Development of the "InfraLaser" System and the Laser Blasting Method for the Structure Repair of Infrastructures

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ABSTRACT In the repair works of Japan's infrastructure maintenance and management, there is a need to develop a technology that can easily remove coating and rust without a thermal effect on the base material, and the laser blasting technology, which can achieve this by only emitting laser beams, is a candidate for this goal. In various fields of infrastructure maintenance and management, we have been progressing on an agile system product development based on customer's feedbacks in accordance with our in-house systematized new business development process. In this report, we will describe the development of the "InfraLaser" system and the laser blasting technology, where we apply a high-power laser and the processing technology that we have cultivated. The laser blasting technology can remove coating and rust faster than existing methods without affecting the base material, and is expected to be friendly to both workers and environment.

1. INTRODUCTION

Since structures of Japan's infrastructure were intensively developed after the period of a rapid economic growth, the problem of aging has become more serious in recent years. It is said that the number of facilities that are more than 50 years old since their constructions will increase dramatically in the near future[1)]. Structures of infrastructures include the road field (bridges, tunnels), the electric power field (towers, electrical structures), the railroad field (towers, bridges, rolling stock, tracks, electrical structures), the industrial plant field (tanks), etc. for terrestrial infrastructures, and the ship field (hull plates, decks, port facilities), etc. for offshore infrastructures, and they are very diverse. Workers are indispensable for these repairs, but repair sites have a strong image as so-called "3D: Demanding, Dirty, Dangerous" workplaces, and it is said that workforce availability becomes more difficult. In addition, there is a 2024 issue of capping overtime hours in transportation and construction industries for the work style reform. Therefore, in a society with a declining population and rapidly aging society with fewer children, the amount of work per worker will have to be reduced. At the same time, it is assumed that the difficulty of securing workers will also increase. As a result, it can be said that the maintenance and management for Japan's structures of infrastructures is becoming increasingly difficult. In recent years, the use of high-power lasers as a surface treatment method in the field of infrastructure maintenance and management has been attracting attention[2)].

Since our establishment in 1884. we have been contributing to infrastructure constructions through the manufacture of power and communication cables. Contributing to maintenance and management of Japan's infrastructures is an important theme for us in order to protect safety, security, and comfort of people's lives in the future. Photonics technology, which we have cultivated through optical communications and laser processing, is one of our core technologies. With regard to a high-power Fiber Laser (FL), which is very effective in the laser method, we are one of the few Japanese manufacturers that can consistently manufacture a FL oscillator in addition to internal components such as semiconductor lasers for pumping, special optical fibers, fusion splicers, delivery cables, etc. at our group and affiliated companies[3)]. In addition, we are developing laser heads and high-power FL systems for infrastructure maintenance applications. Japanese customers expect us, Japanese manufacturers, to provide Japanese-based training for field workers, domestic maintenance support, and business continuity in the Japanese market in the era of Volatility, Uncertainty, Complexity, and Ambiguity (VUCA). From these perspectives, our customers can also feel the security and the Japanese style communication as values.

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We have newly launched the “InfraLaser” as a brand for our infrastructure maintenance business as a surface treatment solution for structures of infrastructures using high-power FL systems, and are further promoting rapid new business development and business expansion into this infrastructure maintenance market. This report describes the development of the “InfraLaser” system and the laser blasting technology for the repair of railroad and shipping fields.

2. COMPARISON OF EXISTING SURFACE TREATMENT METHODS AND OUR LASER BLASTING METHOD

Advantages of the laser method over surface treatment methods including existing blasting methods are listed below.

(1) Laser processing is possible with only the availability of a power supply, and no raw material is required.
(2) Industrial waste disposal costs associated with processing is extremely low.
(3) Salt removal by dry method is possible and return rust can be delayed.
(4) Vibration and noise during processing is extremely low.
(5) Since there is no reaction force during processing, the load to workers is low.
(6) It is suitable for automation and can be mounted on robots, drones, etc. in the future.

Based on above features, if the surface treatment method using lasers on the same level of the blasting method can be put to practical use, this method will be friendly to both environment and workers, and it is also expected to be a labor-saving technology of the future.

Broadly categorizing materials subject to repair structures of infrastructures, metals with anti-corrosive paint and concrete are the two major applications. In particular, metals with anti-corrosive paint account for many of them and removing deep rust that occurs in severe salt damage areas and aged anti-corrosive paint simultaneously becomes an issue. Table 1 shows a comparison of existing surface treatment methods, including existing blasting methods, and our laser blasting method. Surface treatment method and surface preparation prior to new paint are generally called “Keren” and are classified into 1st to 4th type. 1st type of Keren refers to the complete removal of black scale or red rust, which is an oxide layer of iron, and old coating using the blasting method to expose clean steel surface. 2nd type of Keren refers to the removal of red rust and old coating using wire brush or mechanical tools (needle scaler, disk sander, etc.) to expose the steel surface, but the removal is not complete and also, primer or rust inhibitor can remain.

As shown in Table 1, our laser blasting method (InfraLaser method) can handle from equivalent to 1st type of Keren to equivalent to 2nd type of Keren by varying the output power. In addition, compared to other methods, our laser blasting method has the advantage of being more friendly to both workers and environment in terms of salt removal, consumables, industrial waste, dust countermeasure, noise countermeasure, and reaction force countermeasure. Since the method is a blasting method that emits a laser beam onto the object, the only supply needed is electricity from a power source, and in order to enter the market, where common engine generators used in ordinary construction work are available for outdoor use, it is important to have a faster processing speed than existing methods. Therefore, it can be said that the goal is to achieve a processing speed equivalent to or faster than the fastest sand blasting method.

Table 1 Comparison of existing surface treatment methods and our laser blasting method.

	Our Laser blasting method	Sand blasting	Wet blasting	Machine tools	Stripper
Keren degree	Equivalent to 1st type Equivalent to 2nd type	1st type	Equivalent to 1st type	2nd type	Equivalent to 2nd type
Rust and coating removal	○	○	○	△	△
Salt removal	○	△	× Easy to return rust	×	×
Processing speed	△–○	○	△–○	×	× Multiple applications with water-based stripping solution
Consumables	○	×–△ Abrasive (circulating type is also available.)	△ Water (circulating type is also available)	× Abrasive material	× Stripping solution
Industrial Waste Countermeasure	○	× Abrasive + Coating	× Drainage + Coating	○	× Stripping waste liquid + coating
Dust Countermeasure	○	×	○	△	○
Noise Countermeasure	○	×	×	×	○
Reaction countermeasure	○	×	×	×	○

Remarks: ○ Optimal △ Suitable × Unsuitable

3. CHALLENGES OF EXISTING LASER CLEANING TECHNOLOGIES

The surface treatment using the laser is based on the principle of the "laser ablation". This refers to the phenomenon that surface constituent materials are released and transpired explosively either through laser light absorption and thermalization or with the subsequent plasma generation when high-power and high-density laser light is beamed onto the substance. Figure 1 shows the schematic diagram. Since the optical absorption rate of the laser beam differs between the rust/coating and the base material (e.g., steel or aluminum), it is possible to remove only the rust/coating or to form an anchor pattern to the base material together with the rust/coating removal, depending on the laser emission conditions.

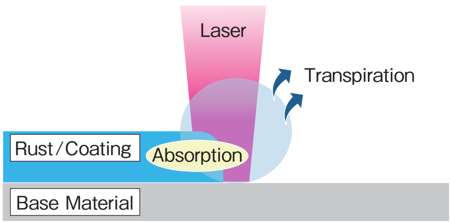


Figure 1 Schematic diagram of the coating removal using the laser.

The technology currently in practical use is called the "laser cleaning". In recent years, "laser cleaning" systems seen at exhibitions and on video websites are often equipped with nanosecond pulsed lasers with an average optical output power of several tens to several hundreds of watts class[4), 5)]. We also have a history of developing similar pulsed FLs and the pulsed FL-related components that make them up[6)], and we will describe some challenges of the pulsed method that we are recognizing. The laser oscillator systems include a pulsed solid-state (Nd: YAG) laser in the 1064 nm wavelength band and, more recently, a system equipped with a pulsed FL. The "laser cleaning" using the pulsed method is effective in removing machine oils and thin rust that forms on molds, and has been used in factory production processes for long time. On the other hand, it is difficult to remove deep rust and thick anti-corrosive coating formed in heavy salt damage areas in a short time, and we receive comments from customers that improvements are needed in terms of speed compared to the processing speed of existing methods.

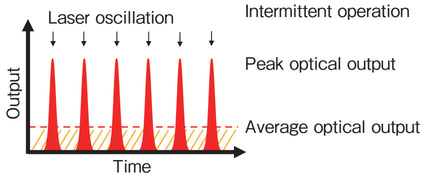
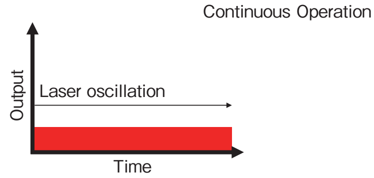
Nanosecond pulsed lasers with an average optical output of 500 W to 1 kW class can also achieve the coating removal under certain conditions. On the other hand, since the laser is emitted in pulses, the processing phenomenon occurs only when the pulsed laser oscillates, and it is necessary to scan the laser spot back and forth many times on the same spot, so improvement of the processing speed is a challenge. In this power band, the peak optical output is also high, ranging from several kW to 10 kW, so damage due to the laser ablation of the base material and thermal effects on the base material due to the continuous emission become problematic (later mention). In the case of the pulsed FL method, in addition to the peak optical output, the optical density is also high, so more attention must be paid to the damage caused by laser ablation of the base material. The overall problem with the pulsed laser system is that the power supply is supplied according to the peak optical output, so the power supply capacity required is large compared to the average optical output, and the housing size is huge, making it difficult to operate in the field. In addition, in many cases, a power transformer is required separately from the main unit if the product is made overseas.

4. FEATURES OF OUR LASER BLASTING METHOD

In order to realize a compact and easy-to-use system, we believe that a continuous wave (CW) type FL with a wavelength of 1070 nm, which generally has an electro-optic conversion efficiency of 30% or more and has an extremely high laser beam quality, is suitable. In order to increase the processing speed, it is effective to increase the optical output of the CW-FL. On the other hand, if the amount of heat emitted from the CW-FL onto the steel surface is large, the steel surface will melt at the same time as the coating is removed, causing a thermal effect on the base material. At the same time, the black scale, which is a stable oxide layer of iron, is formed on the molten steel surface. Since the black scale inhibits adhesion with the paint, in order to process at the same level of 1st type of Keren, it is our technology challenge to suppress the thermal effect on the steel material while applying high optical output CW-FL to increase processing speed. Although we will not go into details, we have solved this problem by making full use of our unique optical technology.

Table 2 shows the comparison of existing surface treatment methods using the pulsed laser and the CW laser method. In addition, Figure 2 shows cross-sectional microstructures of coated steel SM400B after the laser blasting using the pulsed laser method and our CW laser method (Chapter 6 Development of the "InfraLaser" system for the railway vehicle bogie repairs), respectively. The pulsed laser method and the CW laser method were compared with an average optical output of 500 W and a CW optical output of 500 W, respectively. In the pulsed laser method, since the peak optical output is several KWs and high, a spatter is generated during the laser blasting, resulting in the thickness reduction. On the other hand, in our CW laser method, a normal processed surface after removing the coating was obtained without thickness reduction. After the laser blasting shown in Figure 2, we evaluated the Vickers hardness Hv from the front surface to the back surface for the steel material to investigate the thermal effect (Figure 3). In the pulsed laser method, since it takes time to remove the coating, the Vickers hardness Hv increases near the surface and

Table 2 Comparison of existing surface treatment method using the pulsed laser and the one using the CW laser.

	Pulsed laser method	CW Laser Method
Image of laser oscillation		
Advantages	• Minimal thermal effects on base material.	• High processing speed. • Smaller power supply capacity.
Disadvantages	• Slow processing speed. • Thermal effect on base material occurs when average output is increased for coating removal. • Power supply capacity needs to be adjusted to peak optical output. • Thermal effect occurs when power is increased.	• Thermal effect occurs. Solved by our original optical technology.

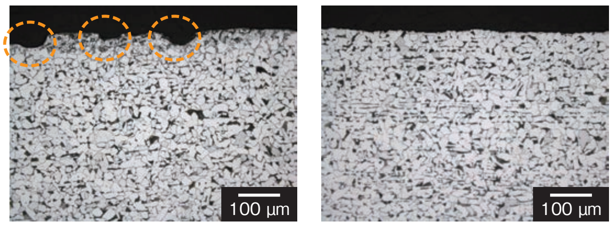


Figure 2 Cross-sectional microstructures of coated steel SM400B after the laser blasting using the pulsed laser method and our CW laser method, respectively.

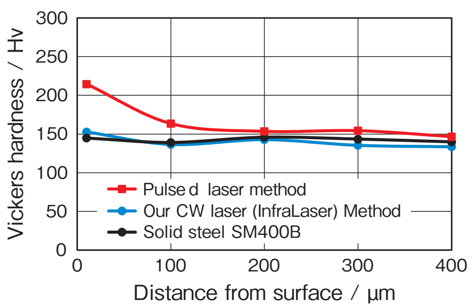


Figure 3 Evaluation results of Vickers hardness Hv from the surface to the back side for the steel after the laser blasting shown in Figure 2. Evaluation results for solid steel SM400B are shown as a reference.

the steel material is softened. On the other hand, in our CW laser method, the Vickers hardness overlaps with the reference solid steel SM400B's Vickers hardness Hv, it is confirmed that there is no heat effect or black scale generation during the coating removal.

5. METHODOLOGY FOR DEVELOPING THE "INFRALASER" SYSTEM

In the structures of infrastructure, since the objects to be repaired differ greatly depending on the industry sector, and also, the work-sites are different, systems that we receive as needs are different in many cases. Therefore, the laser blasting technology also needs to be optimized for each sector. In infrastructure maintenance and management field, since the anti-corrosive paint used are different, it is necessary to develop a prototype laser processing system and a processing technology appropriate for each sector. Therefore, we are developing the "InfraLaser" system by utilizing the new business creation process at fuzzy front ends. Our new business development process is described in detail in Reference[7].

Table 3 shows the development process of the "InfraLaser" system based on our new business creation process. In **Phase 0**, we will build a hypothesis where a laser processing method can be applied in the field of infrastructure maintenance and management. In **Phase 1**, we will conduct job searches based on hypotheses in a wide range of repair segments. In **Phase 2**, a concept prototyping, experimental equipment will be constructed by combining existing industrial laser equipment (later mention). In the creation of a verification field in **Phase 3**, since it is important for customers to experience our laser blasting, we opened the "InfraLaser Lab" at our Chiba

Table 3 Development of the "InfraLaser" system based on our new business creation process.

Development phase	Action item	Action items in the "InfraLaser" system and the method development
Phase 0	Knowledge acquisition	Hypothesis building for the application of the laser method in the repair field of infrastructure maintenance and management.
Phase 1	Job search	Job search through the introduction of materials to customers, etc.
Phase 2	Concept prototyping	Minimal experimental facility construction combining existing industrial laser products.
Phase 3	Verification field creation	Invite customers to visit the InfraLaser Lab to experience laser processing.
Phase 4	Product prototyping	Creation of an MVP by bundling customer feedback in Phases 1- 3 and field verification test.
Phase 5	Business scenario sharpening	Completion of the product realization process, including specification and design review (DR), and finalization of the sales format.

Works in January 2023 as a base for co-creation with customers (Figure 4)[8]. In **Phase 4** product prototyping, we will compile the feedback obtained at the “InfraLaser Lab” and create a Minimum Viable Product (MVP) based on the lean startup method. Since field verification test is also required for structures of infrastructure, we have also prepared a transportation truck for field verification test as shown in Figure 5. In addition, we are also the manufacturer of metal materials, mainly copper, where the metal technology is one of our core technologies. Metallurgical evaluation of base materials such as steel and aluminum can be performed by ourselves. On the other hand, since we have limited knowledge in structural materials, we are conducting joint research with Kyoto University in an industry-academia collaboration to evaluate it.

Figure 4 The InfraLaser Lab opened at our Chiba Works. Left: Exterior view of the building, right: Experiment space in the InfraLaser Lab.

Figure 5 The InfraLaser truck for the field verification test.

Finally, **Phase 5** will be the sharpening, which is the final step of the business scenario. Here, the product will be formally specified, a Design Review (DR) will be conducted based on the ISO9001 quality management system, and then, the commercialization process will be completed. We will also work with the sales department to establish the form of sales and maintenance. Toward the social implementation, we are actively providing education and suggestions for customers to use the “InfraLaser” systems safely while gaining a good understanding of customers’ worksites.

6. DEVELOPMENT OF THE “INFRALASER” SYSTEM FOR THE RAILWAY VEHICLE BOGIE REPAIR

Figure 6 is an external image of the compact “InfraLaser” system that has passed **Phase 4** of the development process shown in Table 3 and is scheduled to begin receiving orders from March, 2024 in **Phase 5**[9]. Since the welded parts of steel structures such as railway vehicle bogies are important for maintaining strength, there is a case where regular inspections are mandatory by law.

Figure 7 shows a picture of work with this product. Traditionally, mechanical tools such as needle scalers and sanders have been used to remove the protective coating from these welds, but dust, noise, and vibrations generated during the work put a burden on workers and became problems. In order to solve these problems, we developed and equipped a lightweight handheld laser head (weighing less than 2 kg) that can be safely operated with one hand, and that is designed to be easy to handle during maintenance. The flexible delivery cable with a length of 20 m is used, and the design with a consideration for an easy of handling on work-site was applied. The power supply capacity is also compatible with a three-phase 200V/20A power supply.

Figure 6 External picture of the compact “InfraLaser” system.

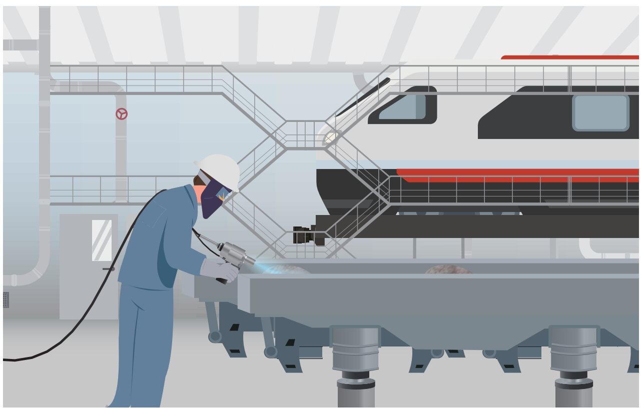
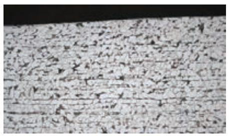
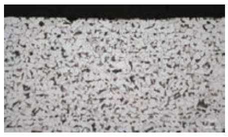
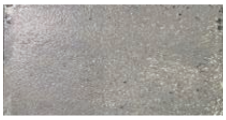
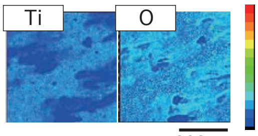
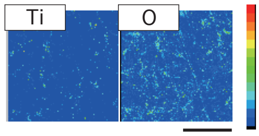


Figure 7 Picture of the processing work with our laser blasting method.

Table 4 **Comparison of laser processing results using machine tools (needle scaler) and those using our laser blasting method.**

	Machine tools (Needle Scaler)	Our laser blasting method
Cross-section view	 100 µm No change in microstructure.	 100 µm No change in microstructure.
Sample appearance	 10 mm With paint residue.	 10 mm No paint residue.
Paint information	Acrylic water-based paint, Gray color, Paint thickness: approx. 100 µm	
Residual element mapping by Electron Probe Micro Analyzer (EPMA) after processing	 200 µm Paint residue present. *Assessed by titanium (Ti) in paint components.	 200 µm No paint residue, No surface oxidation. *Surface oxidation is determined by oxygen (O).

In the development, we conducted an evaluation of laser processing on the coated steel for railway vehicle bogies. As a test specimen, we prepared a steel material SM400B with a thickness of 9 mm with approximately 100 mm. Its surface is painted with an acrylic paint (grey color). and the comparison after removing the coating using the mechanical tools method (needle scaler) and our laser blasting method was carried out. Table 4 shows the comparison results. As shown in Figure 8, processing speeds in these cases were 0.2 and 1.4 m^2/h using the mechanical tool method and our laser blasting method, respectively. Compared to existing mechanical tool methods, our laser blasting method can achieve a processing speed approximately seven times faster, and are also considered to be effective in a labor-saving in term of the work efficiency.

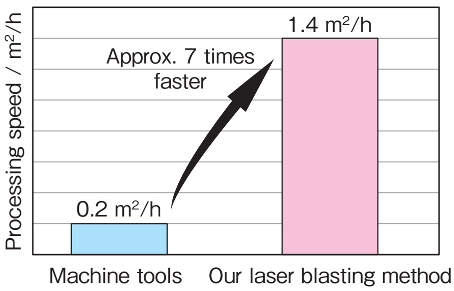


Figure 8 **Comparison of laser processing results using machine tools (needle scaler) and those using our laser blasting method.**

Comparing the optical microscope image and the surface photograph of the cross-sectional metal structure of steel material SM400B after the processing shown in Table 4, no difference was observed in the cross-sectional metal structure between the two after the processing. Next, a comparison of elemental mapping of titanium and oxygen using an Electronic Probe Micro Analyzer (EPMA) revealed that residual titanium contained in the paint and oxygen on the surface were detected in the mechanical tool processing. On the other hand, these elements were almost not detected in the laser processing. In general, the coating removal using mechanical tools is equivalent to 2nd type of Keren, which can be said to be a reasonable result with a small amount of paint residue remaining. In the laser processing, the surface of the SM400B steel material can be clearly exposed, and can be considered that the laser blasting technology is equivalent to 1st type of Keren. Furthermore, under these laser emission conditions, it has been confirmed that there is almost no thermal effect on the base material even after repeated emission 50 times. Additionally, safety has been confirmed that there is no change in the condition of pork or work clothes, which are intended to be skin, if the product is applied once by mistake under the same conditions as the laser processing. To prevent such accidental emission, the laser is fully equipped with an interlock, so workers can work safely by wearing laser safety goggles and work clothes with long sleeves and long pants.

7. DEVELOPMENT OF THE "INFRALASER" SYSTEM FOR THE SHIP HULL PLATE REPAIR

Ship transportation accounts for 99% of Japan's trade, and ships are important offshore infrastructure. Ships are required to undergo periodic inspections, and ships enter docks, and inspections and repairs are carried out. Sand blasting method shown in Figure 9, which shows a working view, is often used in ship hull plate repair (rust and coating removal) in Japan. The sand blasting method has issues in terms of its impact on the atmosphere and oceans due to the release of abrasive materials. The replacement to the laser blasting method, which emits extremely little waste, is expected to reduce the environmental burden and to improve the occupational health. On this assumption, Tsuneishi Shipbuilding Co., Ltd. (Located in Fukuyama City, Hiroshima Prefecture) was interested in this and provided us with a field verification test for the development of the “InfraLaser” system for ship hull plate repair[10].

Figure 9 Sand blasting operation.

Based on the development process shown in Table 3, a concept prototype of **Phase 2** was constructed using a 6 kW optical output FL used in laser welding applications and a Galvano scanner for laser welding. In addition, regarding **Phase 3**, in this case, as shown in Figure 10, a complete set of equipment was brought to Tsuneishi Shipbuilding Co., Ltd., and a laser emission experiment was carried out outdoors in May 2022, using rusted steel plates in heavy salt damage areas and a portion of ship hull plate as a ship. At this time, the processing speed for rusted steel plates in heavy salt damage areas was approximately 5 m^2/h. In order to handle thicker coating such as ship hull plate repair, it is necessary to master the use of laser beams with higher optical output and to achieve a processing speed equivalent to sand blasting. Customers told us that the welding Galvano scanner (approximately 25 kg) as processing equipment is far from a practical use in terms of weight. Then, we were able to recognize once again development issues. Therefore, in preparation for **Phase 4**, we began to develop a water-cooled laser head that is more compact, lighter, and capable of high-speed laser processing.

Figure 11 shows the developed water-cooled laser head with an optical output of 6 kW, the state when the laser is emitted onto a steel material (SS400) deeply rusted in heavy salt damage areas, and a photograph after the laser emission. The water-cooled laser head is lightweight, weighing approximately 4 kg. In addition, since no reaction force is generated during laser processing. we are developing an ultimate labor-saving technology that can be equipped on robots and other equipment as the “InfraLaser” system in the future (Figure 12). In this optical configuration, it is possible to emit laser beams with a width of 60 mm, and the laser blasting processing of approximately 20 m^2/h is possible on the steel rusted in heavy salt damage areas. This is a water-cooled laser head that can achieve processing speed that is equal to or higher than the one of sand blasting. Based on the development process shown in Table 3, we are proceeding with a product development toward the commercialization in 2025 with a system that is friendly to both people and environment in the shipbuilding industry.

Figure 10 Field verification test at Tsuneishi Shipbuilding Corporation using the conceptual prototype equipment.

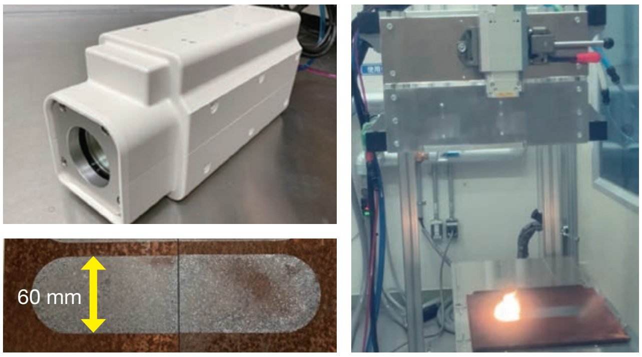


Figure 11 The 6 kW compatible laser head (upper left), the state during the laser emission (right), and the picture after the laser emission (lower left).

Figure 12 Image of the future development of the “InfraLaser” system for ship’s hull plate repair.

8. CONCLUSION

This report described the development process of the “InfraLaser” system and the laser blasting technology, as well as examples of development in the railroad and shipbuilding fields. The compact “InfraLaser” system for the railroad field can achieve a processing speed about seven times faster than that of conventional mechanical tools. Since the hand-held compact laser head enables easy operation without reaction force, the worker's workload can be reduced. In the ship field, we reported on the development of a water-cooled laser head that can achieve a processing speed equivalent to the existing sand blasting method. Since no reaction force is generated during laser blasting, we are promoting the use of automated robots as the ultimate labor-saving technology. Infrastructure maintenance and management fields are extremely vast, and we are planning to develop and propose optimal systems for other fields and sectors besides ships. we hope to contribute to Japan’ infrastructure maintenance and management as a domestic manufacturer capable of designing and manufacturing optimal laser systems in the field of infrastructure maintenance and management. Laser blasting technology using the “InfraLaser” is expected to be implemented in society as a very easy coating and rust removal system by increasing the speed of coating and rust removal beyond that of existing methods without affecting the base material. We hope to contribute to the “realization of safe, secure, and comfortable lifestyles,” as stated in our Group Vision 2030, through the society implementation in the field of Japan’ future infrastructure maintenance and management.

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