Surface hardening of two cast irons by friction stir processing

Hidetoshi Fujii1, Yasufumi Yamaguchi2, Toshifumi Kikuchi1, Shoji Kiguchi2, Kiyoshi Nogi1

1Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibraki, Osaka 567-0047, Japan
2Faculty of Science and Engineering, Kinki University, 3-4-1 Kowakae, Higashi-Osaka, Osaka, Japan

E-mail: fujii@jwri.osaka-u.ac.jp

Abstract. The Friction Stir Processing (FSP) was applied to the surface hardening of cast irons. Flake graphite cast iron (FC300) and nodular graphite cast iron (FCD700) were used to investigate the validity of this method. The matrices of the FC300 and FC700 cast irons are pearlite. The rotary tool is a 25mm diameter cylindrical tool, and the travelling speed was varied between 50 and 150mm/min in order to control the heat input at the constant rotation speed of 900rpm. As a result, it has been clarified that a Vickers hardness of about 700HV is obtained for both cast irons. It is considered that a very fine martensite structure is formed because the FSP generates the heat very locally, and a very high cooling rate is constantly obtained. When a tool without an umbo (probe) is used, the domain in which graphite is crushed and striated is minimized. This leads to obtaining a much harder sample. The hardness change depends on the size of the martensite, which can be controlled by the process conditions, such as the tool traveling speed and the load. Based on these results, it was clarified that the FSP has many advantages for cast irons, such as a higher hardness and lower distortion. As a result, no post surface heat treatment and no post machining are required to obtain the required hardness, while these processes are generally required when using the traditional methods.

1. Introduction

Cast iron has excellent material characteristics, such as abrasion resistance, corrosion resistance, machinability, and vibration absorptivity, and accordingly, it has been used in various industrial fields, such as automobile parts, industrial machine parts, and machine tool parts. Currently, a weight saving and advanced features are being requested, thus the material of choice is changing from cast irons to aluminum alloys and magnesium alloys, but in contrast to these developments, some high added values, such as a higher performance [1-3] and thinner product [4,5] are requested for the cast iron components.

In this study, friction stir processing (FSP), whose principle is the same as friction stir welding [6], was used as one of the surface treatment methods for cast irons. Many such studies of FSP have already been intensively conducted for aluminum alloys [7-13]. This method solves many problems, such as gas inclusion and grain growth in the weld of aluminum alloys [14]. For ferroalloys, on the other hand, there is no report concerning the FSP because some issues, such as the durability of the tool, have to be solved, although some research studies on friction stir welding [15-17] have begun.
2. Experimental

Five-mm-thick flake graphite cast iron (FC300) and nodular graphite cast iron (FCD700) plates were used as the test materials. Table 1 shows their chemical compositions. The matrix for both materials is perlite, and therefore, the Vickers hardness of the nodular graphite cast iron is 200-230HV, while for the flake graphite cast iron, it is 170-210HV.

A cylindrical tool with a 25mm diameter was used and the tilt angle was 3 degrees. The tool material was a tungsten carbide-based alloy [15-17]. The travelling speed was varied between 50 and 150mm/min in order to control the heat input, while the rotation speed of the tool was constant at 900rpm. After performing the FSP, the hardness of the matrix was measured on a cross section (0-1.5mm depth) using a Vickers testing machine. The microstructure was observed using an optical microscope.

| Material | C     | Si    | Mn    | P     | S     | Mg    | Cu    |
|----------|-------|-------|-------|-------|-------|-------|-------|
| FC300    | 3.07  | 1.65  | 0.75  | 0.07  | 0.050 | –     | –     |
| FCD700   | 3.60  | 2.25  | 0.35  | 0.02  | 0.008 | 0.045 | 0.70  |

3. Results and discussion

3.1 Hardness and microstructure

Figure 1 shows the surface appearances of the FCD700 cast iron friction stir processed under various conditions. All experiments were performed while increasing the load during the process. The optimum conditions of the FSP were determined by observing the groove defect formed at the center of the sample and the peeling off of the material due to the adhesion to the tool as defects.

For the FCD700 cast iron, an excellent surface without any defects was obtained at 50mm/min, when the load exceeded about 3.0×10^3 kgf. On the other hand, at 100 or 150 mm/min, a load of 3.5×10^3 kgf or more was necessary, and the required minimum load increased with the increasing tool traveling speed. Moreover, the modified region becomes narrower when compared to the 50mm/min case.

The formation of the defects is significantly related to the heat input. When the heat input is insufficient, for example, under the conditions of 900 rpm and 2×10^3 kgf, a defect is formed during the early
stage by scooping out the material, as shown in Fig.1. This is because the cast iron does not soften due to the insufficient heat input, and then a flash is formed by a cutting-like phenomenon. When the heat input is excessive, the surface material is peeled off as if the material is melted because it softens too much. A good microstructure formed by the plastic flows without the surface being peeled off can be obtained by controlling the heat input properly. Therefore, it is necessary to adjust the process conditions, such as the rotation speed and the traveling speed, in order to optimize the heat input. In this case, there was neither no distortion nor a change in the dimensions of the material, which is completely different from that obtained by other surface hardening methods.

Figure 2 shows the Vickers hardness distribution in the depth direction at the central part and at 6mm from the center on the advancing side and the retreating side on a cross section vertical to the welding direction after the FSP. It was found that a high and comparatively steady hardness is obtained in the area from 0.2 to 1.0 mm in depth while a low value was observed at 0.1 mm from the surface. The hardness between 0.2 to 1.0 mm exceeds 700 HV.

Figure 3 shows the microstructure at a high magnification. A very fine needlelike martensite structure is observed. It is considered that this structure was generated because the material was locally heated and rapidly cooled during the FSP. On the other hand, the size and density of the martensite are changed even in the same martensite structure. The martensite structure is fine, and its density is high in a very hard microstructure which exceeds 700 HV.

3.2 Effect of graphite shape

Figures 4 show the Vickers hardness distribution of the flake graphite cast iron friction stir processed in a way similar to the nodular graphite cast iron. An average value higher than 700 HV is obtained to about 1 mm depth, and values higher than 800 HV were also measured at many points. Figure 5 shows an example of the microstructure. A
martensitic structure is formed throughout the region. It can be seen in Fig.4 that the hardness of the central part decreases near the surface. Since the hardness of the mother material is lower, the bottom of the tool enters more deeply compared to the FCD 700. Accordingly, the domain is expanded, where the graphite was crushed and striated by plastic flow, and the hardness then decreased.

4. Conclusions

The friction stir processing was successfully performed on the surface of cast iron using a rotating φ25mm WC based cylindrical tool at the speed of 900 rpm (friction stir processing), and the following points have been clarified;
1. The average hardness of about 700 HV for the matrix is obtained for both the flake graphite cast iron and the spheroidal graphite cast iron. This is because an extremely fine martensite phase is formed by this process.
2. It is considered that a very fine martensite structure is formed because the FSP generates the heat very locally, and a very high cooling is constantly obtained.
3. The hardness changes depending on the size of the martensite, which can be controlled by the process conditions, such as the tool traveling speed and the load.

Based on these results, it was clarified that the FSP has many advantages when used for cast irons, such as higher hardness and lower distortion.

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