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The Art of Gift-Giving: Laser Cutting as a Value-Added Technology for Fabricating Customized Biodegradable Packaging

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Abstract

It is a custom in certain cultures to send and exchange gifts for special occasions. This remarkable custom led to the idea of applying the laser cutting technology and using it as value-added to fulfill any custom shape of the packaging. Laser cutting applications in customized packaging can be helpful to be value-added to the digital printing system and reduce time consumption in the post-press rather than focused on die-cutting. Only the biodegradable substrate was used in this experiment. Rather than focusing on die-cutting, laser cutting is applied to reduce the hustle and reduce the post-press bottleneck. As a result, it is possible to produce more customized packaging in a short time. The laser cutting experiment was planned and conducted using a CO_2 laser cutting machine. One of the laser cutting parameters, such as laser power, was tested in the experiment. The study also identified the parameter and optimal setting for the specific thickness of the paperboard. Also, subsequently, the optimum laser power was determined. The results showed that 50-60% laser power is the most significant ratio affecting the clean cuts of the specific thickness of materials.

Introduction

It is a custom in certain countries to send and exchange gifts for special occasions. Kayama, A. discussed this custom in such a beautiful way to understand the art of gift-giving in Japan [1]. The gift-giving custom is a huge part of Japanese culture [2]. One of the items that preferred to be sent as gifts is the high quality of fresh fruits. In the gift-giving custom, high-quality fresh fruits are essential gift items [3]. Fresh fruits are one of the types of gift that is exchanged in two major seasonal occasions (*ochugen*) in summer and (*o-seibo*; handover at a visit to residence in gift-giving occasions in the past) in winter [4]. In Japan, the gift-giving custom is a special ritual and has become a year-round tradition and is viewed as an essential aspect. This gift-giving culture inspires researchers with more opportunities to experiment with ideas and shapes for customized packaging. Also, by proposing sustainable packaging, it gives the opportunity to packaging designers to reduce single-use plastics and excessive packaging application in packaging design.

The packaging itself performs a wide range of functions, such as product protection. In the case of food, it can keep it fresh and prevent deterioration [5]. Secondly, packaging has an esthetic value that convinces the consumer to choose a specific and gives more sentimental value for them or the receivers they will give [6-10]. Thirdly, packaging plays its role as an information function. The packaging displays information about ingredients, expiry date, and so on. [11-15]. Lastly, packaging must have a practical function. Packaging must be functional, easy to handle and use. The laser cutting elements help to design and customize the packaging and facilitate the functionality of the packaging. Laser cutting gives value added to packaging, especially the kind that needs customization and personalized touch. CO_2 laser achieves its application on various substrates such as paper and paperboard for producing packaging that can be cut, engraved, and perforated. The values coming from the customized design and packaging bring out the abstract qualities of the product. Laser cutting also can cut windows and openings on a package. If the packaging has other elements such as tear openings, laser cutting can do that too. Functional packaging with innovative technology becomes easier than ever with laser cutting technology [15, 16].

The laser, derived from Light Amplification by Stimulated Emission of Radiation, is an electrical-optical device that yields coherent radiation. Presently, two types of lasers cutting equipment are the most desired: CO_2 laser and fiber laser [17, 18]. For this experimental study, only CO_2 laser will be discussed. The CO_2 laser is the gaseous state laser whose main characteristic is establishing the active medium (mixture of gases) and the wavelength. The laser beam-treated material or substrate will be cut, guided through a system of mirrors to the focus system. The cut width, known as kerf width, is exceptionally narrow, ordinarily between 0.1 and 1.0 mm [19, 20]. There is light produced by CO_2 lase. However, it is invisible and falling in the far-infrared range of the light spectrum [21].

The CO_2 laser application in packaging not just for cutting but also includes perforating, marking, engraving, and kiss cutting [22]. Thus, laser cutting systems complement each other with the digital printing system. The focus on digital printing and laser cutting is the easy customization and supply chain optimization, which includes short runs, demand, and just-in-time production. Correspondingly, laser cutting is the piece of digital processing in post-press. This significant ability reduces production time, inventory, and the number of changeover times. Hence, laser cutting is recommended when an individual product needs to be done by hand, as it will be too expensive to use die-cutting to produce one or small quantities. Additionally, laser cutting is required when creating packaging with high accuracy of complex geometries [23]. The application of laser cutting is the best option to produce customized packaging for a short time. With the reduction in the cost of CO_2 laser development cost, the application of laser cutting for paper materials has become more efficient [24]. The distinguishing features of laser cutting are its flexibility and its high-quality cuts. Furthermore, the laser cutting machine is contactless. Its non-contact nature allows it to maintain a sanitary environment of sensitive materials such as food packaging [25]. However, there are but few published research results and reviews about laser cutting of paper-based materials or substrates.

Materials and Method

In this study, paper-based packaging was proposed to give an alternative to the existing single-use plastics and excessive layers of gift packaging. Paper material such as paperboard is used to fabricate the proposed packaging solution. This study focused on using biodegradable as an environmental matter to users. Thus, the application of eco-friendly packaging must always be considered [26, 27]. The materials used were paperboard with a thickness of 0.44 mm and a grammage of 310 g/m². The materials were provided by Oji Materia Co. Ltd, Japan. The experiments were performed using a 20 W CO_2 laser cutting machine (Podea Corsa by PODEA). The laser cutting was performed at laser power and a cutting speed constantly set at 20 mm/s. The illustration software used for packaging design was Adobe Illustrator 2021.

One of the parameters of laser cutting efficiency is the ratio of laser power output in a test to the highest possible power in percentage. After pretests, the prototype development view was designed and cut out using the laser cutter at different laser power ratios. The heat-affected zone (HAZ) and cutting edges were observed using an industrial optical microscope (Olympus SZX10, Olympus, Japan).

Results and Discussion

The function of the laser cutter in packaging design is not only for cutting and creasing but also to give sentimental value by adding a personalized touch of irregular shapes or decoration specifically for the receiver. The laser touches the substrate, evaporates at that moment, and creates the desired shapes. Figures 1a and 1b show images of laser-cut paperboard in open and close view, respectively. The laser cutter can cut any specific shape or personalized decorative design (Fig.2). The application of laser cutting opened various possibilities in packaging design. By regulating the laser cutting parameters, the paper materials can be completely cut or crease for folding purposes.

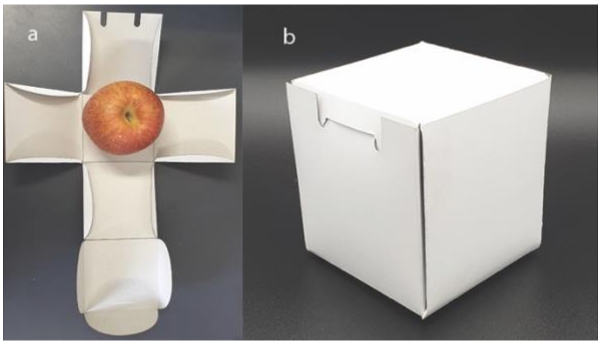

Figure. 1 (a) Open and **(b)** close packaging before personalized design and shapes

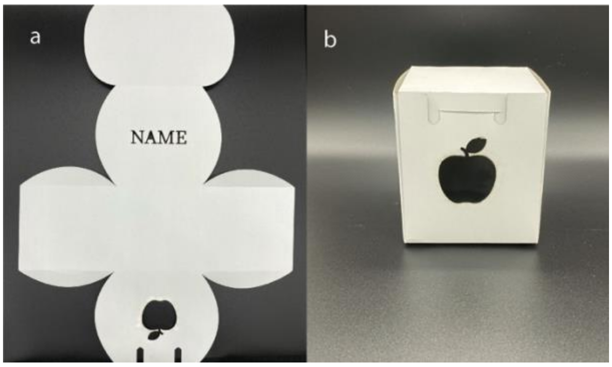

Figure. 2 (a) Open and **(b)** close packaging after personalized design and shapes

The mechanism of laser cutting involves heating the material to the temperature of evaporation. The physical change that a material undergoes is the change of the solid to a gaseous state [28]. The laser cutting machine that operated for this experiment used a percentage unit. The testing started from 10% to 100% power as the power below 50% did not give enough ability to cut the 0.44 mm thick paperboard. The results showed that using below 50% of laser power was insufficient to cut the 0.44 mm paperboard (310g/m2) at 25 mm/s in cutting speed. Therefore, the testing was extended to 50% to 100% of laser power. The cut edge was rough, and the edges on the two sides were not detached adequately from the paperboard sheet (Fig. 3).

At a laser power ratio below 50%, cut edges did not come off properly from the sheet. Thus, the packaging cannot be built as the edges are still attached to the sheet. If the packaging is taken off forcefully, the rough edges will appear on the packaging. The most heat-affected area can be seen with the edges at 80-100% laser power ratios. As a result, for this paperboard, a 50% laser power ratio was enough to cut the custom shape of the packaging.

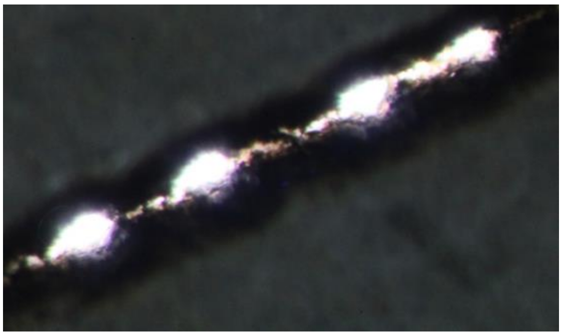

Figure. 3 Rough edges cut at 40% laser power.

However, at a 50% laser power ratio, cut edges were not cleaner compared to those at 60% laser power. Consequently, a 60% laser power ratio was an optimum and efficient setting for this paperboard. The scale of the picture shown in Figure 4 and the top views of the edges of the paperboard cut at varied levels of laser power are shown in Figure 5.

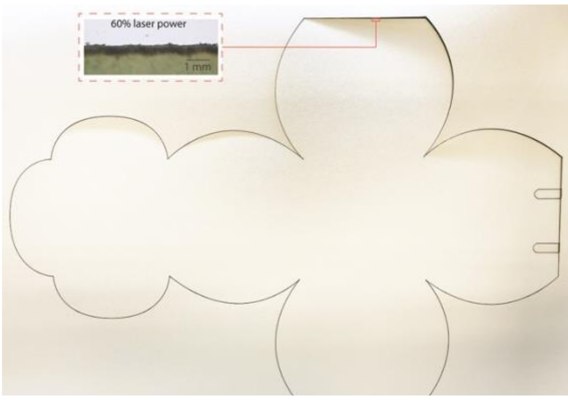

Figure. 4 The edge of cut enlarged in the picture

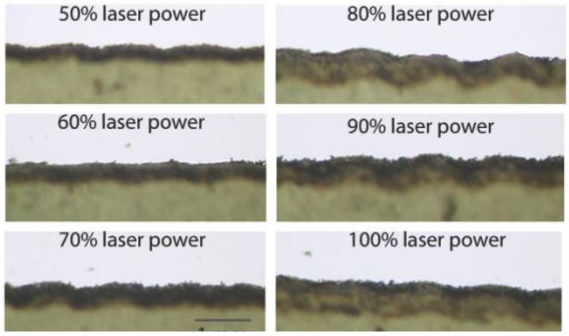

Figure. 5 Heated-affected zones magnified by stereomicroscope

The advantage of using the laser cutter was that the set was straightforward. For a beginner or a new user, there is no need to know everything about the mechanisms of laser cutting to operate it. The laser cutter mechanically moved a paperboard sheet on the computer numerical controlled (CNC) X-Y table for this experimental study. As the whole area of the paperboard sheet was mounted on the area at a maximum to produce the specific packaging dimension, the setpoint for this experiment was set to X: 0; Y:0. Thus, the cut component and custom paperboard packaging were ready to be used immediately after cutting without any subsequent cleaning operation. When laser power was increased at a fixed scan speed, heated zones in the cutting edges were visible. The stereomicroscope carried out the evaluation of cut edge differences. The cut edges turned dark and became darker with an excessive laser power ratio. During the cutting, the cellulosic material was likely carbonized, meaning that there were no excessive chippings that would be discharged when mechanical cutting methods were applied. Based on the observation, the consequence of energy input onto the cut zone can be two situations:

Situation 1: When too much energy was put into the cut zone of the 0.44 mm (thickness) paperboard, the laser-cut edges surrounding the customized packaging became overheated and damaged.

Situation 2: When too little energy is put into the cut zone of the 0.44 mm (thickness) paperboard, the laser-cut edges surrounding the customized packaging become rough and cannot be effectively removed from the sheet.

When laser power increased without changing of cutting speed, the visible color change was observed by the naked eye. Cut edges turned yellow with the excess amount of laser power. This led to the significance of why the other factor, such as the component of commercial-grade paper, must be understood. Also, the surface treatment of paper-based materials needs to be identified. This could be improved to reduce the surface damage of the materials after the laser beam cut the material. Furthermore, the response to the laser power is not always defined based on thickness. Grammage may be more suitable as a parameter. After the paperboard has been tested, it can be highlighted that the paperboard is also suitable for laser cutting. However, there is a lack of basic studies of laser processing of paper materials, and this has been a motivation of this paper. Also, by proposing sustainable packaging, it gives the opportunity to packaging designers to reduce single-use plastics and excessive packaging application in packaging design development.

Conclusion

The capability of a 20 W low-power CO_2 laser in cutting paper-based materials has been studied. Material such as paperboard was cut with various laser power. The study was focused on using CO_2 as an option to fabricate customized packaging. This technology has been increasingly applied and developed over the years. This is due to the demand for quality, precision, and the need for reduction. For this paper-based packaging, personalized packaging was proposed, and there is a significant reason for using sustainable materials. The application of laser cutting in processing paper materials is found mainly in packaging design and personalized packaging. However, there is a lack of basic studies of laser processing of paper materials as the existing application is for small volumes and for individual products. To increase the application of laser cutting the paper-based and personalized packaging, the interaction between the laser beam and the component of materials itself must be understood. As a result, the knowledge on laser processing of paper materials is needed, and it increased the possibilities of the use of laser in cutting, creasing, and surface treatment of paper-based materials can be realized.

References

[1] Befu, H. (2021). 11. Gift-Giving in a Modernizing Japan. In Japanese Culture and Behavior (pp. 158-170). University of Hawaii Press.

[2] Kumayama, A. (1990). Understanding gift-giving in Japan. The International Executive, 31(4), 19–21. doi:10.1002/tie.5060310407

[3] Gehrt, K. C., & Shim, S. (2002). Situational influence in the international marketplace: An examination of Japanese gift-giving. Journal of Marketing Theory and Practice, 10(1), 11-22.

[4] Sherry L. Lotz, Soyeon Shim, Kenneth C. Gehrt, A study of Japanese consumers' cognitive hierarchies in formal and informal gift-giving situations, Psychology & Marketing, 10.1002/mar.10059, 20, 1, (59-85), (2002).

[5] Wikström, F., Williams, H., Trischler, J., & Rowe, Z. (2019). The importance of packaging functions for food waste of different products in households. Sustainability, 11(9), 2641.

[6] Bigoin-Gagnan, A., & Lacoste-Badie, S. (2018). Symmetry influences packaging aesthetic evaluation and purchase intention—International Journal of Retail & Distribution Management.

[7] Geng, X., & Lin, Q. (2021, January). Discussion on the Aesthetic Function Design of Pet Staple Food Packaging. In The 6th International Conference on Arts, Design and Contemporary Education (ICADCE 2020) (pp. 679-682). Atlantis Press.

[8] Yangang, Z. (2021, January). Research on the Influence of Modern Consumer Psychology on Packaging Design Based on Image Analysis. In Proceedings of the 2021 International Conference on Bioinformatics and Intelligent Computing (pp. 327-332).

[9] Wang, Z. (2020, July). Humanized Design Concept in Product Packaging Design. In Journal of Physics: Conference Series(Vol. 1578, No. 1, p. 012196). IOP Publishing.

[10] Barnes, A. (2017). Telling stories: The role of graphic design and branding in the creation of 'authenticity within food packaging. International Journal of Food Design, 2(2), 183-202

[11] Wyrwa, J., & Barska, A. (2017). Packaging as a source of information about food products. Procedia Engineering, 182, 770-779

[12] Ankiel, M., Sojkin, B., & Grzybowska-Brzezińska, M. (2020). Packaging as a Source of Information on the Product in Food Purchasing Decisions: The Case of Poland. European Research Studies, 23, 356-372.

[13] Mruk-Tomczak, D., Jerzyk, E., & Wawrzynkiewicz, N. (2019). Consumer engagement and the perception of packaging information. Olsztyn Economic Journal, 14(2), 195-207.

[14] Lo, S. C., Tung, J., & Huang, K. P. (2017). Customer perception and preference on product packaging. International Journal of Organizational Innovation, 9(3), 3-15

[15] Hassan, S. H., Leng, L. W., & Peng, W. W. (2012). The influence of food product packaging attributes in purchase decisions: A study among consumers in Penang, Malaysia. Journal of Agribusiness Marketing, Vol. 5, December 2012, p. 14-28.

[16] Bozzola, M., & Giorgi, C. D. (2019). Social packaging. Design for wide sustainability. The Design Journal, 22(sup1), 737-749

[17] Badoniya, P. (2018). CO2 laser cutting of different materials–a review. Int. Res. J. Eng. Technol.(IRJET), 5, 2103-2115].

[18] Sołtysiak, R., Wasilewski, P., Sołtysiak, A., Troszyński, A., & Maćkowiak, P. (2019). The analysis of Fiber and CO2 laser cutting accuracy. In MATEC Web of Conferences (Vol. 290, p. 03016). EDP Sciences.
[19] Amaral, I., Silva, F. J. G., Pinto, G. F. L., Campilho, R. D. S. G., & Gouveia, R. M. (2019). Improving the Cut Surface Quality by Optimizing Parameters in the Fibre Laser Cutting Process. Procedia Manufacturing, 38, 1111-1120.
[20] Powell, J. (2012). CO2 Laser Cutting. Springer Science & Business Media.
[21] Riveiro, A., Quintero, F., Lusquiños, F., Comesaña, R., & Pou, J. (2010). Parametric investigation of CO2 laser cutting of 2024-T3 alloy. Journal of Materials Processing Technology, 210(9), 1138-1152.
[22] Muangpool, T., & Pullteap, S. (2018, March). Reviews on laser cutting technology for industrial applications. In the Third International Conference on Photonics Solutions (ICPS2017)(Vol. 10714, p. 107140Q). International Society for Optics and Photonics.
[23] Ellison, R., Kogl, U. M., & Leifson, M. (2019). U.S. Patent No. 10,470,486. Washington, DC: U.S. Patent and Trademark Office.
[24] Stepanov, A., Saukkonen, E., & Piili, H. (2015). Possibilities of laser processing of paper materials. Physics Procedia, 78, 138-146.
[25] Tercan, H., Al Khawli, T., Eppelt, U., Büscher, C., Meisen, T., & Jeschke, S. (2017). Improving the laser cutting process design by machine learning techniques. Production Engineering, 11(2), 195-203.
[26] Svanes, E., Vold, M., Møller, H., Pettersen, M. K., Larsen, H., & Hanssen, O. J. (2010). Sustainable packaging design: a holistic methodology for packaging design. Packaging Technology and Science: An International Journal, 23(3), 161-175.
[27] Nguyen, A. T., Parker, L., Brennan, L., & Lockrey, S. (2020). A consumer definition of eco-friendly packaging. Journal of Cleaner Production, 252, 119792.
[28] Piili, H.: "Characterisation of laser beam and paper material interaction," Ph.D. thesis, Lappeenranta University of Technology, 2013

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