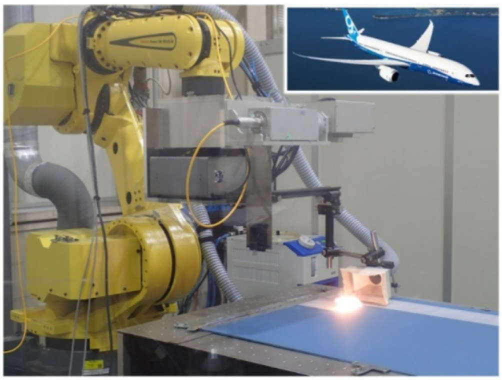
Development of High Speed Selective Laser Paint Stripping Technology on Composite Material with Friendly Environment for Operators



SATOSHI GYOBU[*1] TAKUMI SATO[*1]

TOSHIKATSU NOHARA[*1] SANEYUKI GOYA[*2]

Laser paint stripping has been attracting attention as a paint stripping method from the viewpoint of the SDGs (Sustainable Development Goals) in recent years, because the method produces less waste and provides excellent working environment properties. While laser paint stripping technology has generally been applied to paint removal from metal surfaces, the technology has not yet been practically applied to paint removal from surfaces of thermally susceptible materials, such as composite materials, due to the risk of heat input by the laser. This report describes on the development of a short-pulse laser paint stripping technology that suppresses heat effects on the composite base material, and a selective laser paint stripping technology that can strip only the topcoat from composite material surfaces among the primer and topcoats.

1. Introduction

Composite materials are used in many products of Mitsubishi Heavy Industries, Ltd., including aircraft, helicopters, and ships, which require weight reduction, and need to be repainted at the time of periodic maintenance. Currently, paint stripping methods with sanding or removers are widely used, but the former causes dust inhalation by workers and creates a poor working environment, while the latter uses a large amount of organic solvents and generates a lot of waste, which is not suitable for the SDGs and limits the applicable areas.

As an alternative to the above technologies, laser paint stripping technology has been attracting attention. This technology allows for remote laser irradiation and thus provides a good working environment and generates no waste other than dust during the stripping process, making it possible to achieve environmentally friendly paint removal. Other advantages of the laser paint stripping technology include good work reproducibility due to electrical control, and the ability to reduce the number of workers as a result of realizing operation at night due to automation with a robot equipped with a laser head.

The principle of laser paint stripping is shown in **Figure 1**. By irradiating a target with a laser, the energy propagates to the target, which vaporizes and removes the target. A wide range of lasers, from continuous wave to pulsed lasers, are used for laser paint stripping **(Figure 2)**. Pulsed lasers are those that repeat laser oscillation of extremely short duration (pulse width) such as microseconds or nanoseconds at a constant repetition frequency. Among these, lasers with pulse widths in the order of nanoseconds are called short-pulse lasers, and are suitable for low heat input processing. Continuous-wave lasers are capable of high-speed paint stripping with their high power, but have a large heat effect on the stripping target. On the other hand, short-pulse lasers can achieve low heat input processing by narrowing the pulse width to the nanosecond order, enabling high-quality stripping. In recent years, the power of short-pulse lasers has become higher (to kW class), which improves the stripping efficiency.

*1 Manufacturing Technology Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.
*2 Chief Staff Researcher, Manufacturing Technology Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

Laser stripping technology is generally used to remove paint, deposits, rust, etc., from metal base material surfaces. However, it has not been applied to materials with low heat resistance, such as resins and organic compounds, due to the risk of heat effects on the base material caused by the heat input of the laser. We inferred that the use of a short-pulse laser as a means of reducing the heat input caused by lasers would make it possible to strip paint while minimizing the heat effect on the base material. In addition, we assumed a case of suppressing direct laser irradiation to the base material by stopping laser irradiation when stripping of only the topcoat is completed with the primer coat left, as shown in **Figure 3**.

This report describes on the development of a short-pulse laser paint stripping technology that suppresses heat effects on composite base materials and a selective paint stripping technology that selectively strips only the topcoat.

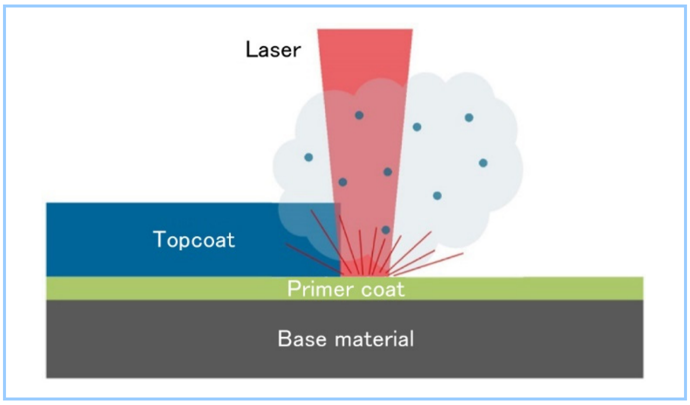


Figure 1 Illustration of laser paint stripping

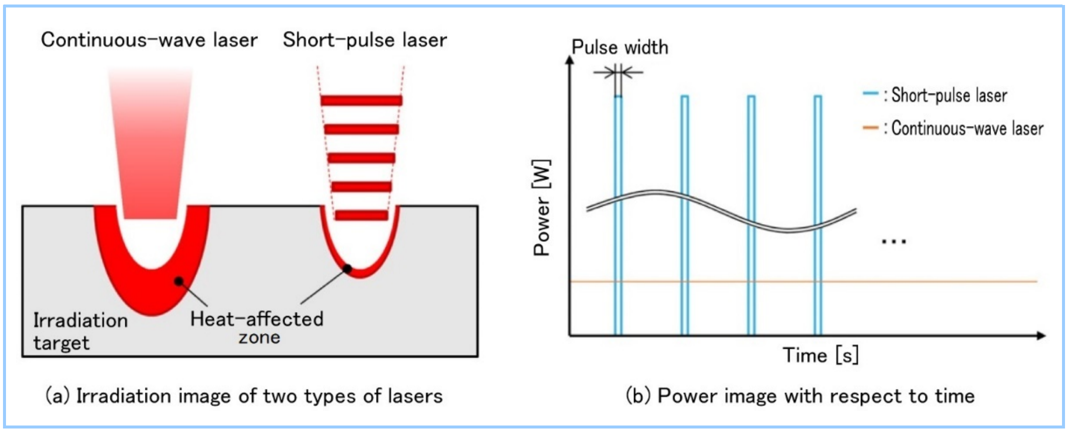


Figure 2 Irradiation image of two types of lasers

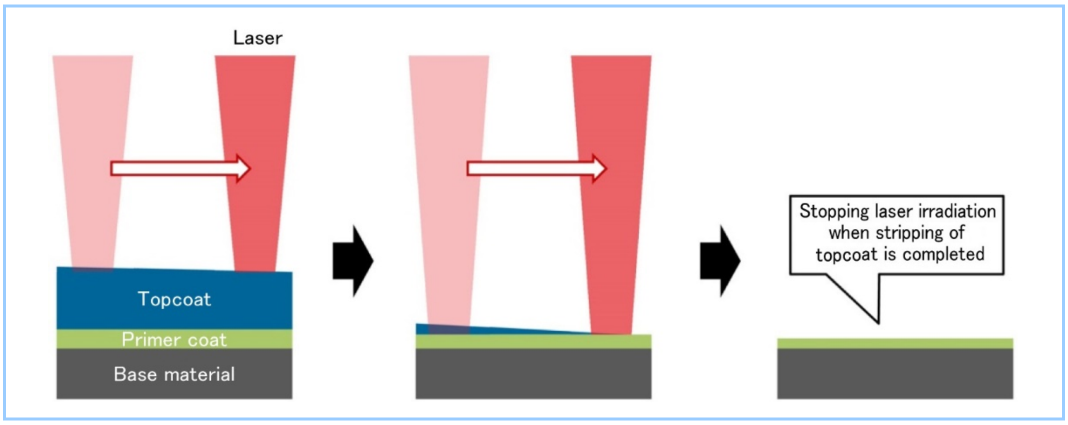


Figure 3 Illustration of stripping topcoat

2. Development of short-pulse laser paint stripping technology for composite material surfaces

In the development of a short-pulse paint stripping technology, first, we evaluated the basic capability of laser paint stripping by checking the paint stripping capability of laser irradiation targeting a topcoat under single shot, line-scanning, and area-scanning conditions.

Figure 4 illustrates the configuration of the laser paint stripper. The laser head is equipped with a galvano optical system for laser scanning. A laser from the short-pulse laser oscillator is input into the laser head. The laser head narrows the laser beam down to a predetermined beam diameter and irradiates the target with it. By high-speed scanning the target with the laser beam, a certain area of paint is stripped off. Paint stripping of a large area is performed by repeating the process as shown in **Figure 5**, where the robot holds the laser head and performs paint stripping of one location, then moves to the next location and performs paint stripping there.

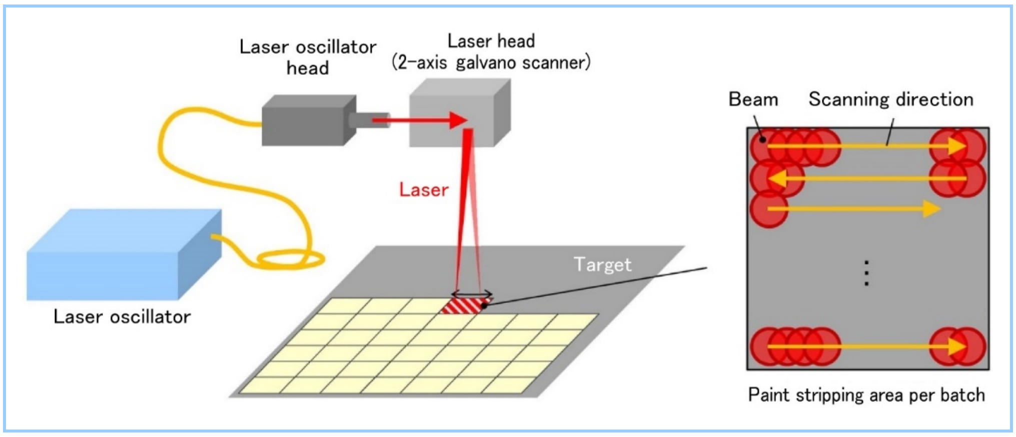


Figure 4 Configuration of laser paint stripper

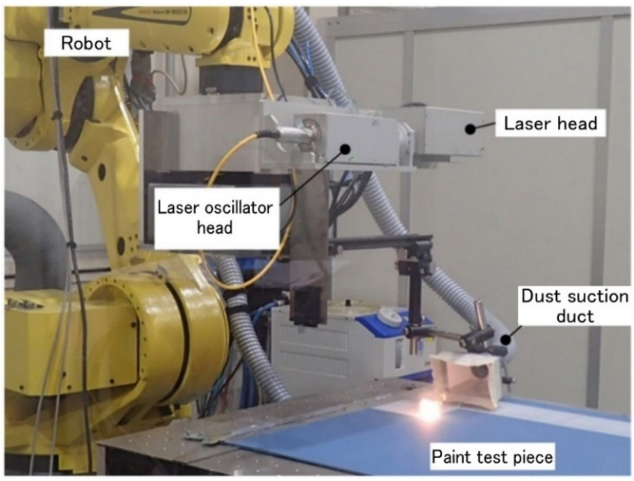


Figure 5 Laser paint stripping using robot

2.1 Evaluation of removal depth in single shot, line-scanning, and area-scanning irradiations with short-pulse laser

Accumulation of heat generated by a short-pulse laser stripping is low, so it is assumed, for example, that the removal depth in line-scanning irradiation is obtained by accumulating the removal depths in single shot, and that the removal depth of area-scanning irradiation is obtained by accumulating the removal depths of line-scanning irradiation. In this chapter, to understand the basic capabilities of short-pulse laser paint stripping, we compared the measured removal depth in line-scanning irradiation with the estimated removal depth obtained by accumulating the removal depths in single shot, and the measured removal depth in area-scanning irradiation with the estimated removal depth obtained by adding up the removal depths in line-scanning irradiation.

Figure 6 and **Table 1** illustrate the removal depth of each irradiation. The paint removal depth in single shot is represented by the shape of the Gaussian distribution of the beam as shown in Table

1. The removal depth at point A shown in Table 1 in line-scanning and area-scanning irradiations where laser beams are irradiated in an overlapping manner was calculated by adding up the removal depths at the corresponding point in each beam profile. When point A is irradiated with laser beams *n* times in line-scanning irradiation, the depth stripped by the i-th beam is defined as d_i, and the depth stripped by single shot is defined as *d*. If the values of d_1, d_2, ..., d_n follow the Gaussian distribution, the integrated value of d_1 to d_n corresponds to about 60% of *n* x *d*. From the above, the relationship between the removal depth in line-scanning irradiation and the removal depth in single shot can be expressed as follows:

$$\sum_{i=1}^{n} d_i = 0.6nd \quad (1)$$

The above relationship holds true for the removal depths in area-scanning and line-scanning irradiations as well.

As a result of comparing the measured and estimated removal depths, it was confirmed that the measured removal depths in line-scanning and area-scanning irradiations for stripping the topcoat tended to be generally in line with the estimated removal depths as shown in Figure 6(c). The reason for the slightly larger measured removal depths in the area-scanning irradiation is thought to be due to the heat storage effect of the continuous irradiation of the laser.

From the above, it was found that the removal depth in line-scanning is determined by adding up the removal depths in single shot and that the removal depth in area-scanning is determined by adding up the removal depths in line-scanning, and the effect of laser heat storage on removal depths is considered to be small.

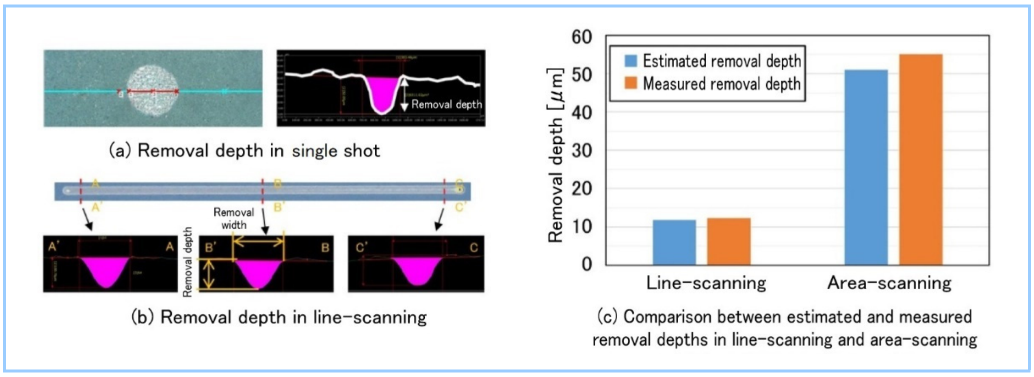
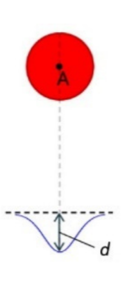
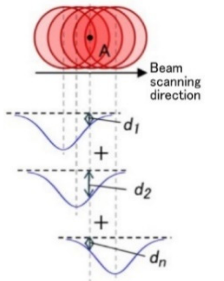


Figure 6 Evaluation result of topcoat of removal depths in single shot, line-scanning, and area-scanning irradiation

Table 1 Illustration of removal depth in single shot, line-scanning, and area-scanning

	Single shot	Line-scanning and area-scanning
Beam profile		
Removal depth at point A		

2.2 Evaluation of temperature rise in short-pulse laser irradiation

With the similar apparatus to that used in section 2.1, the temperature of the composite base material surface in paint stripping was measured. Using a test piece with a thermocouple embedded between the base material and the primer coat as shown in **Figure 7**, the temperature evaluation was conducted by measuring the temperature during one laser beam irradiation onto the primer coat. The results showed that the temperature increased when the laser passed directly over the thermocouple, and the maximum temperature was about 85°C. The alteration temperature of the composite material is near 200°C, so this temperature rise due to laser irradiation is considered to be sufficiently low.

It was confirmed by this result that laser paint stripping is possible while suppressing alteration of the composite material.

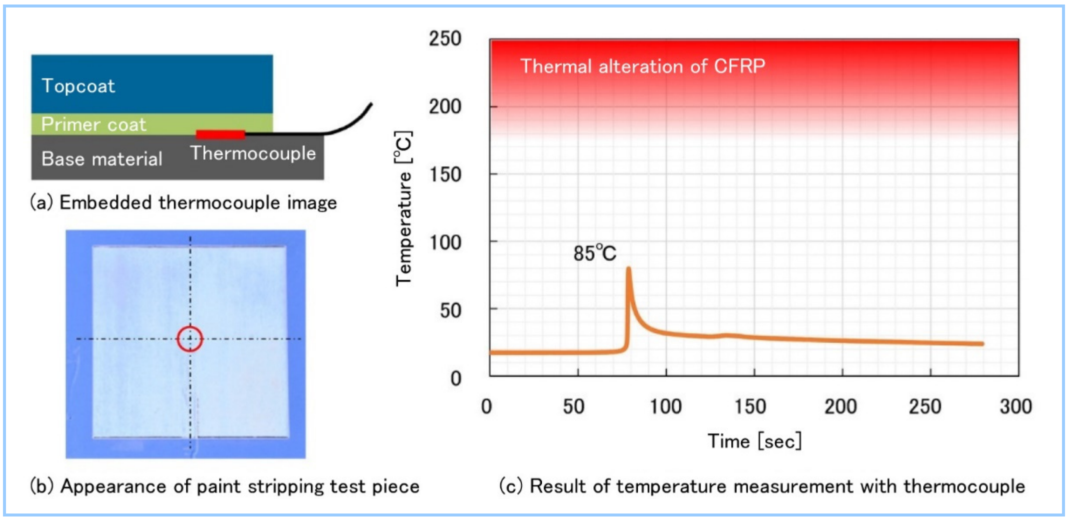


Figure 7　Result of base material temperature measurement in laser irradiation using test piece embedded with thermocouple

3. Development of selective paint stripping technology

One of the characteristics of short-pulse laser paint stripping is the capability of selective processing of materials. Each material has a unique ablation threshold (energy density at which sublimation occurs) due to the material properties such as boiling point and absorption rate. When the laser fluence (energy density = pulse energy / beam area) is below the threshold, stripping of the target is not performed. When the laser fluence is above the threshold, stripping of the target is performed. Generally, the ablation threshold is higher for high-boiling-point materials such as metals and lower for low-boiling-point materials such as resins and organic materials. Topcoats handled in this report contain more organic materials than primer coats, so ablation is likely to be accelerated.

To understand the stripping thresholds of the topcoat and the primer coat, we evaluated, for each material, the amount stripped by one-shot laser irradiation at different fluences to investigate the fluence dependence of the stripping efficiency. **Figure 8** shows a graph summarizing the relationship between the stripping speed ratio and the fluence of the topcoat and the primer coat. The d_{max} in the figure is the removal depth under the maximum fluence condition verified in this report for the topcoat and the primer coat materials. From the graph, the ablation thresholds of the topcoat and the primer coat were confirmed at fluences of about 300 μJ/mm^2 and 500 μJ/mm^2, respectively. These results indicate that only the topcoat can be selectively stripped by using a fluence of 300 μJ/mm^2 to 500 μJ/mm^2.

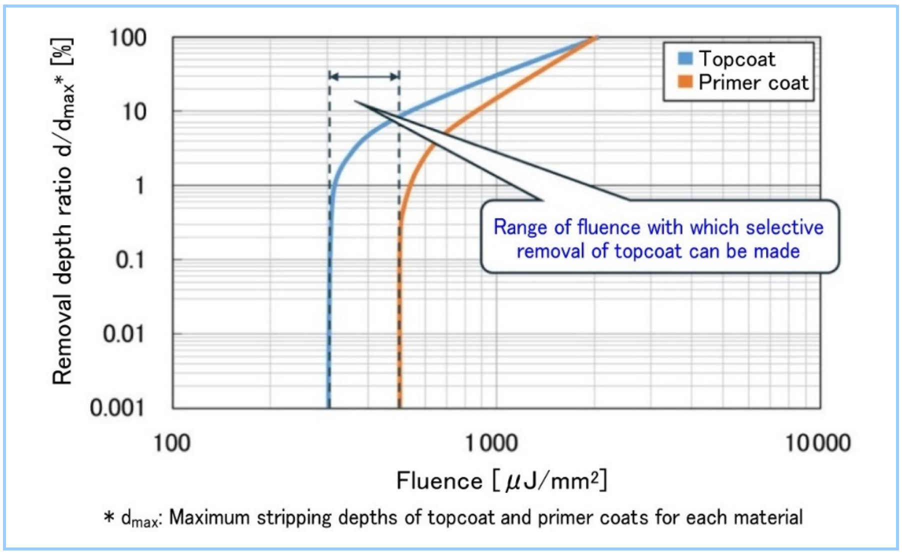


Figure 8　Relationship between removal depth and fluence for each coat

Based on the above evaluation result of the amount stripped by one-shot laser irradiation, the removal speed ratios of the topcoats and primer coats when the laser was continuously area-scanning was similarly evaluated. **Figure 9** shows a graph summarizing the correlation of the removal speed ratio to the laser power for the topcoats and primer coats. The average power represented on the horizontal axis indicates the percentage of laser power set by the laser oscillator. In the average power range of 50-60%, the topcoat was removed with almost no removal of the primer coat, and the removal speed ratio of the topcoat to the primer coat was more than 40 times, thus enabling selective removal of the topcoat. The 100% power condition, under which the topcoat removal speed is about 4 times faster than the current method (sanding), is considered suitable to the topcoat high-speed removal condition.

Based on the above results, we devised a composite material paint stripping process that combines high-speed removal and selective removal conditions, as shown in **Figure 10**. By performing high-speed removal until any portion of the primer coat is exposed and then performing selective removal, the topcoat can be selectively removed at high speed and with minimal heat effects on the primer coat and base material. **Figure 11** shows the results of actual topcoat stripping using this process. It was confirmed that the topcoat was stripped off the laser-irradiated area with the primer coat remaining. It was also confirmed that no damage such as heat effect, layer delamination, or alteration was observed on the primer coat and base material, as shown in **Figure 12**.

As described above, the prospect of enabling selective removal of only the topcoat by appropriately selecting the fluence, and selective and high-speed removal of the target topcoat by adjusting the average power has been obtained. As for the removal quality, it was confirmed that the combination of the high-speed and selective removal conditions described above makes it possible to selectively removal the topcoat without damage to the composite material, such as heat effects and layer delamination.

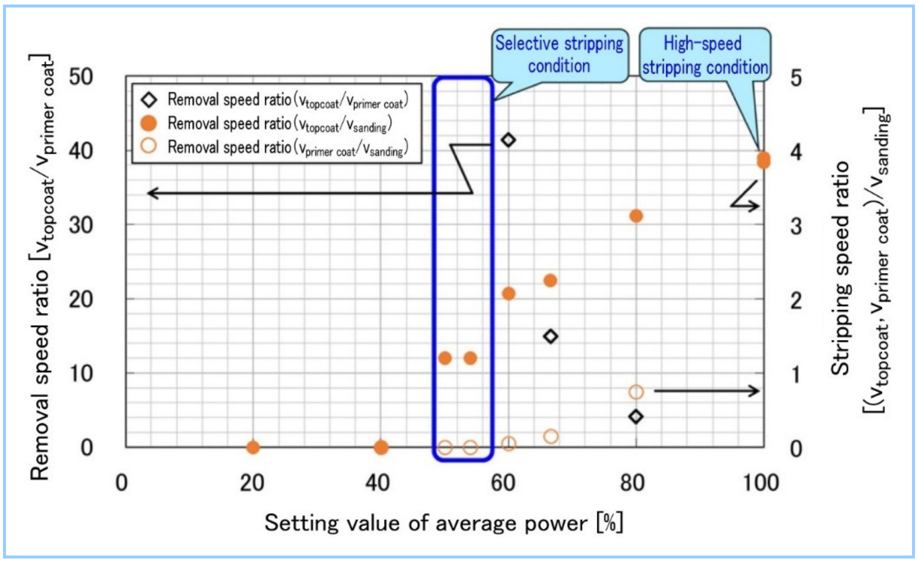


Figure 9 Relationship between removal speed ratio and average power setting value of each coat

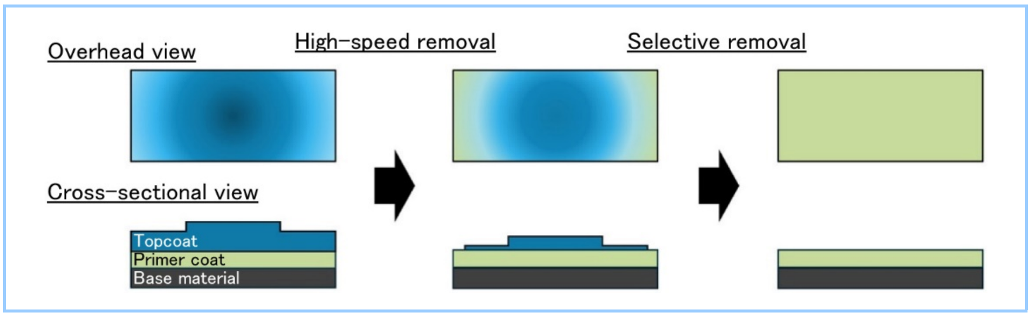


Figure 10 Illustration of removal combining high-speed removal and selective removal conditions

Figure 11 Appearance of test piece after paint stripping under combination of high-speed and selective removal conditions

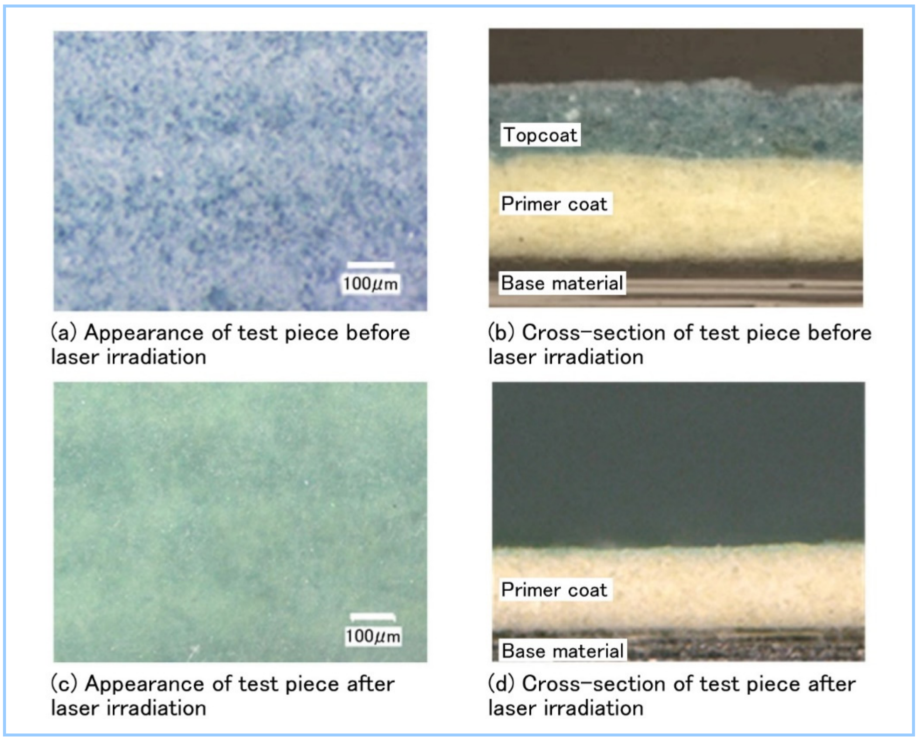


Figure 12 Surface and cross-section of test piece after paint stripping under combination of high-speed and selective removal conditions

4. Conclusion

This report described the development of a short-pulse laser paint stripping technology for composite material surfaces. To evaluate the capability of laser paint stripping, we checked the tendency of topcoat removal depth of single shot, line-scanning, and area-scanning, and confirmed that the removal depth of line-scanning and area-scanning could be represented by adding up the removal depths of single shot. To evaluate the heat input to composite base materials caused by laser irradiation, we investigated the temperature rise in laser irradiation using a thermocouple embedded between the base material and the primer coat. As a result, the maximum temperature was found to be about 85°C, sufficiently lower than the alteration temperature of composite materials, which verified that paint stripping with low heat input could be achieved.

To minimize damage to the base material, we studied the fluence (energy density) conditions that would allow selective removal of only the topcoat. Thus, we realized the possibility of selective removal of only the topcoat and suppressing removal of the primer coat layer, by adjusting the fluence to the range with which the topcoat removal speed is high and the primer coat removal speed is low. It is expected that this technology can improve the working environment properties and significantly reduce the waste of organic solvents, etc., as well as shorten the work time by eliminating some human work.

Moving forward, we plan to develop a technology for automatic removal of residual coat that may occur in laser paint stripping due to uneven coating layer thickness by combining the technology studied this time with an image recognition technology for detecting the residual coat, and to apply it to actual equipment. We will also continue to promote the development of laser paint stripping technology to expand the application of the technology studied this time.

References

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