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Liberation of Materials by Electrical Disintegration for Recycling

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Liberation is very important to separate different materials from the wasted composites for recycling the components. It is necessary to develop the new crushing method to tear off the composites along the boundary of different materials. As the waste materials include many kinds of inorganic and organic components, it is difficult to liberate them by conventional crushing and grinding methods. In this study, the exfoliations along the boundary of materials, such as, concrete, silicon with silica, nail in wood and liquid crystal display have been investigated by electrical crushing (disintegration) method.

Key Words : Liberation, Electrical disintegration, Recycling, Exfoliation

1. Introduction

Liberation is very important for recycling the waste materials. This paper presents an electrical crushing (disintegration) method for this purpose. Conventional crushing and grinding machines break up the materials at random fragmentation for minerals in rocks, ceramics and wasted electric tools, and so on and consume a large amount of energy. Instead of conventional comminution methods, the electrical disintegration (ED) using a lightning discharge impulse has been investigated in this study. The principle is to apply a plasma current to flowing along the grain boundary between the different materials and the expansion of the heated boundary causes the breakage of composite materials. This fragmentation occurs mainly by the breakage of the tensile strength. Andres[1] has reviewed the electrical disintegration of rock, which is commercially used to obtain the diamond and emerald from the host rock. The relationship between the electrical breakdown voltage and the time required to increase the voltage was reported in FRANKA-Process of Germany[2]. On the other hand, some electrohydraulic disintegration (EHD) method, in which the electrode is not directly touched on the specimen but use a shockwave in water has been reported. As EHD method uses mainly the breakage of compressive strength, much more energy will be required as comparing with the breakage of the tensile strength.

On the other hand, several other liberation methods using electric and magnetic fields have been reported[3]. The high frequency heating of the wet granodiorite caused the reduction of tensile strength and the boundaries of mineral grains were observed on the breakage surface. The microwave heating was applied to crushing the taconite in Minnesota. The heated magnetite in the taconite was expanded and liberated from the unheated quartz. All these liberation method is related to the difference of magnetic and electric characteristics of each components constituting the materials.

The comparison between the mechanical crushing and the electrical crushing is shown in Fig.1. In the mechanical crushing, one crushed product may include different kinds of materials, while, in the electrical crushing the different materials are crushed along the boundary of materials, therefore, the well liberated crushed products are obtained.

2. Samples

Following four samples are used for the electrical crushing in this study.

1. Synthesized Concrete

A synthesized disc shape concrete sample was mixed up with mortal and 6 to 10mm glass beads. The thickness of the concrete sample is 22mm and its diameter is 40mm.

2. Silicon crystal stuck on the silica crucible

Silicone crystal was prepared in a silica crucible. After recovering silicon crystal, there is some silicon stuck on the crucible. For the recycling silicon and silica, the silicon should be separated from the silica crucible. The sample of crystal silicon (about 50mm x 50mm x 40mm) stuck on the silica crucible (thickness is

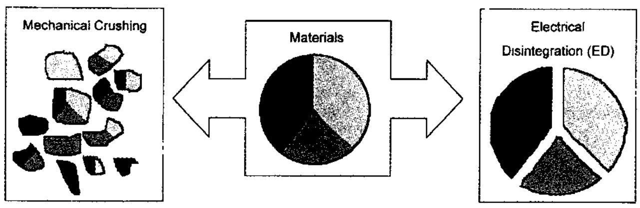


Figure 1 The comparison with mechanical crushing and electrical crushing.

about 15mm) is employed in this study.

3. Wood with iron (nail)

A Japanese hemlock and a Ezo-pine timber are often used to build the house. It is important to separate woods and nails from the building waste. The sample size of the hemlock and the Ezo-pine timber is 30mm x 30mm, and the length is ranged from 40mm to 80mm. The steel nails (diameter 1.7mm, length 12.5mm) have been hidden inside these woods.

4. Display plate sandwiching liquid crystal

Many liquid crystal displays for personal computer are used. In this study, the liquid crystal displays of the personal note-type computer is removed from the computer display. The display sandwiching liquid crystal by two glass and plastics coating with indium tin oxide are crushed and separated into two glasses or plastic (film) parts.

3. Experimental Apparatus

The impulse high voltage supply apparatus was constructed by Pulse Electronic Engineering Co, Ltd., Japan.

The duration of wave front can be regulated to 0.2, 0.5 and 1.2 μs. The maximum applied voltage and charge energy is about 70kV and 800 J, respectively. The schematic diagram of the experimental set-up of the electrical crushing is shown in Fig. 2. The sample blocks are immersed in the distilled water and are sandwiched between a rod-like iron electrode and a grounded copper plate. It was reported[4] that the electrode shape is very important for crushing. In this study, the wedge type electrode of 5mm diameter is used for the higher energy supply. The electrode is set in contact with the center of the cylindrical core surface or in a few mm above the center. As shown in the figure, a coil type ammeter was placed around the ground code electrode and connected to the oscilloscope. The voltage between the impulse voltage generator and ground electrode was measured by a probe connected to the oscilloscope. The charging energy E_1 of the high voltage generator is expressed in equation (1) :

$$E_1 = 0.5CV^2 \qquad (1)$$

where C is the electrostatic capacity of generator ($0.25\mu F$ in this study) and V is the voltage.

When the sample is broken by the impulse, the consumed energy

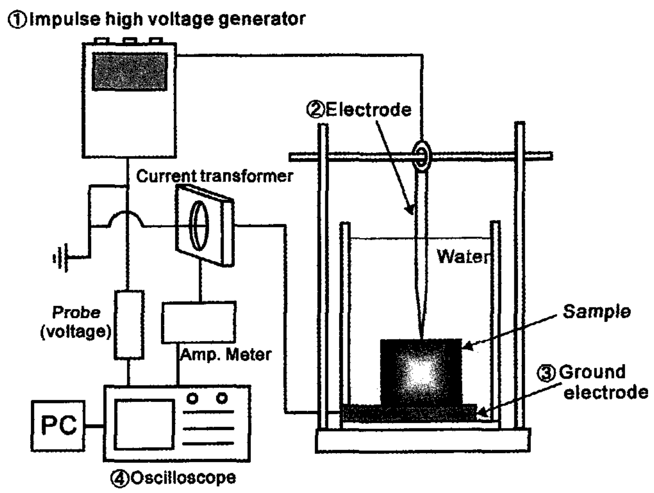


Figure 2 Experimental setup for electrical crushing.

E_2 is calculated from the equation (2) by using products of the sum of the voltage V per period Δt and the sum of current I per voltage applied period Δt measured by the oscilloscope.

$$E_2 = \Sigma VI\Delta t \qquad (2)$$

The relationship between the dielectric breakdown field strength and the duration of the wave front to increase the voltage is shown in Fig. 3[2]. When air is surrounding the sample, the electrical breakdown always results in the air. However, when the rock is in the water, the breakdown does not appear in the surrounding water

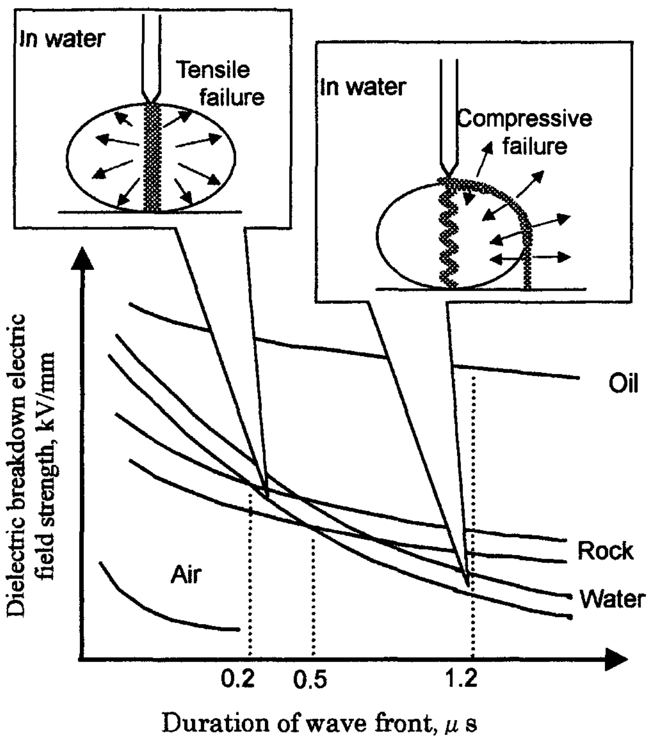


Figure 3 The relationship between dielectric breakdown strength and duration of wave front.

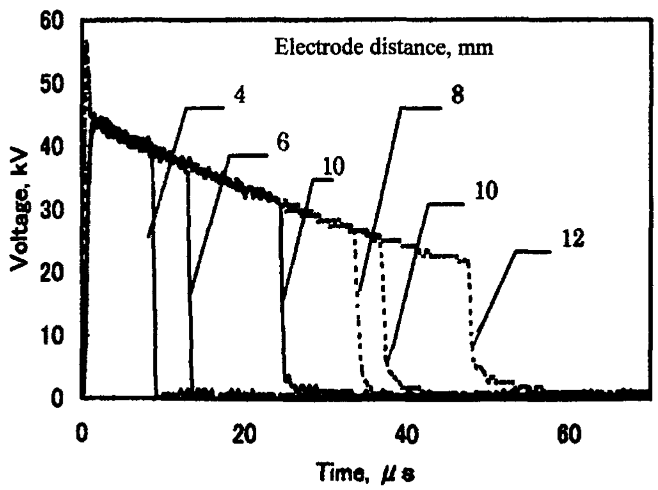


Figure 4 Voltage patterns of dielectric breakdown to several distances of electrode in water.

but does occur inside the rock when the duration of the wave front is less than a specific value. If the higher resistivitiy oil is used around the sample, the electrical break down always occurs inside the rock and mortar even if a large period wave front is used.

4. Results and Discussions

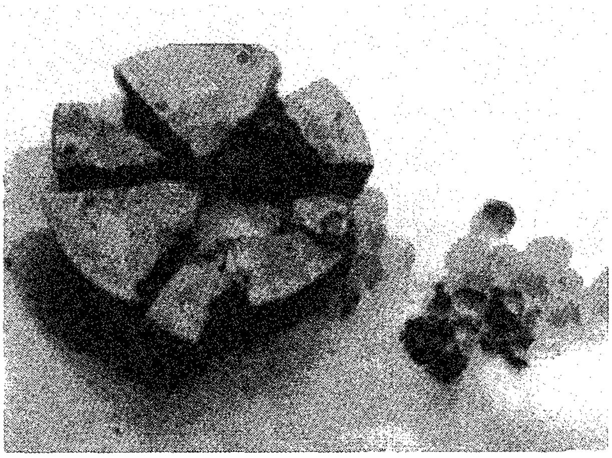
4-1. No samples between electrodes

Figure 4 shows the comparison between the voltage patterns of the dielectric breakdown between various distances of electrodes in water and the duration of wave front. No solid material is set between the electrodes. The same maximum voltage 45kV is applied in all distances between electrodes. Comparing the duration of wave fronts between 1.2μs and 0.2μs, the period to reach the dielectric breakdown is longer in 0.2μs than in 1.2μs at the same electrode distance. For the longer period to reach the dielectric breakdown, a high voltage can be applied between electrodes in the shorter duration of wave front. The integration of the applied voltage multiplies the electric current means the higher energy application between the electrodes in the shorter duration of wave front. The slope of decreasing voltage before dielectric breakdown is almost the same in any distances between electrodes and both duration of wave fronts. Increasing the distance between electrodes, the longer period of high voltage is necessary to reach the dielectric breakdown.

4-2. Samples between electrodes

4-2-1. Synthesized Concrete

The fragmentations of the concrete sample containing 6mm glass beads by electrical crushing are shown in (a), (b) Fig. 5. The applied maximum voltages are 25kV and 30kV, respectively. The use of higher voltage caused more liberation of the glass beads. The most of glass beads are completely liberated from mortal in same shape and not broken by electrical crushing. The maximum electric current was about 400A. The impulse disintegration of concrete caused the fragmentation by the tensile strength is shown in the crushed sample of Fig. 5. The resulting consumed energy was much lower than that required for mechanical compressive breakage[3]. Regarding the practical application for the concrete crushing, the applied energy was approximately 230J during the electrical disintegration, while it was decreased up to one-thirty of its value (7kJ) during the mechanical crushing. The concrete was mainly broken by exceeding the tensile strength due to the thermal



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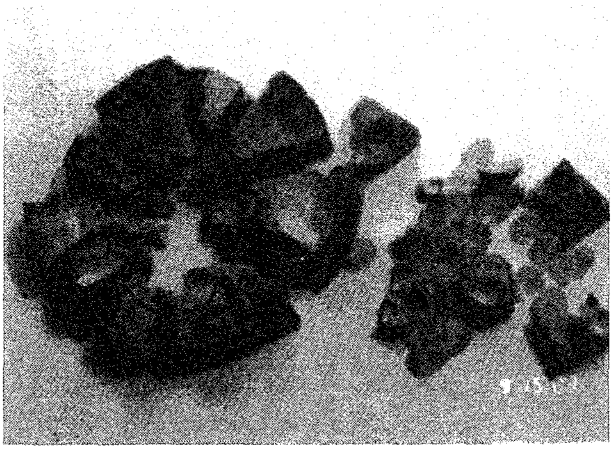

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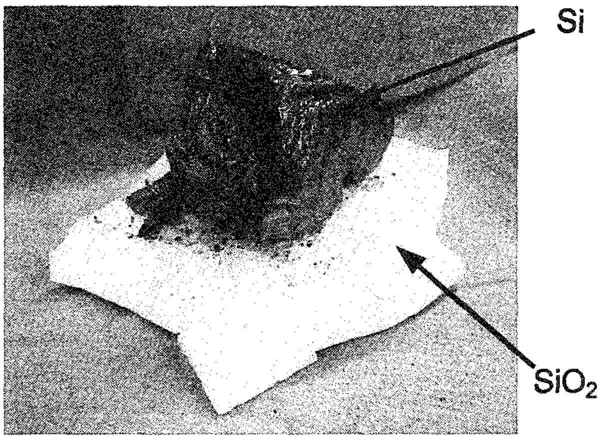
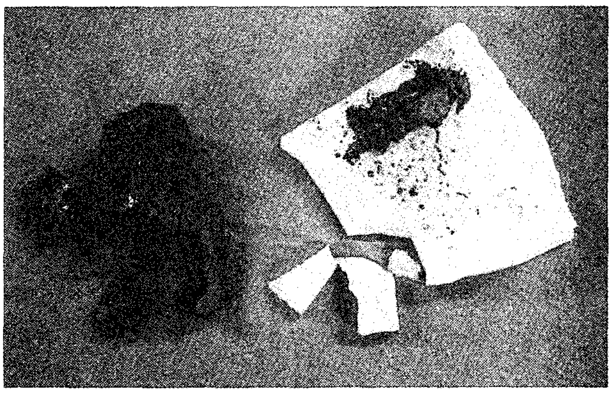
Figure 5 Fragmentation of concrete samples by electrical crushing. (Duration of wave front 1.2μs) Applied voltage (a) 25kV Photo-55, (b) 30kV Photo-56



(a) Before crushing : lump of single crystal silicon and silica



(b) After crushing

Figure 6 Photographs of (a) before crushing (lump of single crystal silicon and silica) and (b) after crushing by electrical high voltage impulse.
(Total impulse voltage is 40kV in the duration of wave front of 0.2μs.)

expansion caused by the large current flow of plasma. The well liberated gravel particles by electrical disintegration has been achieved.

4-2-2. Silicon crystal stuck on the silica crucible

In order to recycle crystal silicon and silica, Figure 6 (a) shows a lump of silicon stuck on silica crucible, which is crushed by using the electrical disintegration. The size of crystal silicon is about 50mm x 50mm x 40mm, and the thickness of silica plate is about 15mm. In this study, the applied voltage of the electrical impulse is two times of 70kV in the duration of wave front of 0.2 μs. Figure 6 (a) shows the result of after electrical disintegration. This result clearly demonstrates that the electrical fragmentation of the different materials is crushed along their boundaries. The pure individual components with a high degree of liberation can be obtained by ED method.

4-2-3. Wood with iron nail

In Japan, the Japanese hemlock and the Ezo-pine timber with hidden nails are often used to build the private house. It is important to separate nail from woods in order to recycle each of materials. The size of the hemlock and Ezo-pine timber is 30mm x 30mm and the length is ranged from 40mm to 80mm. The steel nails of 1.7mm diameter and 12.5mm length have been hidden inside these woods. The schematic illustration of experimental setup of timber-nail sample and electrode of apparatus is shown in Fig. 7. In this condition, the electrode points parallel to the nail on

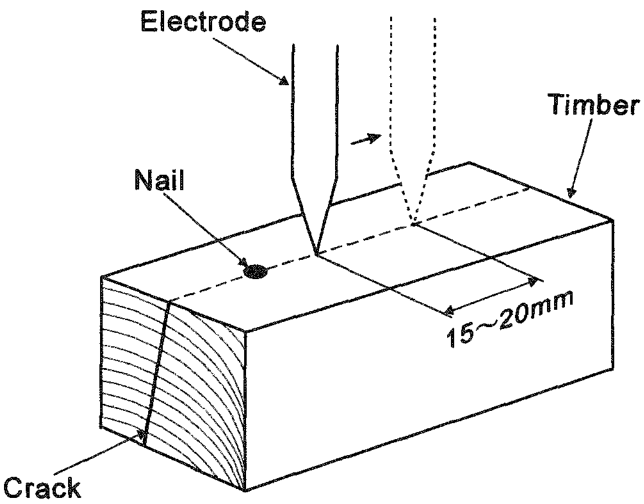


Figure 7 Experimental situation of timber-nail and electrode of apparatus.

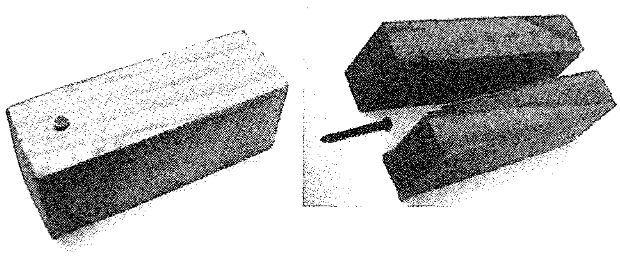


Figure 8 Photograph of sample woods (80mm timber and nail), and after electrical crushing. (135.62kV in the duration of wave front of 0.2 μs)

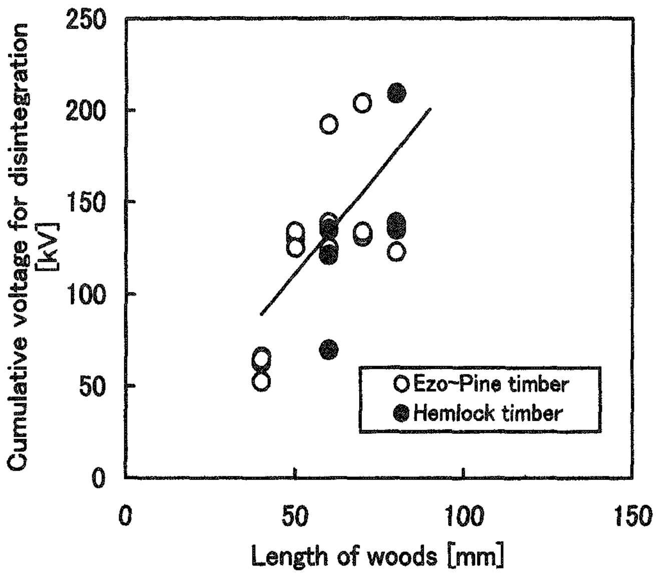
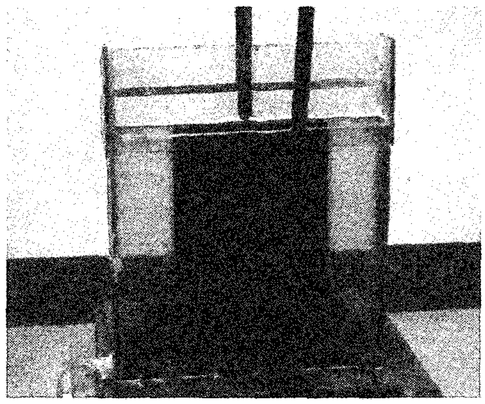
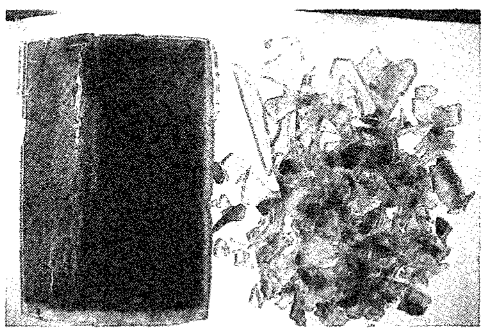


Figure 9 Relationship between cumulative voltage for disintegration and of woods.



(a) experimental setup for electrical disintegration of display



(b) after electrical crushing

Figure 10 Photographs of (a) experimental setup for electrical disintegration of display and (b) the after electrical crushing. (53.76kV in the duration of wave front of 0.2 μs) the timber surface. The photographs of sample woods (80mm), crushed woods and nail are shown in Fig. 8. When some (1 up to 3) charged electrical impulse are applied to the timber from the electrode, the timber is crushed into two pieces and liberated the nails. The cumulative charged voltage for disintegration is 135.6kV in the duration of wave front of 0.2μs. It is obviously that the nail completely separate from woods by using electrical fragmentation. The relationship between cumulative voltage for disintegration and length of woods is plotted in Fig. 9. It can be seen that the cumulative voltage for disintegration is almost proportionally to the length of two kinds of woods. This result illustrated the possibility of new recycling technique for building wastes including woods and nail. Considering the previous experimental results [3], the sample is better liberation by applying a few high-voltage impulses rather than many low-voltage impulses, if high-voltage impulse is required to crush woods.

4-2-4. Display plate sandwiching liquid crystal

Many liquid crystal displays for personal computer are used. However it is difficult to recycle them. In this study, the liquid crystal displays of note-type computer have been crushed by the electric high voltage impulse. Photographs of the experimental set-up for the electrical disintegration of the display and the products after the electrical crushing are shown in Fig. 10 (a) and (b). The size of used display sample is 135 x 99 x 2.3 (mm). After crushing, the two glass plates are separated from each other, and one side of the glass is completely broken to small pieces when the impulse voltage is 53.76kV in the duration of wave front of 0.2 μs (Fig. 10(b)). It is expected that the electrical crushing is a useful new fragmentation method for the liquid crystal display of a computer monitor. Additionally, when the liquid crystal display is crushed, the measured voltage and the current are illustrated in Fig. 11. In this study, the maximum voltage and the current is 47.5kV at 0.1μs and 1750A at the 3μs respectively. The electric current flowing in the liquid crystal display slightly delays after high voltage is applied to the sample. Therefore the difference between maximum voltage time and current time is approximately 3μs.

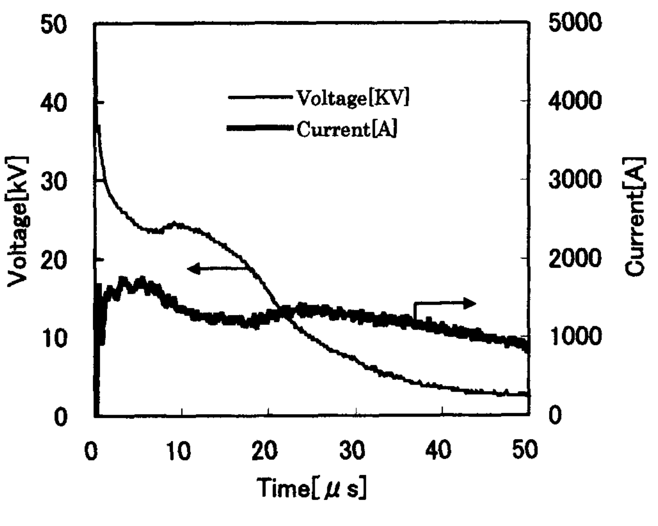


Figure 11 Voltage and current of electrical crushing to liquid crystal display.

5. Conclusions

The electrical crushing of different samples for the recycling purpose has been investigated by the electrical disintegration method using the discharged high voltage impulse.

In no samples between the electrodes, the smaller duration of the wave front (i.e. 0.2μs) can keep the high voltage for a longer period. Consequently, the longer period to reach the dielectric breakdown, the higher voltage can be applied between the electrodes in a shorter duration of wave front.

Four samples, such as concrete, single crystal silicon and silica, woods and iron nail and the display of liquid crystal panel, are examined to crush them by using the electrical disintegration to obtain the high degree of liberation in the practical recycle performance. In each sample, the single component is separated and obtained from the mixed materials by using some the high voltage impulse. Following results of liberation and fragmentation for recycling purpose have been carried out.

(1) Liberation of beads and mortal from concrete
(2) Liberation of silicon and silica from lump of single crystal silicon and silica
(3) Liberation of timber and nail from the woods for building house
(4) Fragmentation of liquid crystal display

Consequently, the experimental results suggested that the electrical disintegration method is feasible to liberate and separate the components of different resistivity as the new recycling technique.

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