Abstract – Exploding wires have been studied extensively in the past for the purposes of acting as high voltage opening switches, X-ray generators, and over-voltage protection of electrical equipment. HEM Technologies and Texas Tech University have begun to study such exploding wires and foils as shockwave generators in liquids for industrial applications. Specific industrial applications being studied are for e-waste recycling and as a replacement for oil well hydraulic fracturing.

Recycling of consumer electronics such as laptops, cell phones, remote controls, etc. continues to be a global issue. Current recycling methods employ wasteful techniques such as incineration and typically only recover the precious metals used within the waste products. HEM Technologies conducted a feasibility study of using high current pulsed power to generate a shockwave to break apart e-waste into separable components. The materials were immersed in liquid nitrogen and subjected to shockwaves generated by a fusing wire array. The shockwave impact results on different electronic devices were then analyzed for comparison.

In the petroleum industry, hydraulic fracturing has also become a global issue as the technique is costly and risks contaminating adjacent water sources. HEM Technologies and Texas Tech University have begun to study shockwaves generated by exploding wires and foils to generate microfractures in rock substrate as a substitute for hydraulic fracturing. The system uses the same basic pulsed power setup as used for the e-waste studies. The initial development results are presented.

1. Introduction

Recycling of e-waste has become a significant problem today. Outdated electronics have numerous heavy and rare metals that could be recovered if a suitable means of recovery could be developed. Current recycling methods involve scrapping of the electronics by crushing, shredding, and incineration. This method will only allow recovery of the precious and heavy metals while the plastics and other waste products are burned. The incineration method also requires cleaning of the fumes generated.

Cryogenic processing of waste has become a common practice in recycling tires into crumb rubber. The low temperatures allow the rubber to become brittle and processed in a hammer mill [1]. Due to the multilayer structures of e-waste, it is believed that cryogenic processing may be used for processing also.

Previous attempts at using pulsed power to separate e-waste have employed exploding wires with surface flashover in water [2] or direct arc discharges into the e-waste immersed in LN_2. Although successful, it was found to not be cost effective. Extremely high voltages with fast risetimes were required in order to have the discharge conduct through the e-waste material rather than in the LN_2. Additionally, secondary uncontrollable byproducts were produced from the organic materials on the e-waste [3]. Research at HEM Technologies has focused on an alternative method of generating shockwaves in liquid nitrogen to separate the e-waste.

HEM Technologies and Texas Tech University have also considered using the same technique of generating shockwaves in liquids as an alternative technology to hydraulic fracturing. Hydraulic fracturing is a commonly used method in the petroleum industry of creating fractures in oil deposit bedrock with high pressure water in order to bleed out the oil and gas more efficiently [4]. However, this technique requires millions of liters of water which needs to be cleaned after mixing with oil and can cause seepage of contaminated water and oil into underground water reservoirs. The cost of the process and clean-up makes an alternative such as the proposed technology feasible. The generation of shockwaves for fracturing rock is already well known and commonly called plasma blasting, but the shockwave generation is commonly made by an arc discharge rather than using an exploding wire [5–7].

2. Experimental setup

For the generation of shockwaves to separate e-waste, HEM Technologies constructed a capacitive power supply consisting of a 7.2 uF high energy capacitor bank charged to 20 kV and discharged through a pressurized spark gap. Fig. 1 shows the experimental setup for e-waste separation.

The shockwave generator consisted of a twelve strand (36 awg) tinned cooper wire load attached to the center conductor of a liquid nitrogen chamber. The center conductor passes through an aluminum lid which covers the liquid nitrogen chamber. Six threaded stainless steel rods and an aluminum plate complete the electric circuit to the outer conductor. Fig. 2 shows the shockwave generator setup in detail.
The sample to be shocked was mounted to the threaded steel rods approximately 2.5 to 5 cm from the center wire array. The test chamber consisted of a 25 cm diameter stainless steel container inserted in a Styrofoam and spray insulation box. The container was filled with liquid nitrogen prior to testing.

Fig. 1. E-waste separation setup

For the rock fracturing test, HEM Technologies constructed a 20 kV, 2 kJ capacitive power supply to power an exploding foil system for the Texas Tech Dept of Petroleum Engineering. The power supply consists of a 10 μF capacitor, a 20 kV power supply to charge the capacitor, and a pressurized spark gap to fire the system. The system is fired by releasing the air pressure in the spark gap and allowing the spark gap to self-break. The high voltage pulse is then transmitted to the load through a 2.0 m length of RG-218 50 Ω, coax cable. Diagnostics include a Tektronix P6015A high voltage probe and a Pearson 101 current monitor integrated into the capacitor and spark gap firing module of the system. The data is recorded on a GW Instek 60 MHz oscilloscope. Fig. 3 shows the experimental setup for testing.

Fig. 3. Experimental setup for exploding foil tests to fracture rock

The exploding foil loads consisted of short strips of 200 μm aluminum foil of various lengths inserted into cast blocks of cement. The cement was cast around a 2.5 cm diameter pvc pipe. The pvc pipe had two lengthwise slits in the center coinciding with the location of the exploding foil. The slits were approximately 0.4 × 7.5 cm in size and located across from each other in the pipe. The coax load was inserted into the pipe from the top and sealed with plumbers putty around the top end. The foil was inserted in the pvc pipe with ≈ 100 ml of water to transport the shockwaves. Fig. 4 shows the load test setup. Provided that the pvc pipe remained intact, multiple test shots could be conducted on one cast sample allowing monitoring of growth of surface fractures from shot to shot.

Fig. 4. Experimental setup for fracturing rock with explosively generated shockwaves in liquids

3. Experimental results

Figures 5, a and b show the voltage and current waveforms for the power supply to the load. Fig. 5, a is for a short circuited load from an arc discharge and Fig. 5, b is for an exploding foil matched to absorb most of the energy from the power supply. The current and voltage waveforms in the figures are not in phase due to their relative locations in the circuit. As can be seen, Fig. 5, a shows a simple oscillating waveform with a resistive decay. Fig. 5, b, however, decays quickly to zero as the energy is absorbed by the foil load prior to fusing.
A qualitative study of separating e-waste with an exploding wire shockwave generator was conducted on a variety of samples to include cell phones, remote controls, and electronic boards. The samples were only exposed to one test shot each. Fig. 6 shows the results for some of the e-waste tested and the energy stored in the power supply for each respective shot.

As can be clearly seen, a single exposure resulted in significant destruction of the e-waste. In all cases, the electronic boards have been separated from the casing. The LCD screen on the cellphone has been separated also. The only significant damage found on the circuit board components, however, was some separation and de-laminating on capacitors.

Similarly, the blasting of the cement blocks resulted in significant fracturing of the blocks. Fig. 7 shows photos of fracturing occurring from shockwaves. The samples shown were exposed to different exposure times or conditions. Fig. 5, b was exposed to the largest single shockwave from a 12.5 cm length of foil creating 12 separate surface fractures.

Figure 5, c shows both a surface view and side view for the fractures caused by a single explosion. Note that the fractures along the side of the block in Fig. 5, c are wet indicating that the shockwave has driven the water into the fractures.

4. Summary and conclusions

HEM Technologies and Texas Tech University have conducted studies for industrial application of shockwaves in liquids. Studies were conducted for recycling of e-waste and for generating fractures in rock. The pulsed power system used fusing wires and foils in liquids and was found to be a reliable means of generating strong shockwaves.

The shockwave generator was successful in separating most of the e-waste tested. However, circuit boards showed little effect from the shockwaves. They may require much stronger shockwaves before showing any effects such as de-lamination or separation of board components. Focusing of the shockwave and higher energies may achieve these results.

The shockwave generator was also successful in generating fractures in concrete block samples. Also, water from the shockwave was forced into the fractures which could aid in creating additional fractures from multiple shot applications. Matching of the energy supplied to the foil was also achieved thus maximizing the available electrical energy for generating shockwaves. Further testing is required in larger concrete blocks and bedrock samples to determine the
length of fracturing and simulate down-hole conditions.

References


