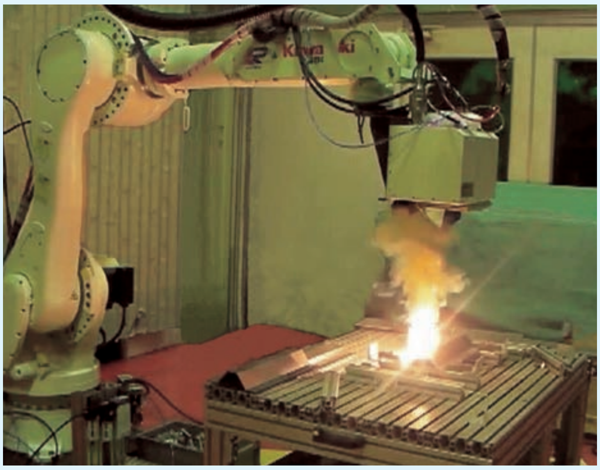
Advanced joining robot system



The environment surrounding the manufacturing industry is rapidly changing, and a reduction in energy consumption and a decrease in global warming gas emissions are being demanded of the industry. The demand goes beyond products to impact production processes, and a compatibility of a higher order between this demand and the quality of joints is needed. This paper describes the latest trends in Friction Spot Joining and Hybrid Laser-arc welding technology and how these technologies are applied.

Preface

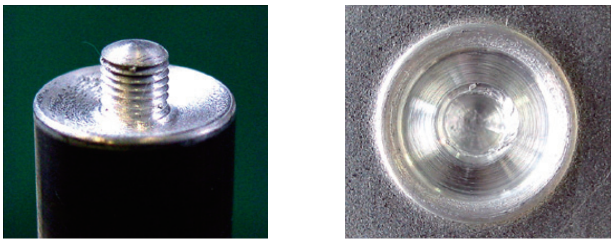
Robots arriving on the market from various manufacturers have shown remarkable improvements in robot unit performance, in operations speed and positioning precision, etc. However, this performance is evenly matched among the robots, and manufacturers are called upon to deliver higher cost performance by robot unit, or propose robot systems that come with auxiliary functions and additional functions. Auxiliary functions include handling, cutting, processing, joining, grinding and polishing, and various other production processes.

In particular, with regard to trends in joining technology, Friction Stir Welding (FSW), which was developed around 1990 by TWI (The Welding Institute) in Britain, is mainly applied to aluminum alloy railway cars, while Friction Spot Joining (FSJ), which was developed by Kawasaki as a further application of FSW, has been introduced to the production lines of automobile manufacturers, and the number of car models and vehicles using FSJ is steadily increasing. In addition, rapid advances in electronic devices over the past few years have led to improvements in controls and monitoring functions for conventional arc welding and resistance spot welding. As for laser oscillators, whose application is growing at a remarkable rate, efforts are underway to increase output capacity mainly in fiber lasers.

1 Friction Spot Joining (FSJ)

(1) Overview of FSJ

FSJ is performed using the joining tool shown in Fig. 1, featuring a threaded protrusion (probe) at the front tip. As a result, in the joining area an indentation is left behind where the probe was pressed in. The joining process is performed in three stages, as shown in Fig. 2. Two workpieces stacked on top of each other are first softened through friction heat generated between the rotating pressing tool and the workpieces, and then joined by having the upper and lower materials stirred by the probe threads. Then, the joining tool is extracted without moving in the direction of the workpiece surface to complete the joining process.



(a) FSJ joining tool (b) Joint

Fig. 1 FSJ joining tool and joint

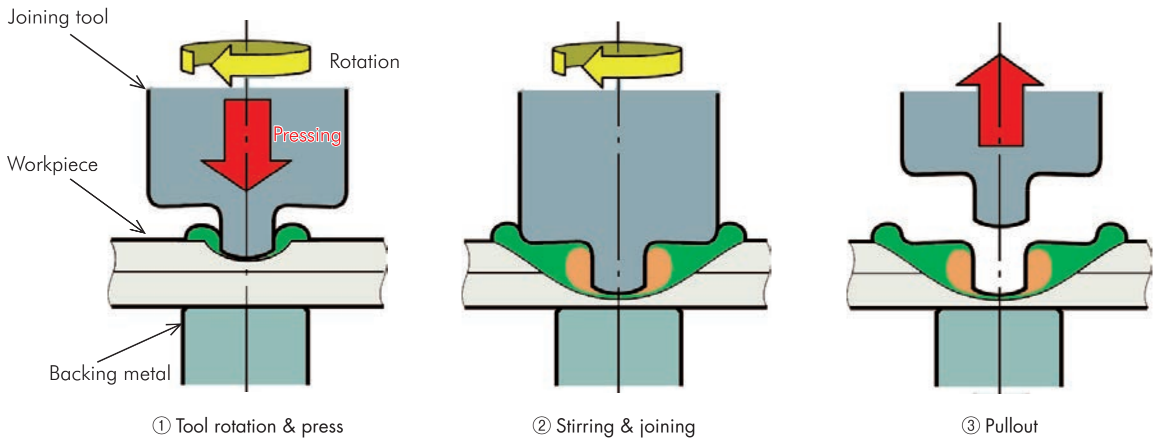


Fig. 2 Schematic diagram of FSJ joining process

(2) Conditions surrounding FSJ

In transport equipment sectors centering on the automobile industry, demand is rising for energy savings and reduction of global warming gas emissions.

Moreover, these needs are not limited to automobiles, aircraft, railway cars, marine vessels, and other products, but also extend to the manufacturing processes as well. As a result, energy savings in the manufacturing process have become an urgent issue in addition to creating lighter vehicle bodies.

(3) Applications in automotive industry

In the automobile industry, high tensile strength steel, light alloys such as aluminum alloys, and resin materials are finding increasing application mainly for the external plates of vehicle bodies to achieve lighter weight. With the application of materials other than the conventional steel, there is demand for introduction of new processes in cutting and joining processes, and within the joining process, FSJ is finding wider application for spot joining, a technique that is frequently used in external plate joining. Since a wide variety of workpieces flow through automobile production lines, an industrial articulated robot has been introduced to enable handling the various welding points of each workpiece. This robot can be used to perform high-precision repetitive joining operations by teaching not just the operation positions but also the tool pressing force, rotation speed, and other elements of the joining operation. An FSJ robot is configured by mounting an FSJ gun on a mid-size robot with a payload capacity of 165 kgf or 200 kgf, as shown in Fig. 3. Among automobile manufacturers in Japan, aluminum alloy is often used in the front hood, back door, or other so-called cover items, as shown in Fig. 4, and FSJ is used as the joining method. There are already more than 200 FSJ robots out in the market, which have been used on more than 1 million vehicles.

Fig. 3 FSJ robot

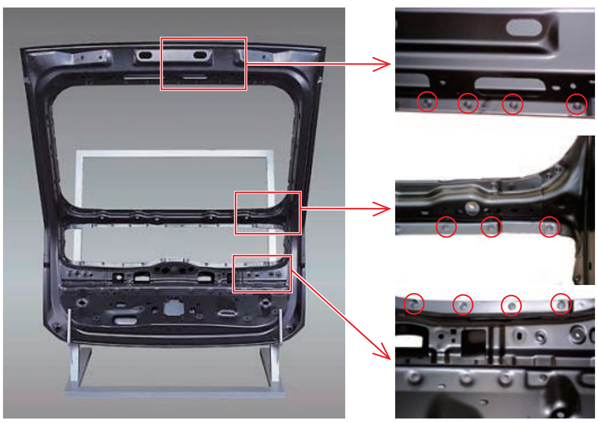


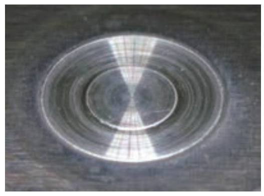
Fig. 4 Example of FSJ application

(4) Applications in aircraft industry

As with external plates of automobile bodies, aircraft fuselage joining involves frequent use of spot joining at lap joints. However, since bumps and indentations due to probe pressing, excess metal, and other factors are severely restricted, demand for application to fuselages is not for the conventional FSJ that leaves a hole, but rather for development of a hole-free FSJ[1)]. Kawasaki is not the only company researching application of hole-free FSJ to aircraft. Overseas, Boeing and Airbus are pursuing research in cooperation with research institutions, and we expect that research will accelerate in the future.

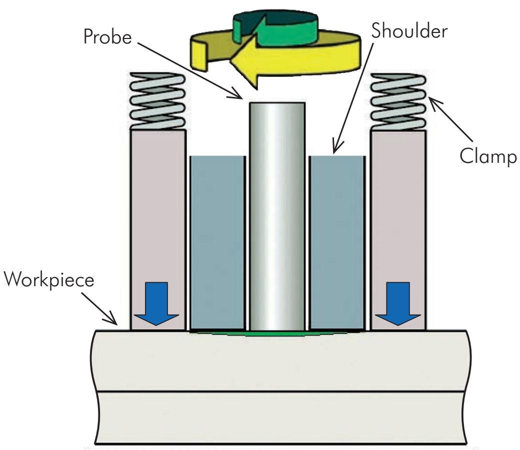
External views of the front end of a hole-free FSJ joining tool and the joint produced with it are shown in Fig. 5. The joining tool is concentrically divided into a probe and shoulder, and we developed a joining method that uses a clamp surrounding the tool for a smooth external appearance after joining. While the newly developed joining process is complex as shown in Fig. 6, the joining mechanism is the same as the conventional FSJ, which involves softening the material with friction and blending it through stirring. The workpiece materials move in response to tool pressure and pullout. The flow of materials in a hole-free FSJ joint is shown in Fig. 7.

(a) Front end

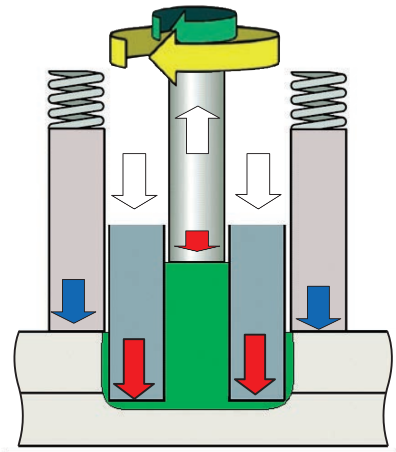


(b) Joint

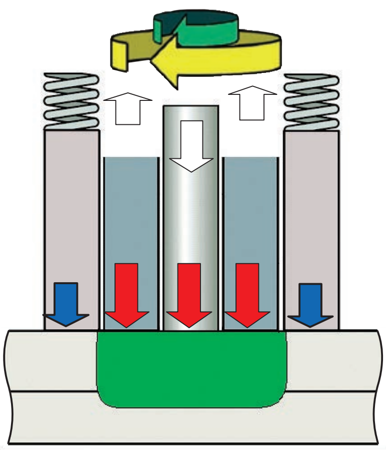
Fig. 5 Front end of hole-free FSJ joining tool and joint



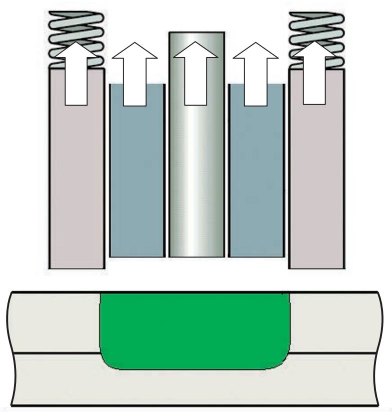
(1) Tool pressing



(2) Stirring & joining



(3) Backfilling



(4) Pullout

Fig. 6 Hole-free FSJ joint process

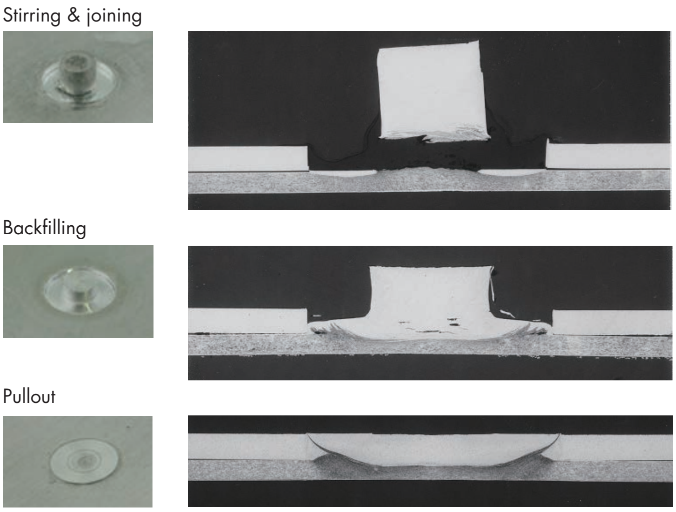


Fig. 7 Materials flow in hole-free FSJ joint

(5) Trends toward standardization

FSW, the joining method on which FSJ is based, had been the subject of efforts to make it an international standard since 2004, and the International Standards Organization (ISO) standardized it in FY 2011. Since its adoption by JIS will ensue in line with the ISO standard, FSW is expected to spread rapidly in Japan as well.

There have also been moves to standardize FSJ at ISO since 2006, and in 2009, Japanese device manufacturers, users, and neutral institutions have established a committee centering around the Japan Light Metal Welding & Construction Association, participating in international conferences toward the standardization of FSJ. Japan is the only country in the world where FSJ is put to practical use, and it plays a leading role in design policies and evaluation methods. Kawasaki in its role as a device manufacturer has been attending committees in Japan and overseas as a chief organizer.

2 Laser-arc welding

Companies that make use of arc welding, laser welding, and other fusion welding are demanding increased product competitiveness through improved productivity and quality. Issues related to fusion welding involve reduction of distortion in welding and control of materials quality degradation.

(1) High-current MAG (Metal Active Gas) welding

In arc welding, which is used for thick plates, we have achieved improved productivity by shrinking the size of the grooves where the weld metal is filled, and increasing the amount of weld metal filled in a single weld. However, if the groove becomes smaller, the arc sometimes cannot reach the bottom of the groove, resulting in fusion defects, etc. In addition, if the welding current is increased, once the current exceeds a certain level, the weld current and the magnetic field arising from the weld current interact, causing liquid droplets to form rotating arcs, which result in a spattered external appearance (Fig. 8). Therefore, we developed the high-current MAG welding method, which concentrates the arc to ensure adequate fusion even at the bottom of narrow grooves, thereby obtaining smooth external appearances even with large current. We have adequately grasped the characteristics of this welding method and implemented it in our robots to improve the efficiency of thick-plate welding.

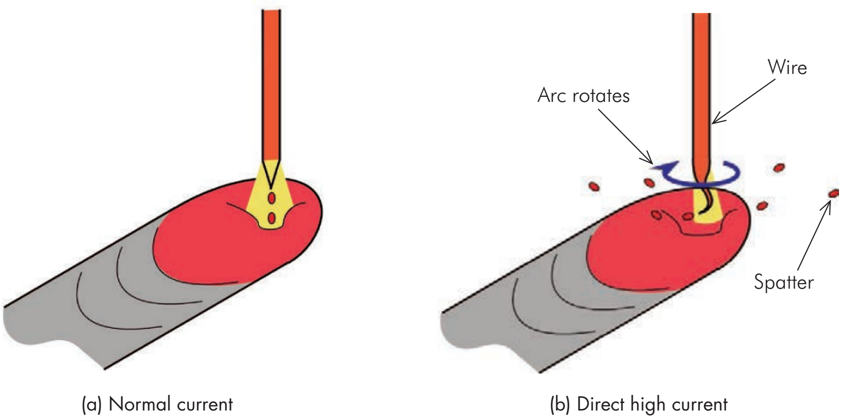


Fig. 8 Rotating arc in high-current welding

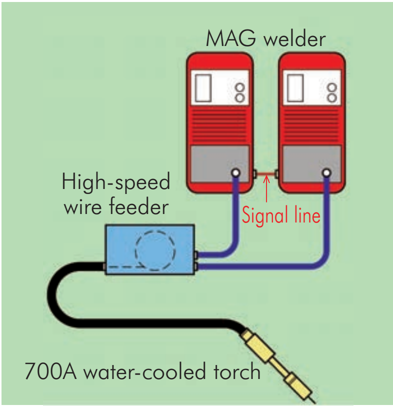
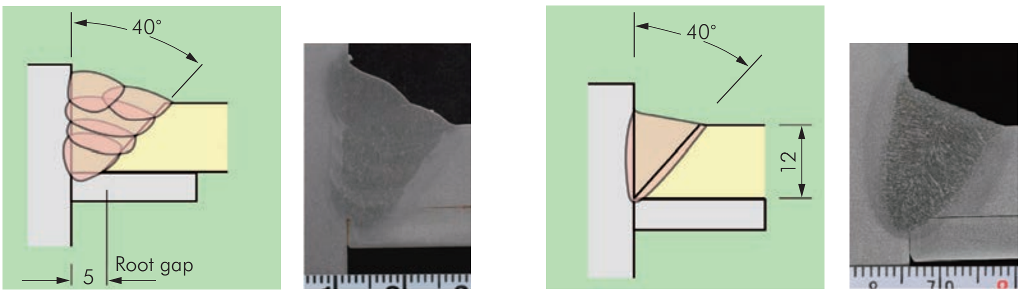


Fig. 9 Device configuration in high-current MAG welding

(i) Principles of high-current MAG welding
As shown in Fig. 9, high-current MAG welding uses two welding power sources and is used in combination with a welding torch capable of withstanding large welding current. With such large current flows, if we simply connect two welding power sources, it can result in a rotating arc and a decline in welding quality. Therefore, we carefully control the current from the welding power sources to achieve a suitable weld droplet transfer even with large current flows.

(ii) Benefits of introducing high-current MAG welding
This welding method has fewer execution paths and smaller grooves than joints formed within a conventional current range, reducing execution time and distortion. For example, the root gap as shown on the left side of Fig. 10 is closed to virtually 0 mm, reducing the amount of welding metal to be filled nearly by half. The right side of Fig. 10 shows a cross-sectional macro photograph of a joint executed within a conventional current range, and a joint executed with high-current MAG welding. With high-current MAG welding, we see that the welding reaches the bottom of narrow grooves, producing good joints with no defects.

In addition, as can be seen from the shape of the joint in Fig. 10, shrinkage of the welding metal is known to result in deformation toward the narrow side of the groove after welding (angular deformation). Fig. 11 shows the external appearance of test samples of both welding methods. We see here that while angular deformation of about 5 degrees occurred with the conventional welding method, this was reduced to about 1 degree with the high-current MAG welding method.



(a) Conventional welding method (b) High-current MAG welding method

Fig. 10 Joint geometry and cross-sectional photo for high-current MAG welding process and conventional welding process

(a) Conventional welding method (b) High-current MAG welding method

Fig. 11 Comparison of deformation between high-current MAG process and conventional welding process

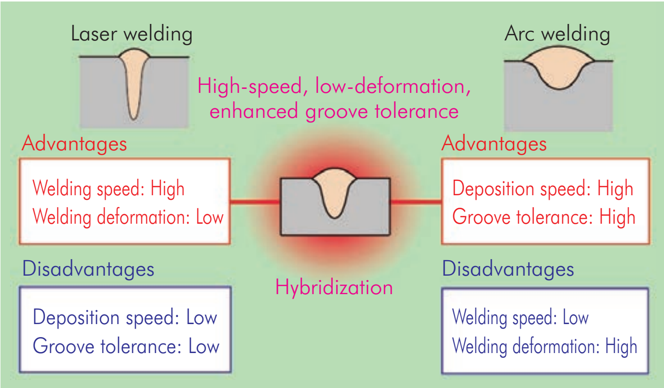


Fig. 12 Advantages of Hybrid Laser-arc welding process

(2) Laser welding

In heavy industries, high quality lasers such as fiber lasers using optical fiber for laser resonance media, and disk lasers using disks for the media constitute the mainstream of laser welding. We at Kawasaki apply laser welding for vehicle side grooves to achieve improved external appearance quality compared with conventional resistance spot welding. Vehicle models and the number of vehicles using laser welding are steadily increasing, with further expansion expected in the future. In addition, we are proceeding with research into a Hybrid Laser-arc welding that can be used together with arc welding. Hybrid Laser-arc welding is a welding method that combines the advantages of both laser welding and arc welding (Fig. 12). We are also advancing research and development into such new welding methods as the remote laser, which operates an optical mirror positioned at a distance from the workpiece at high speeds to perform welding.

Concluding remarks

While joining technology is often said to be a mature field, the appearance of new joining methods such as FSJ and the trend toward increased laser oscillator output show that the joining process in the production lines may actually be entering a period of transformation. Going forward, we will actively introduce these new joining methods to contribute to improved product quality and productivity both at Kawasaki and other companies.

Kazumi Fukuhara
System Engineering Department,
Automotive Group,
Robot Division,
Precision Machinery Company

Doctor of Engineering
Mitsuo Fujimoto
Manufacturing Technology Department,
System Technology Development Center,
Corporate Technology Division

Hideaki Kurokawa
Manufacturing Technology Department,
System Technology Development Center,
Corporate Technology Division

Professional Engineer (Mechanical Engineering)
Mitsuichi Hiratsuka
Control System Department,
System Technology Development Center,
Corporate Technology Division

Reference

1) Fujimoto, M., Okada, H., Kamimuki, K.: "Application study of refill FSSW on Aerospace Industries," 9th International Friction Stir Welding Symposium (2012)