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***Research paper***

# Development of High-Strength Ring Bolt Manufacturing Technique Using Friction Welding

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**Abstract**

In this study, a ring bolt manufacturing technique using friction welding is proposed in order to improve the manufacturing process of the ring bolt. A ring bolt is an automotive part that fixes the position of the automobile's handle when the handle is tilted. First of all, the shape design of the ring bolt is proposed and the optimum friction welding conditions, which directly affect the quality of friction welding, are derived. The experimental results show that the tensile strength (load) of the ring bolt, manufactured using friction welding, is better by 12% than that of products manufactured via the conventional method.

***Keywords***: *Ring bolt, Friction welding, Optimum friction welding factor, Welding condition*

## 1. Introduction

A ring bolt is one of the components of an automotive steering system that fixes the position of the handle when the steering wheel is tilted. Conventional ring bolts were manufactured by hot forging and then pressed to form shapes, which were then fabricated using composite processing. With the conventional method, excessive material and process cost, including mold expense, were required, resulting in exceedingly high manufacturing cost. It would be beneficial in handling the cost aspect if ring bolts are produced by friction welding since tool cost and process cost can be considerably reduced. Friction welding, which is the basic technology of this study, is a process of joining materials using friction heat generated at the contacts by making materials having a relative motion (rotation) while pressed against each other [1, 3, 19].

This process is a unique welding method which reverses the friction phenomenon that has been treated as damaging and reducing the efficiency of the machine. Since the welding surface is only locally heated, the heating area (heat affected part) is minute and uniform compared with other welding methods. The advantage of less deformation and the tensile strength of the joint are also superior to those of the base metal. It has better energy efficiency compared with arc welding; thus, joining is possible even with a slight energy of 10-20%. Furthermore, this environmentally friendly welding method does not emit toxic gas like carbon dioxide [1, 3, 19]. In addition, it doesn't create a casting structure during welding, resulting in excellent mechanical property. It is known to be suitable for high-quality, high-accuracy, and high-strength welding since parameters that affect accuracy and bonding are easily controlled [1, 3, 19]. However, there are limitations in friction welding. Since one side of the base metal should be rotated, the shape becomes limited as a circular one. Furthermore, the long materials or the material which is fixed and not rotated, or the material having a large mass or asymmetrical mass is difficult to use for friction welding. Meanwhile, the tensile strength and fatigue strength of the friction weld are either same as or higher than the material, but impact toughness may be impaired. Particularly, since flash is generated due to distortion and compressive deformation, the fiber structure of the matrix is flown towards the discharge direction of the flash; that is, the vertical direction and the toughness tend to be reduced [1, 3, 19]. For reference, flash means a material that is plastically deformed as a protrusion that occurs around the friction weld when pressure is applied to the base metal using friction heat. Despite these drawbacks, the friction welding is widely being expanded and the drawbacks are being improved by the technology development. To overcome such limitations, radical or reciprocating friction welding method, friction surfacing, and friction stir welding are developed to expand the use scope of friction welding [15]. The problem of poor toughness at the weld area can be resolved by deciding the location, shape, and size of the pressurized bonding area, considering the issues during part design [4, 11, 12].

This study aims to develop a ring bolt manufacturing technology that can remarkably improve the manufacturing issue of the ring bolt which is one of the automobile steering devices. In this study, the problem in the existing manufacturing process of the ring bolts is analyzed and the new design of the shape of the ring bolt is proposed to make friction welding executable. Lastly, the correlation among welding qualities by the interaction of contacting time, compression time, and upset time, which are parameters of friction welding, are investigated to draw optimum welding conditions that directly affect the quality of the friction welding.

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## 2. Analysis of Research Status

Studies about the characteristics of friction welding for the heterogeneous materials were conducted by Oh [16, 17, 18], Jeong [6], Kong et al.[14] and Kang [7,8], and the researches about the decision factors, applications, and strengths of the friction welding are actively progressing to date. Yang [23] has performed research considering the strength and toughness of the weld area by rotation number, friction compression force, upset forging compression pressure, friction heating time, and upset forging compression time for the optimization of friction welding between the heterogeneous materials (STD11 and SCM440). The results confirmed that the joining efficiency of the weld area became more than 100% by drawing the optimum condition for the friction welding, which indicated that friction welding can provide an excellent welding quality. Kong et al. [13] conducted the friction welding for heterogeneous materials between existing forged part SF45 and carbon steel SM45C. After the friction welding performed under the optimum condition, the rotatory fatigue test was conducted for the welding material (as-welded) and post-weld, heat-treated material. The two materials for friction welding were strongly mixed with a well-combined structure of micro-particles without any molten material, particle growth, or defect. Kang et al. [8] used the testing plan method to optimize the process during the friction welding of the AZ31 magnesium alloy. They proposed an optimum friction welding condition using orthogonal array method based on the tensile test results, according to bonding conditions such as fixed rotation number of the spindle, heating pressure, heating time, upset pressure, and upset time for experimental statistical analysis. Sun et al. [22] proposed the welding conditions suitable for AZ61 magnesium alloy sheet by applying various welding speed parameters at the same rotation speed. The mechanical properties evaluation and micro analysis were performed with the results to propose an optimum welding speed with the best bonding efficiency. Chung [4] investigated the problems in the assembly process of the base, which is an automobile shock absorber part, and proposed a base assembly technology using the friction welding that can remarkably improve the problems. He proposed the shape design for the base shell and base cap to implement friction welding. He demonstrated how the tensile strength (load) of the cap assembly and base assembly were improved by friction welding using the optimum parameters. Meanwhile, researches about various materials for friction stir welding (FSW) actively progress throughout many industries ever since it has been developed by the Welding Institute in England in 1991 [5, 20]. The FSW is a solid-phase bonding process that does not use a filler metal. It is known that there is no air pore or crack generation by melting or solidification, the welding deformation is small, and the mechanical properties such as tensile strength, elongation, and residual stress are excellent compared with existing metal inert gas (MIG) [2, 9]. As a major research about FSW, Sun et al. [10, 21] have analyzed the temperature characteristics when welding the magnesium alloy through the experiment and analysis, proceeding with research about the mechanical properties of the welded part. Choi [2] investigated the applicability of FSW on the railway car body by analyzing the effect of the transfer speed of the rotatory tool during the FSW of the Al-6005 T6 extrusion material, which is mainly used in the railway car body on the microstructure and mechanical structure of the above alloy. Kim et al. [10] analyzed the welding characteristics of the FSW for the magnesium alloy AZ31 using flow analysis technique.

## 3. New Ring Bolt Manufacturing Process and Shape Design Using Friction Welding

### 3.1. Problems in the Existing Ring Bolt Manufacturing Process

The ring bolts were traditionally manufactured by making shape with press after hot forging and then a complex process was applied.

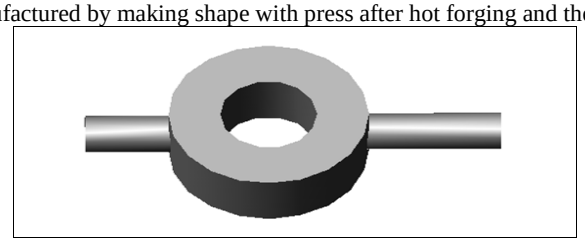
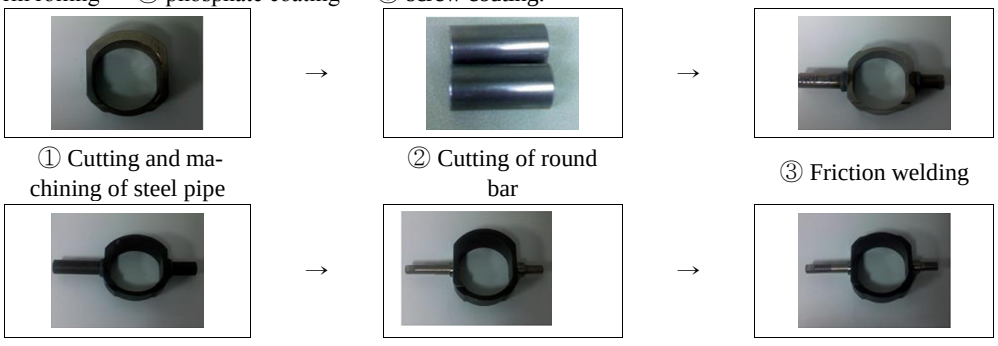


**Fig. 1**: Integrated ring bolt part

The weight of the ring bolt made by the existing process was measured as 350 grams. Therefore, with the conventional method, excessive material and process cost, including mold expense, were required, resulting in exceedingly high manufacturing cost. However, if ring bolts are produced using a friction welding method, tool cost and process cost can be significantly reduced, which is beneficial at a manufacturing cost aspect. Figure 1 below shows the existing integrated type ring bolt.

### 3.2. Ring Bolt Manufacturing Process Using Friction Welding

The high-strength ring bolt manufacturing process using friction welding is composed of eight processes as follows: ① cutting and machining of steel pipe → ② cutting of round bar → ③ friction welding → ④ heat treatment (annealing) → ⑤ flash cutting and turning → ⑥ milling and form rolling → ⑦ phosphate coating → ⑧ screw coating.




① Cutting and machining of steel pipe

② Cutting of round bar

③ Friction welding

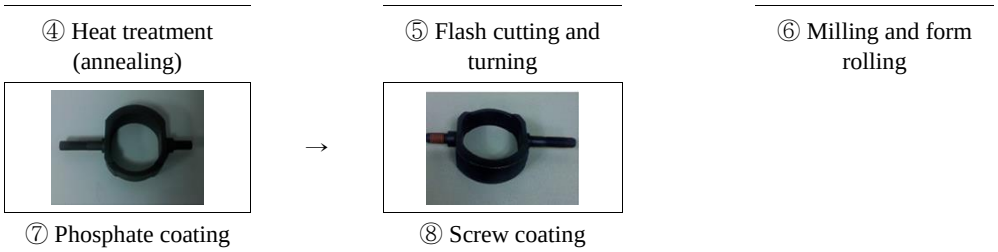



**Fig. 2:** The new ring bolt manufacturing process using friction welding

First, steel tube is cut and processed to make a ring. After that, the ring rod is cut and then the ring and ring rod are joined by friction welding. Adequate heat treatment and machining follow and then the parts are coated. The new ring bolt manufacturing process using friction welding is shown in Figure 2.

The ring bolt developed in this study was manufactured by joining the round bar at both ends and the ring at the center by friction welding unlike the process wherein the ring bolt was processed by conventional integrated hot forging followed by machining its shape. In the improved method, the ring at the center is prepared with the hetero-type steel pipe by drawing process (ERW), and the ring and round bar so prepared are joined by friction welding. Accordingly, the weight of the ring bolt is drastically reduced from 350g to 180g so that material consumption is reduced and mold expense for forging is saved, which makes the resulting product excellent in terms of saving manufacturing cost.

### 3.3. Ring Bolt Material Change and Physical Characteristics Analysis

When the friction welding is applied in the ring bolt manufacturing, a problem of tensile force deterioration can occur. To prevent such a problem, the ring bolt material was changed from the conventional S20C to the steel pipe S45C. S20C material was used because the shape of the ring bolt was machined after hot forging in the conventional method. However, if friction welding is implemented in this case, tensile force can be weakened. Low tensile force may be resolved by using the material S45C, which has a higher carbon component. Detailed steel type and composition analysis results are tabulated in Table 1 and Table 2 below.

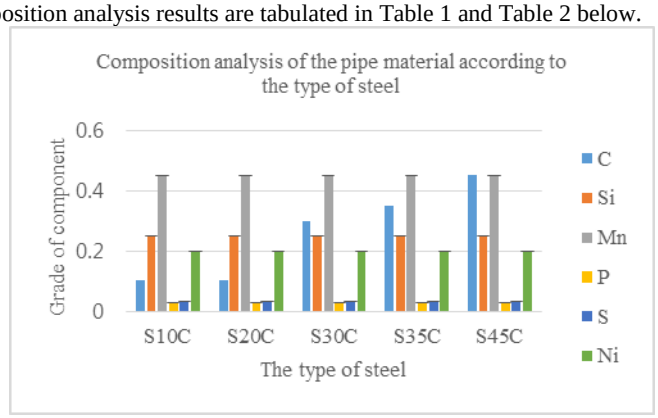



**Fig. 3:** Composition analysis of the pipe material according to the type of steel

**Table 1:** Composition analysis of the pipe material according to the type of steel

| Grade | S10C | S20C | S30C | S35C | S45C |
|---|---|---|---|---|---|
| C | 0.08-0.13 | 0.18-0.23 | 0.27-0.33 | 0.32-0.38 | 0.42-0.48 |
| Si | 0.15-0.35 | 0.15-0.35 | 0.15-0.35 | 0.15-0.35 | 0.15-0.35 |
| Mn | 0.3-0.6 | 0.3-0.6 | 0.6-0.9 | 0.6-0.9 | 0.6-0.9 |
| P | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| S | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |
| Ni | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

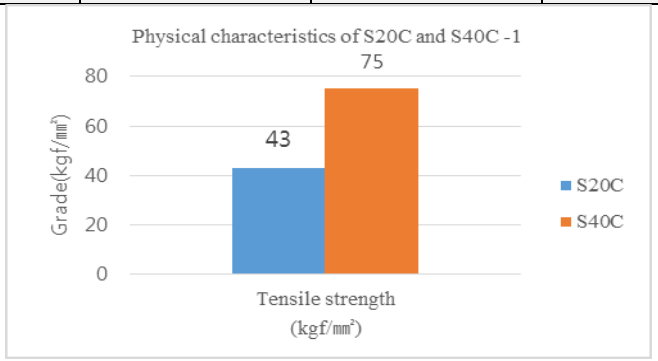



**Fig. 4:** Physical characteristics of S20C and S45C

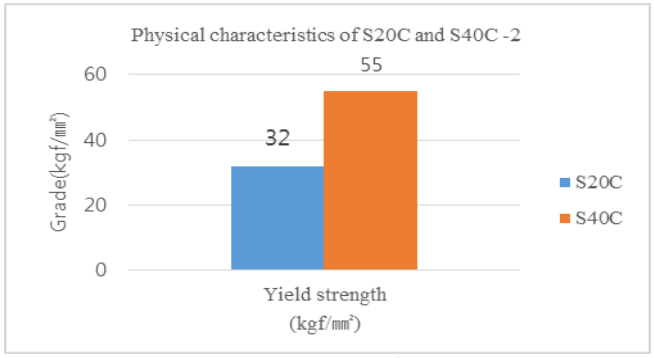



**Fig. 5:** Physical characteristics of S20C and S45C

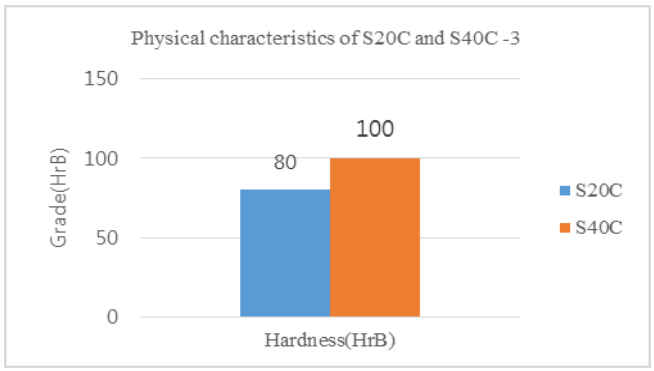



**Fig. 6:** Physical characteristics of S20C and S45C

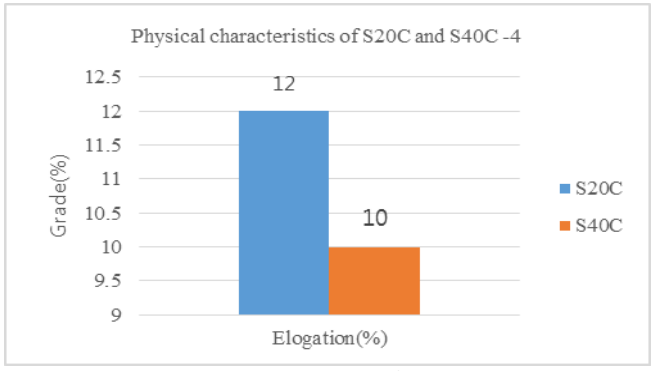



**Fig. 7:** Physical characteristics of S20C and S45C

**Table 2:** Physical characteristics of S20C and S45C

| Grade | Tensile strength (kgf/㎟) | Yield strength (kgf/㎟) | HrB hardness | Elongation (%) |
|---|---|---|---|---|
| S20C | 43 | 32 | 68-92 | 12 |
| S45C | 75 | 55 | 95-105 | 10 |

### 3.4. Ring Bolt Shape Design

It is necessary to change the shape of the ring among the components of the conventional ring bolt in order to apply the friction welding in the ring bolt manufacturing. The process involves a design change necessary to make base material at one side fixed, while the other side of the base material is smoothly rotated on the same axis. The shapes of the ring bolt before and after design change are shown in Figure 8.

The photos of the ring holding the jig design at the fixing side and fabricated jig are presented in Figure 9.

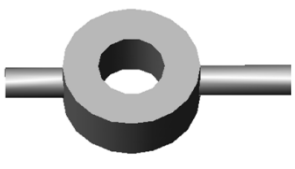
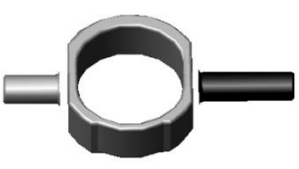
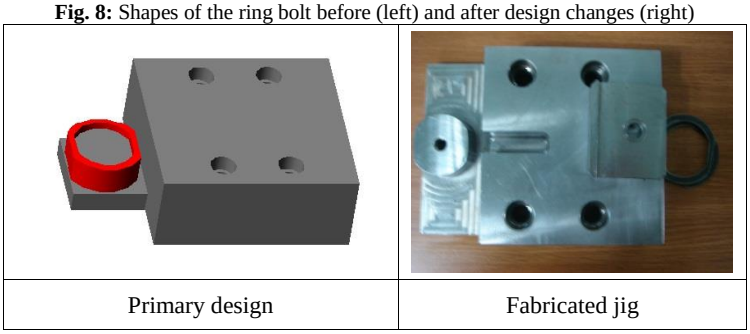
| | |
|---|---|
|  |  |
| Ring bolt produced through the existing method (hot forging) | Ring bolt shape through the changed process |

**Fig. 8:** Shapes of the ring bolt before (left) and after design changes (right)



| Primary design | Fabricated jig |
|---|---|

**Fig. 9:** Ring holding jig design at the fixing side and fabrication

## 4. Setting of Control Conditions for Friction Welding and Experimental Results

### 4.1. Ring Bolt Shape Design

The key parameters that directly affect the welding quality during ring bolt processing are contact pressure (P0), compression pressure (P1), upset pressure (P2), contacting time (T0), compression time (T1), and upset time (T2) as shown in Figure 10. The contact pressure (P0) refers to the pressure at the starting time (T0) when two materials to be joined come into contact, while compression pressure (P1) refers to the pressure at the starting time (T1) when the upset is possible while two materials contact each other and heat of friction is generated. When the heated condition of the friction part is appropriate (T1, P1), rotatory shaft is stopped abruptly by brake and then upset pressure is instantly imposed for upset time T2 to complete the bonding of two materials. The maximum pressure at this time is referred to as upset pressure P2 [1, 3, 4, 19].

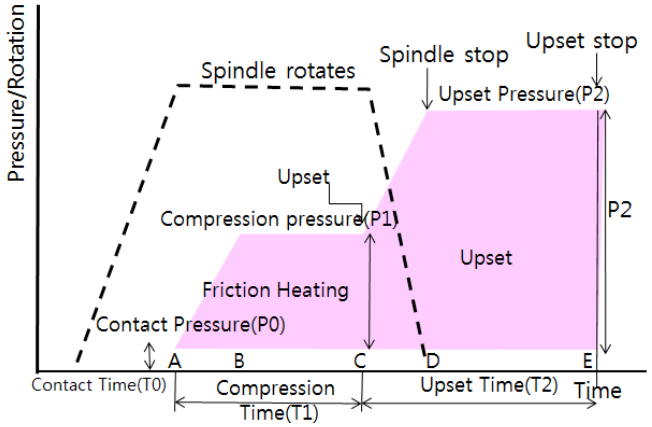
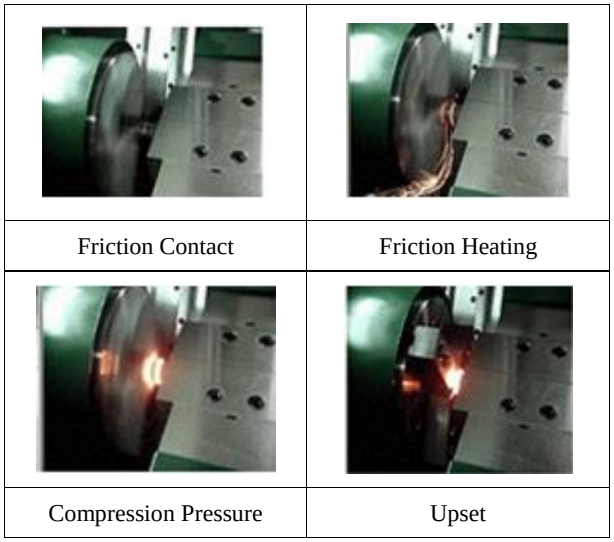



**Fig. 10:** Control Condition of Friction Welding and Cycle



| Friction Contact | Friction Heating |
|---|---|
| Compression Pressure | Upset |

**Fig. 11:** Cycle of Friction Welding

### 4.2. Setting of Control Condition of Friction Welding to Join Ring Bolt

In this study, experiments were repeated by varying contact time, compression time, and upset time to determine the optimum control conditions for friction welding which is to be implemented in joining the ring bolt. First, the contact time (T0) was set at 0.3, the compression time (T1) was set as three levels (1.0, 1.5, and 2.0), and the upset time (T2) was set as two levels (1.5 and 2.0). Meanwhile, the

contact pressure (P0) was set as two levels (45 and 55), the compression pressure (P1) was set as three levels (45, 55, and 65), and the upset pressure (P2) was set as two levels (75 and 85). After setting each condition, a total of 72 rounds of experiments were conducted. The control condition which yielded the best tensile strength (2,487) during experiment was set as the optimum control parameter for joining the ring bolt as shown in Table 3.

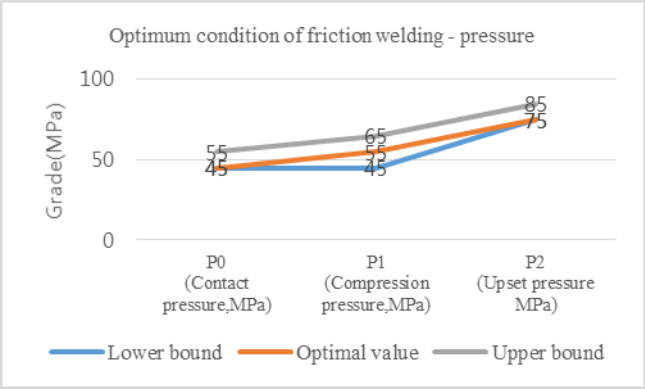



**Fig. 12:** Optimum conditions of friction welding to join the ring bolt

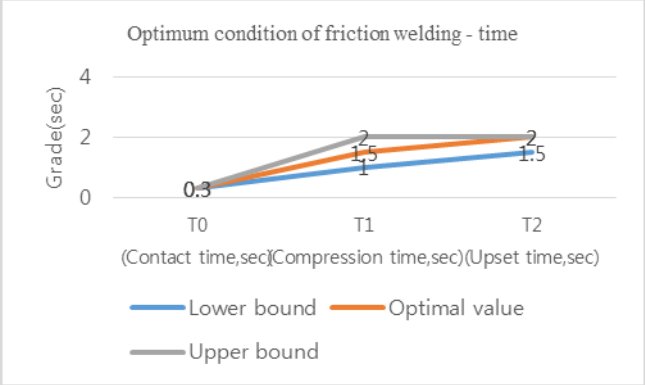



**Fig. 13:** Optimum conditions of friction welding to join the ring bolt

**Table 3 :** Optimum conditions of friction welding to join the ring bolt

| Category | Optimum conditions |
|---|---|
| P0 (contact pressure) | 45MPa |
| P1 (compression pressure) | 55MPa |
| P2 (upset pressure) | 75MPa |
| T0 (contact time) | 0.3sec |
| T1 (compression time) | 1.5sec |
| T2 (upset time) | 2.0sec |

### 4.3. Tensile Strength Experimental Results for Ring Bolt

A tensile strength test was performed after executing the friction welding for the ring bolt with the optimum condition in Table 3. Tensile strength (load) experiment results showed that the ring bolt manufacturing technique using friction welding was better in terms of tensile strength (load) by an average of 12% than that of conventional method as shown in Table 4.

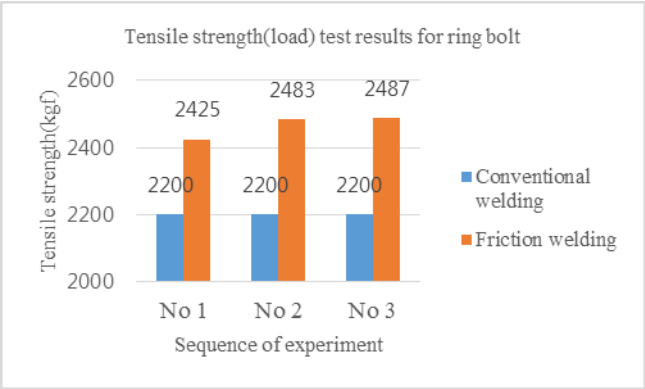



**Fig. 14:** Tensile strength (load) test results for ring bolt

**Table 4 :** Tensile strength (load) test results for ring bolt

| Tensile strength | No. 1 | No. 2 | No. 3 | Average |
|---|---|---|---|---|
| Conventional welding (A) | More than 2,200 kgf | | | |
| Friction welding (B) | 2,425 kgf | 2,483 kgf | 2,487 kgf | 2,465 kgf |
| B/A | 110.2 % | 112.9 % | 113.0 % | 112.0 % |
| Testing photos |  |  |  |  |
| Welding evaluation | The fractures occurred at the areas not in the welded area or ring, which can be evaluated as the welding strength is excellent as shown in photos No. 1, No. 2, and No.3 above, and other photos. | | | |

## 5. Discussion

The friction welding proposed in this study is being applied actively in the automobile parts, industrial machineries parts, and electrical machine parts. Recently, friction welding has been increasingly applied to automobiles parts such as engine valve, cam shaft, and propeller shaft.





| Hollow Cam Shaft (Pipe +Power Cam) | Propeller Shaft (Pipe + Shaft) | Engine Valve (Thermoresistant Alloy Steel+S45C) |
|---|---|---|

**Fig. 15:** Friction welding has been increasingly applied to automobiles parts

Even if there are many merits in the friction welding process, this technology has not been reviewed and used throughout its industry in Korea. Though the superiority and necessity of friction welding are increasing, technical manpower in the relevant fields are short except in specialized fields and laboratories due to a lack of understanding on the characteristics and processes of friction welding. Therefore, it is absolutely necessary to foster technically adept individuals who understand the principles of friction welding, can control the parameters of welding, and design and fabricate various jigs that suit friction welding. In addition, training and empowering specialists to equip them with measuring skills for various physical properties using the appropriate measuring equipment to gauge the welding strength and accuracy of the weld joint and to evaluate the measurement results are needed.

## 6. Conclusion

In this study, a ring bolt manufacturing technique using friction welding is proposed so that it is attributed to improving the manufacturing process of the ring bolt. A ring bolt is a part that fixes the position of the automobile's handle when the handle is tilted. In this study, the problem of ring bolt manufacturing was analyzed while the new ring bolt manufacturing technique using friction welding, which can improve the problem of the conventional method, was proposed. First, a shape design of the ring bolt to implement the friction welding was presented and then the optimum conditions which directly affect the friction welding were derived. It was confirmed that by setting the control parameters of the friction welding, the tensile strength (load) of the ring bolt could be improved by 12% compared with its rate in the conventional method. The technology proposed in this study is joining the ring and bolt separately through friction welding unlike the conventional method wherein the ring bolt was integrally hot forged and machined. The proposed ring bolt manufacturing method can reduce material consumption and save the mold expense for forging, suggesting that the proposed method is excellent in terms of promoting savings in manufacturing cost. The study results showed that the friction welding technology can make the parts occupy economical and quality superiority compared with the forging or cutting process. Therefore, it is expected that this technology can be effectively implemented in the processes for various automobile parts such as crank shaft and various loads.

## Acknowledgement

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