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Highly Effective Image Eraser for Decolorable Toner

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Abstract. *The authors have developed a highly effective image eraser for decolorable toner that comprises leuco dye and developer. Using a heat eraser requiring minimal, printed paper with decolorable toner can be reused repeatedly. However, the erasing is visible in spite of discoloring because of the binding resin remaining on the paper. The new image eraser employs an erasing process consisting of rubbing, dust cleaning, and heating. The processes cause the original image to completely disappear. This method achieved both complete destruction of the printed information and renewal of the used paper. A paper can be reused at least five times in the case that the erasing condition is such that the original image completely disappears. This paper describes the mechanism of the erasing processes. © 2006 Society for Imaging Science and Technology.* [DOI: 10.2352/J.ImagingSci.Technol.(2006)50:6(516)]

INTRODUCTION

Contrary to expectations that the use of computers in offices would lead to the reduced use of paper, recent information technology has boosted paper consumption for printers and duplicators. Consequently, paper consumption has been recognized as an important environmental problem, which has led to the awareness that technology for reusing paper is a possible solution. Reuse technologies are relatively effective, because almost all office paper is abandoned within a short period. There are several reuse technologies such as a toner peeling machine,[1] rewritable marking paper,[2] photofadeable toner,[3] and our decolorable toner.[4] Toshiba Corp. commercialized the decolorable toner named e-blue™ in 2003.

The decolorable (erasable) toner e-blue™ and handwriting in the decolorable ink can be erased at once using a heat eraser for 400 sheets of paper.[5] We have developed and commercialized a batch heat eraser[5] for this purpose. e-blue™ is composed of leuco dye colored by a developer. In the decolorizing process, suitable heating cuts the interaction between the dye and developer, and the dye loses color. The developer diffuses in a binding polymer and is irreversibly trapped by an absorbing material. e-blue™ can be used as a conventional toner for electrophotographic printing and can be erased by heating with a special heat eraser, and the paper can be used repeatedly.

However, the main content of the toner is resin such as polystyrene. The heat erasing can decolorize the colored dye but cannot erase the resin on a sheet of paper. Hence, characters can be read as a ghost image after heat erasing. Image samples before and after heat erasing are shown in Fig. 1. From the viewpoint of environmental protection, batch heat erasing is the best reuse method because the least energy is consumed. However, from the viewpoint of information security, the heat erasing is inadequate.

Solvent erasing,[6] which is another method of erasing the e-blue™, can erase the toner invisibly by contact with an organic solvent, such as acetone or dichloromethane. Since such solvents can solvate the resin of the toner and the paper absorbs the solution into the paper fiber, no trace of the toner is left on the paper after drying the solvent. However, as organic solvents are generally toxic and/or flammable and/or ozone depleting, they are unsuitable for use in offices.

We have discovered a highly effective erasing method, which is suitable for practical use in offices, and here we report the model machine and the invisibly erasing mechanism of the processes. The method consists of three processes: rubbing, cleaning, and heating. Image samples, namely, the original character, after rubbing, and after rubbing and heating, are shown in Fig. 2.

EXPERIMENT

We have discovered a highly effective erasing method consisting of three processes performed in the following order: rubbing, cleaning, and then heating of an e-blue™ printed paper. Heating followed by rubbing did not erase the printed image effectively. The basic process was discovered by hand rubbing with a sand cloth and by heating with an iron. The erasing degrees were confirmed by the naked eye at the first stage of our experiment. The evaluation by the human eye is the severest evaluation.

Before making a trial product of the highly effective erasing machine, we have conducted two series of experi-

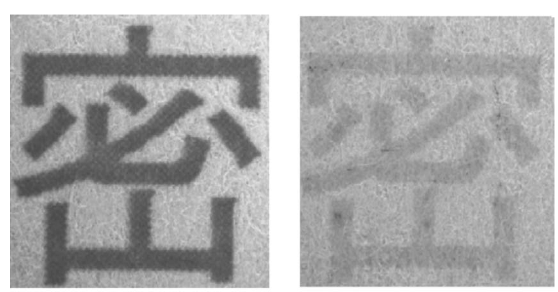

Figure 1. Image samples before and after heat erasing.

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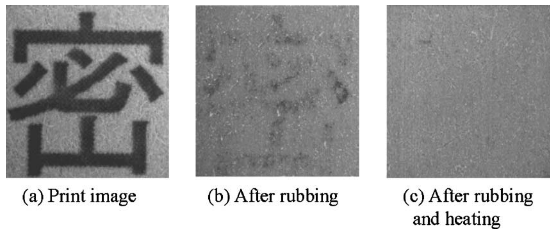

Figure 2. Image samples: original character, after rubbing, after rubbing and heating.

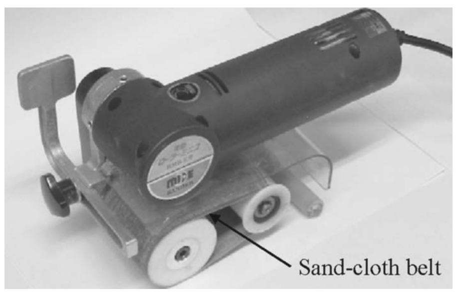

Figure 3. Hand-held belt sander.

ments as follows: (1) selection of rubbing material and (2) optimization of rubbing condition. The toner for the printed sample was e-blue™ and the printer was laser beam printer nx810 (Ricoh Co., Ltd.). The kinds of paper selected for the experiment were as follows: P50S (Toshiba TEC Corp.), paper with ordinary smoothness, and MEN-A4200 (Mitsubishi Chemical Corp.), paper with high smoothness, were selected as examples of paper made from new pulp. XRPCA4 (Fuji Xerox Co.) made from used printed paper (random) and Green100 (Fuji Xerox Co.) made from newspaper were selected as examples of recycled paper.

The test chart consisted of characters of 10–18 points and solid squares of (1 cm^2) to measure the optical density and empty area to measure the original optical density. Optical density was measured with CR300 (Konica Minolta Sensing, Inc.) densitometer.

Experiment on Selection of Rubbing Material

These experiments were conducted by using a hand-held belt sander (Office Main Inc.) as a rubbing machine. The belt sander is shown in Fig. 3. Then, heating was performed using a heat eraser (Toshiba Corp.) at 138 °C for 2 hours.

Roughness of the sander belts[7] used in the experiments was from No. 120 to No. 800. The smoothest rubbing material used in this experiment has a roughness of No. 800. In the case of rubbing rollers with roughness of from No. 800 to No. 1000, it takes too much time to rub the surface of e-blue™-printed paper. Also, roughness numbers higher than 800 caused clogging, and the lifetime of the sander belt was too short, where lifetime means the number of repetitions of effective rubbing with no clogging. In the case of the No. 800 sander belt, 100 times was the limit. On the other hand, in the case of coarse rubbing rollers rougher than No. 120, rubbing was too inhomogeneous. We found that rubbing belts whose roughness numbers higher than 240 could rub homogeneously. Thus, we have concluded that a roughness range from No. 320 to No. 600 is suitable for the rubbing process.

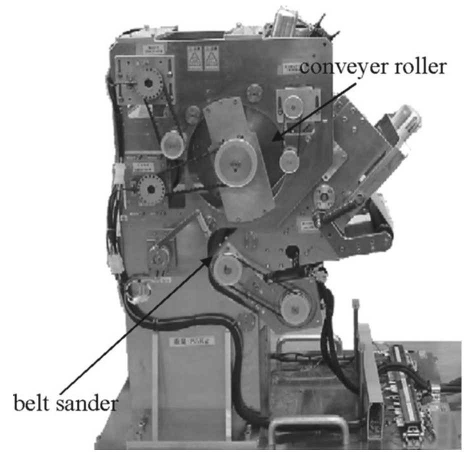

Figure 4. Rubbing machine consisting of a paper conveyer roller and a belt sander.

Optimization of Rubbing Condition

We conducted the rubbing experiments in order to minimize the shaving depth of the surface of the paper by using the rubbing machine as described in the following.

The rubbing machine consisted of a paper conveyor roller and a belt sander with a switching mechanism. A photograph of the rubbing machine is shown in Fig. 4. The sander roller rubbed the surface of the paper on the conveyor roller. The conveyor roller and the belt sander rotated in opposite directions.

The switching mechanism functioned to avoid scratching the surface of the conveyor roller by the sander belt in the case that there was no paper on the conveyor roller to regulate the pressure of the sander belt on the surface of the paper. In this mechanism, there was a pushing roller on the backside of the sander belt, which could control the hardness of the roller by changing the series of roller materials. We have observed tearing of paper in the case that both the conveyor roller and the pushing roller have hard surfaces.

We evaluated the degree of invisibility to the naked eye by observation by ten people. We concluded that the optical density of 0.1 after rubbing was sufficient for an image to be erased by heating to invisibility. We used the optical density of 0.1 as a standard value after rubbing.

Optimization of Rubbing Velocity

We reconfirmed the roughness of the sander belt to be Nos. 400–600 and selected the pressure roller hardness[8] of 30 by comparing the rubbed image to the standard optical density of 0.1. A coarse sander belt of less than No. 320 caused paper to fall from the conveyor roller and the fine sander belt of more than No. 600 did not achieve the desired optical density.

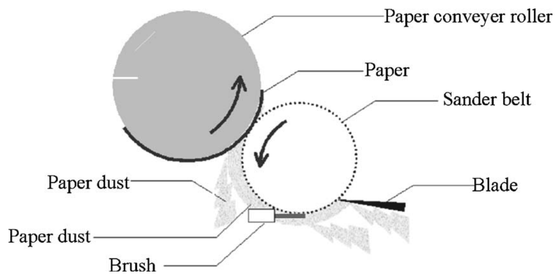

Figure 5. Outline of brush and blade in rubbing machine.

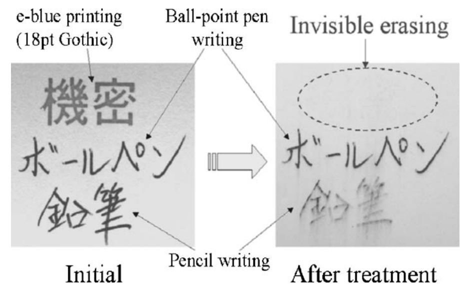

Figure 6. Image samples before and after rubbing and heating.

In the case of the above mentioned conditions of materials, the rubbing velocity of the sander belt is related to the conveyor roller. That is, the rubbing degree of any given point on paper is determined by the rubbing velocity of the sander belt and the time of rubbing which depends in turn on the velocity of the conveyor roller. The velocity of the conveyor roller was set to 4–10 m/min, which is comparable to the speed of an ordinary shredder machine. The velocity of the rubbing belt was set at 4–8 m/s, which enabled a rubbed image with the standard optical density of 0.1. As a result, we concluded that the depth of rubbing corresponding to the standard optical density of 0.1 was about 5 μm.

Optimization of Rubbing Dust Treatment

Dust treatment is one of the most important factors concerning realization of the highly effective eraser. The rubbing process generates paper dust, which will contaminate both the surface of paper and the sander roller. Air suction and filtration were effective for removing the paper dust. The required air displacement was more than 6 m^3/min. The filter was made of polyester nonwoven fabric. The filter removes 99.9% of dust whose size is 0.3 μm or more.

We have found that the air stream at the surface of the high-speed sander belt conveys paper dust and causes trouble in many parts of the machine. We can avoid this stream by implementing several blades on the surface of the belt to cut the stream, as shown in Fig. 5. Also, a brush was effective for cleaning the surface of the sander belt. The angles of the blade and the brush should be regulated to optimize the suction of paper dust stream. More than three blades and brushes were effective for prolonging the lifetime of the sander belt by avoiding the paper dust contamination. After the first step, although the remaining parts of toner corresponding to a figure were scattered on the paper surface, the figure was recognizable because the original shape of the figure can be supposed from the remaining parts.

A human can recognize a figure on a homogeneous ground when the shape has sufficient independent area in sight.[9] This is a necessary condition for perceiving a figure. In order to reconstruct a figure in the brain, the figure must have sufficient unity related to a memory in the brain. In regard to reconstruction of an original image in the brain, human perception is subject to a limit depending on the extent of the broken parts of the original figure. The rubbing

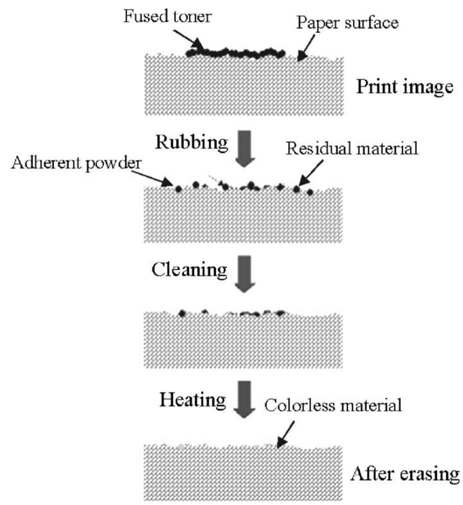

Figure 7. Cross-sectional schematics of image forming material on paper.

subdivides the figure and scatters shaved toner on the paper surface. The subdividing and scattering make it difficult for the human brain to reconstruct the figure.

THE PRINCIPLE OF INVISIBLE ERASING

There is a view that shaving the surface of a sheet of paper would constitute invisible erasing. Conventionally, in order to erase a printed image by rubbing the paper surface, it is necessary to shave off a layer of paper fiber to the depth reached by the toner. Naturally, if sufficient shaving is performed, printed characters will be erased invisibly.

Ordinary paper for office printing has a thickness of 75～100 μm. In our experiment, the tendency of the printer to jam for the paper shaved to a level thinner than 50 μm was observed. Shaving should therefore be restricted to the minimum necessary so that the paper is reusable.

Our method involves shaving the paper surface very slightly; we have found that the shaving depth can be reduced to about 5 μm in the case of the e-blue™. With this shaving depth, 5 μm, characters are legible in the case of conventional toner, handwriting with a ball-point pen, handwriting with a pencil and the e-blue™ toner as shown in Fig. 6. A character was legible after rubbing as shown in Fig. 7, because the rubbing removes only parts of the character. The human brain is capable of restructuring the complete image of the character from the parts remaining on the paper.

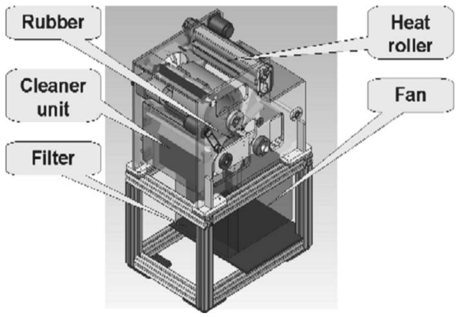

Figure 8. Trial product of highly effective image eraser.

As a result of heating, however, the characters printed with e-blue™ toner disappeared. Only decolorable ink or a toner such as e-blue™ can be erased to illegibility by heating after rubbing. Due to the Liebmann Effect[10] it is difficult for the human brain to recognize the figure when the brightness is the same level, even if the color is different. A sufficient difference in brightness is needed in order to recognize a figure from the ground. When the difference in the brightness between the figure and the ground is too small, it is difficult to recognize the figure. Also, due to the area effect,[11] it is also difficult for the human brain to recognize the figure when the area of the figure is too small. A sufficient area is required for a figure to be recognized from the ground. If the difference in the brightness between a figure and the ground is too small, a small figure cannot be recognized. The rubbing process subdivides and scatters the image and the heating process reduces the difference in brightness; the optical density.

We have also confirmed that neither ultraviolet radiation nor in infrared camera assists an image recovery. An infrared camera detects the difference in temperature on the surface of a paper. The difference in temperature between scattered and fixed toner on the surface of a paper is slight.

TRIAL PRODUCT

The highly effective eraser consists mainly of four parts: a paper conveyor roller, a rubbing roller, a dust cleaning system, and a heat roller. A rubbing roller was installed instead of a sander belt to realize a more compact machine. Figure 8 shows an illustration of the highly effective image eraser. The paper conveyor roller has a device to hold paper during the rubbing process. This conveyor roller has a metal surface and a diameter of 240 mm. The conveyor roller has a mechanism to fix a paper at the first stage of the rubbing process. The rubbing machine consists of a roller covered with rubber and sand cloth. The sand cloth belt length on the roller was about 470 mm. The lifetime, which has the same meaning as above, of this rubbing sand cloth is sufficient for erasing ~1000 sheets of paper. We have regulated the depth of the shaving from 4 to 6 μm by regulating the pressure between the rubbing roller and the conveyor roller and by regulating the speed of the rubbing roller. To shave paper of different thicknesses to a suitable depth, we prepared a mechanism in the trial product to regulate the pressure between the rubbing roller and the conveyor roller.

Table I. Typical erasing conditions of the trial product.

	Condition	Remarks
Toner	e-blue™	Toshiba
Paper	Green100 P50S	Fuji Xerox Toshiba TEC
Paper carry speed (mm/s)	34	
Polishing sheet speed (m/s)	3.0	Roughness No. 400
Heating roll temperature (°C)	228	

As the rubbing causes paper and toner dust, the dust cleaning system has to work effectively as mentioned above. The cleaning system consists of a cleaning brush, air ducts, a filter, and a draft fan. The air ducts are aerodynamic in order to control the air stream into the filter. The exhausted air does not contain the dust. We measured particles around the exhaust port of the fan and the trial product using a particle counter, and it became clear that there was no problem according to the enviromental health and safety laws of Japan.

The heat roller used is a conventional one that is also used in a laser beam printer. The required heating temperature range was 200–240 °C for a feeding speed of 5–50 mm/s.

As summarized in Table I, the typical operating conditions of the trial product were selected so as to maintain paper with minimum damage as follows. The conditions were also regulated so as to erase an 18-point Gothic character of e-blue™, considering that an 18-point character is sufficiently large for confidential information. A Gothic character has a large printed area and it was not easy to break the character by rubbing as described above. We assumed that a confidential document was written with 8- to 14-point characters, and the possibility of larger character, such as an 18-point character, being used was disregarded. Thus, if 18-point Gothic character can be erased, it is sufficient to confirm the efficiency of our method.

In the case of a photograph, the confidential information can be erased easily by various means, because the clarity of the picture is the most important condition. In this case, the rubbing process is usually sufficient to spoil the clarity of the picture. We therefore suppose that confidential information exists in a document and is expressed by a sentence or clause, not by the images. Of course, there are confidential images such as blueprints of new products, in which confidential information is expressed by lines and curves accompanied by characters indicating length, angle, etc. However, in this case, the confidential information is expressed using characters of relatively small size.

As mentioned in the experimental section, we have found that paper-powder dust is an important factor in the realization of a highly effective image eraser. Although we have minimized the shaving depth of the paper, a small amount of paper-powder dust will be generated and accumulate.

Air suction and filtration were effective for removing the paper dust. The air displacement ability of the draft fan was more than 6 m^3/min. The filter was made of polyester nonwoven fabric. The filter removes 99.9% of dust whose size is 0.3 μm or more. We have performed particle-counting tests in a room and confirmed that the dust level is insufficient to constitute a hazard.

We have examined the energy consumption of the trial product. The trial product consumed about 1500 W h for erasing 400 sheets of paper, because rubbing and heating were performed sheet by sheet. On the other hand, the batch heat eraser consumed only 450 W h for decolorizing 400 sheets of paper. These results indicate that erasing to invisibility requires three times as much energy as heat erasing does. Although we will be able to improve the energy efficiency of the highly effective image eraser, we expect the batch heat erasing to be more efficient than invisible erasing from the viewpoint of life cycle assessment.[12]

The main consumable is the rubbing roller. In the case of 470 mm belt length, the lifetime of the belt was confirmed to be sufficient for a period during which more than 1000 sheets of paper were treated, and then the belt was replaced. This replacement frequency is less than for the frequency of trash disposal in the case of a typical shredder; on average, trash disposal is performed once every 300 sheets of paper shredded, because the volume of shredded paper is so large.

RESULTS AND DISCUSSION

The merits of this method are invisibility of erasure and repeated reuse of the paper. The degree of information security is thought to be better than in the case of a simple shredder. A simple shredder destroys information by cutting a document into pieces.[13] The information can be read again if the pieces of the document are reconnected in a process akin to doing a jigsaw puzzle.

Our highly effective image eraser does not permit recovery of erased information, and the erased paper can be reused repeatedly. However, the process is sheet by sheet and energy intensive compared with the simple heat eraser for e-blue™. It will consume more energy than simple heat erasing since it includes rubbing and dust removal processes. Variations of the application are summarized as follows:

(A) A highly effective image eraser is an alternative to a shredder. In this case, a sheet feeder or automatic feeder is added. For a highly confidential document, the result of erasing must be confirmed immediately, as in the case of a shredder. The user may feed the document sheet by sheet. The user can accumulate used documents where anyone can see them in the case of nonconfidential documents, and an automatic feeder can be applied.

A new paper circulation system is proposed as follows:

(1) decolorable toner printing and decolorable ink handwriting,
(2) separation of used paper into damaged paper, ordinary manuscript, confidential document, and accumulation of the separated paper,
(3) nonconfidential documents are erased by the heat eraser and the paper is reused,
(4) the highly effective image eraser erases confidential documents, and
(5) damaged paper is sent to a paper recycling plant.

(B) A rubbing machine provides for pretreatment prior to heat erasing. Considering the energy consumption, the combination of a rubbing machine for the e-blue™ printed paper and a heat eraser is advantageous. Sheet by sheet treatment as in the case of conventional reuse[1] is an energy intensive method. A batch heat eraser is the best solution.

(C) A multifunctional printer type is a combination of a printer and the highly effective image eraser. Used paper is loaded in a printer tray just as though it were new paper. The used paper is automatically rubbed and heat erased, and then loaded for printing. This product will be the most energy intensive system.

CONCLUSION

We have created a new concept: a highly effective image eraser. We have made a trial product and confirmed its capability.

The image eraser employs an erasing process consisting of rubbing, dust cleaning, and heating. After the process, no trace of the original image can be recognized. This method achieved both complete destruction of information and renewal of the printed paper. Compared with solvent erasing, the new process is easy to use in offices.

The invisibly erasing mechanism is explained in terms of perception of the human brain via eyesight. The rubbing process involves subdividing and scattering the original image and the heating process involves reducing the difference in brightness, i.e., the optical density. Thus, only e-blue™ printed images can be erased invisibly.

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