1- Kenneth Butcher, Selee Corporation Vice-president of Research and Development – Provider of the sacrificial objects

2- Cutnell and Johnson Physics Textbook as presented by Dr. Kolena's Physics with Topics class at the North Carolina School of Science and Math.

3- High-Speed Photography with Computer Control Authored by Dr. Loren M. Winters, 1991

Appendix

Filters: Production and Use

The ceramic filters produced by Selee Corporation are used to filter molten metal. The large filters that we used are designed to filter aluminum while the smaller filters are used for copper. The porous ceramic material removes impurities in the metal as it flows through the filter. This process is done on most metal used in the world. Filters are designed for all kinds of applications, ranging from the preparation of steel for cars to the filtering of aluminum alloys for precision aircraft engine parts.

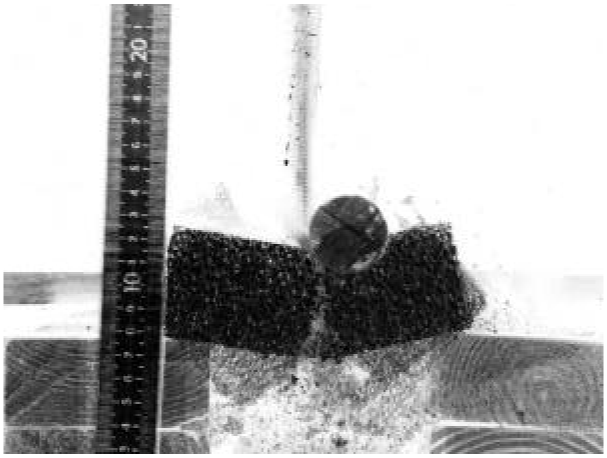
The basic production procedure for the filters is fairly simple. Polyurethane foam of the desired density, shape, and size is coated in a ceramic slurry made by the company. The foam is then rolled to remove excess slurry, dried by various methods, and fired in a kiln. Different densities, shapes, sizes, slurries, and firing methods are used to make filters with different qualities.

For more information, see the Selee Corporation web site at www.selee.com.

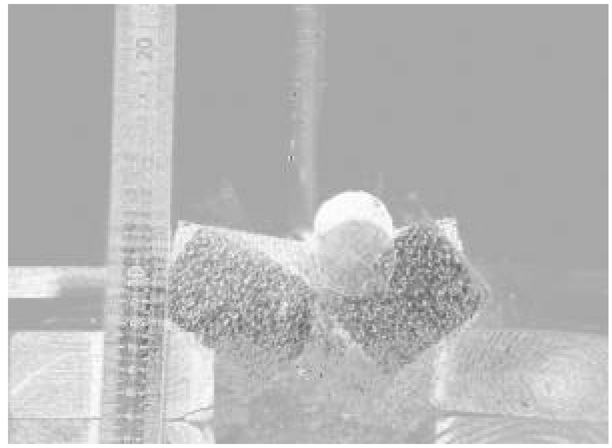
CER20143

A Single Photo Separated into black, yellow, cyan, and magenta

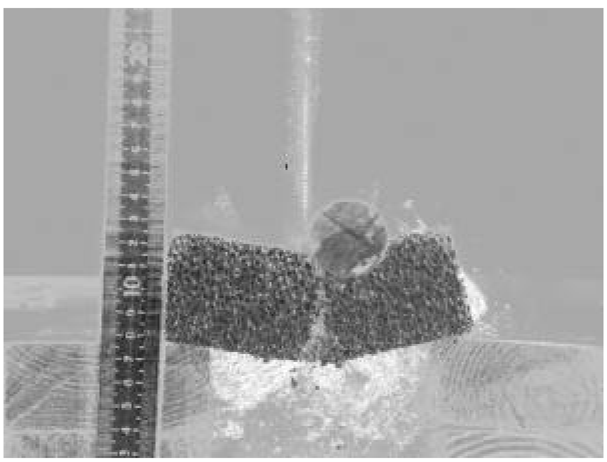
1



2



3



4