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New Surfacing Material DHW™: From Repair Welding to Additive Manufacturing in Die Casting Molds

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ABSTRACT

Die casting molds are repair welded due to changes in the mold design, errors in machining and damages in service. Especially, damaged molds by heat checking are repeatedly repaired during maintenance time by TIG and laser welding with Maraging steel or H13 type rods. However, these welding materials are less resisting to heat checking than un-welded substrate mold steels especially welded without post-heating. Tackling this issue, DHW has been developed by optimizing the chemistry of H13. The features of DHW are as follows.

1) DHW weld metal shows almost the same hardness as un-welded mold parts even without post heating and harder hardness than Maraging steel. As a result, DHW has superior heat checking resistance to Maraging steel.
2) On the other hand, the hardness of DHW is lower than that of H13 weld metal, which results in suppressing gross cracking form repair welded parts.
3) DHW weld metal shows the same resistance to soldering due to the same nitriding capability.
4) DHW is available to repair welding in almost the same welding process as that for Maraging steels.

Now, DHW has been supplied to the market as 1.0 to 3.2 mm dia. rod and 0.3 to 0.5 mm wire, and contributing to extend the life of welded parts in actual die casting molds. Furthermore, by using powder and fine wire, DHW is expected to apply to additive manufacturing.

INTRODUCTION

With the expanding demand of high fuel economy to meet emission regulation, automakers are pursuing light weight vehicles. To achieve the weight reduction of vehicles, it is projected increasing number of aluminum die castings will be applied[1]. Urgent issues die casters are tackling in their shops are high quality die castings and cost reduction. Among them cost cutting is a key issue in manufacturing boosting die castings. Generally, heat checking is the most popular failure mode of die casting molds. When we look at the failure mode of die casting molds as shown in Fig.1, heat checking counts almost 78 %[2]. When these patterns are heavily transferred to the die castings, molds are repaired during maintenance time, because it is really expensive to be substituted by newly made molds. Therefore, molds are used by the repetition of repairing to the scheduled number of products for each mold according to the production plan. In repairing of damaged molds, deposition the metals by welding is the most popular, especially by Tungsten electrode Inert Gas (TIG) welding. For small area, laser or electron beam welding by using fine filler are applied. As welding filler, Maraging and H13 type steels are generally used[3)]. However, these steels have difficulties in several ways. Maraging steel is comparatively easy in welding, but as welded, the hardness is limited to around 30-35 HRC. This is the main reason of its inferior heat checking resistance to general H13 steel[4)]. Of course by post heating that works as an aging process, hardness such as 50-53 HRC is attainable, but post heating is generally omitted by actual shop reasons. Especially, when enough time is not available and when damaged parts have to be repaired on site without dismantling molds set due to urgency in the production. In addition to this, in Japan, Cobalt regulations as hazardous element recently suppress the usage of this steel[5)]. When H13 is considered as weld filler, the major problem is too high hardness as welded[3)], which deteriorates toughness and heat checking resistance much worse than substrate. If repaired molds are post heated at appropriate temperature, heat checking resistance might be improved again. However, it is not always available to post heat treat mainly due to on site busy schedule.

In these circumstances, we have developed new welding rods[6)]. The target is to suppress heat checking of repaired parts and to sustain molds until subsequent maintenance period. In this paper, fundamental characteristics and the performance of DHW in actual applications are reported.

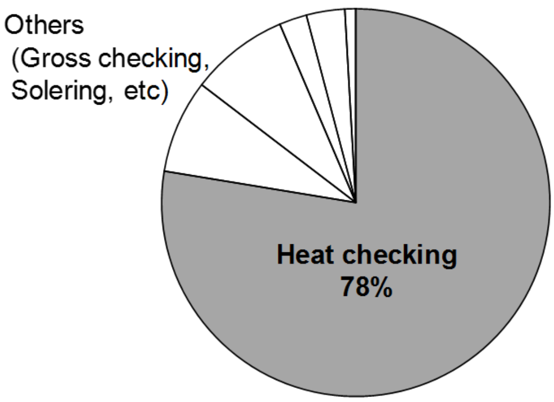

Fig. 1 Failure modes in die casting molds.

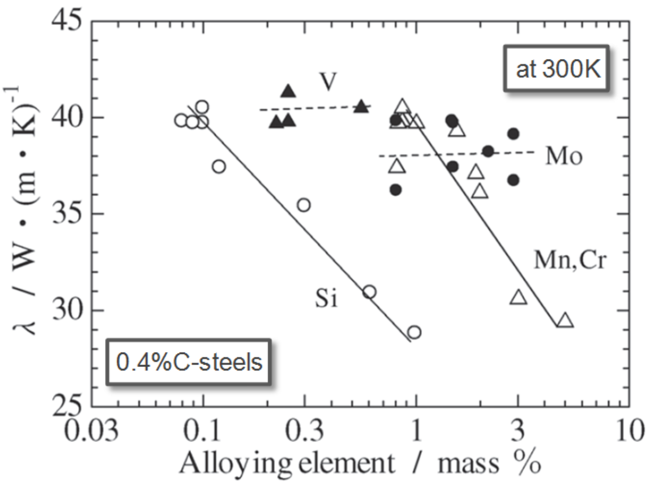

Fig. 2 Effects of alloying elements on thermal conductivity (46 HRC).

ALLOY DESIGN OF THE WELD STEEL

Heat checking is a failure mode by thermal fatigue and the resistance to it is improved by two ways: increasing in yield strength and reducing in the tensile stress generated during operation. The former is, furthermore, realized by raising the hardness and the latter by diminishing the temperature gradient with using high thermal conductivity mold steel[7)]. As for the effect of alloying elements on the thermal conductivity, 0.4 % C steels with the hardness 46 HRC was already tested by varying Si, Mn, Cr, Mo and V contents[7)]. Relationship between the amount of alloy elements and thermal conductivity is shown in Fig. 2. It is found that increasing Si, Mn and Cr content reduces thermal conductivity, however Mo and V have no effect on it.

New weld material, DHW, was alloy designed on the basis of H13 chemistry to be well compatible with the base metal. Pursuing this target, C content was adjusted to obtain the same hardness in weld metal and substrate without post heating. Si content was reduced to attain high thermal conductivity. The chemical composition of DHW is shown in Table 1. Being different from Maraging steel, DHW doesn't contains Co to meet the hazardous element regulation.

Table 1 chemical composition of DHW (mass%)

	C	*Si*	Mn	Ni	*Cr*	*Mo*	*V*	*Co*
DHW	0.2	0.3	0.4	-	5.2	1.2	0.4	-
18 % Maraging steel	-	-	-	18.5	-	4.8	-	9.0
H13	0.4	1.0	0.4	-	*5.3*	1.2	1.0	-

FUNDAMENTAL CHARACTERISTICS OF DEVELOPED MATERIAL

The properties of welded material were studied by TIG welding on H13 base metal. Welding conditions and an example of test piece are shown in Table 2 and Fig. 3, respectively.

Table 2 Welding conditions.

Welding rod (Diameter)	DHW, 18%Ni Maraging steel, H13 (1.6mm)
Welding power source	INVERTER ELECON 300P
Shielding gas	Pure Ar, 10 ℓ/min
Welding current	120 A
Welding speed	5 cm/min
Distance from tungsten electrode to base material	5 mm
Weaving	None
Base metal and specimen	H13 (440HV), 25x55x10mm The flat plane 25x55mm was welded.
Pre-heating , Post-heating	None

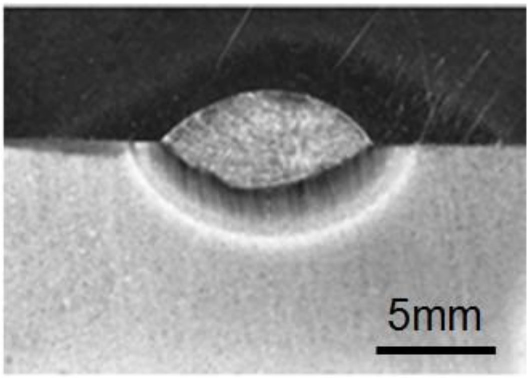

Fig. 3 An example of welded DHW.

HARDNESS PROFILE

Vickers hardness distribution from the welded part to H13 base metal is shown in Fig. 4. And the optical micrograph of welded DHW is shown in Fig. 5. Hardness of DHW is about 500 HV, almost the same as un-welded base metal. Welded Maraging steel exhibits only 350 HV, lower than base metal. H13 welded part increases its hardness up to 650 HV that is much higher than base metal. DHW, on the other hand, shows almost the same hardness in the welded part through base metal.

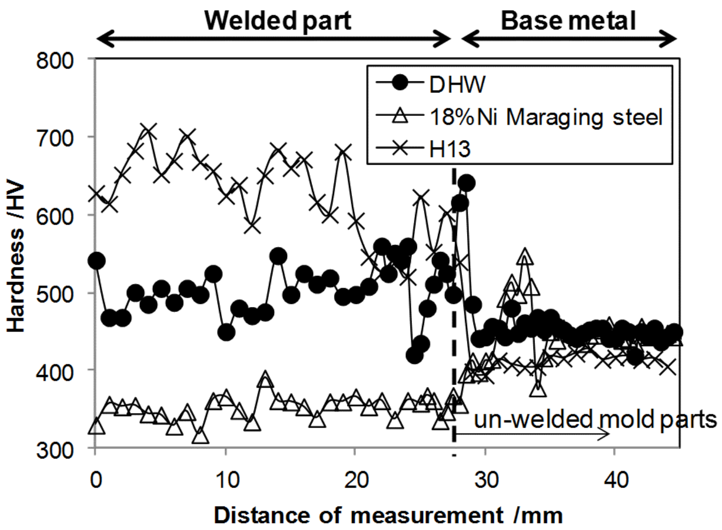

Fig. 4 Hardness distribution as welded.

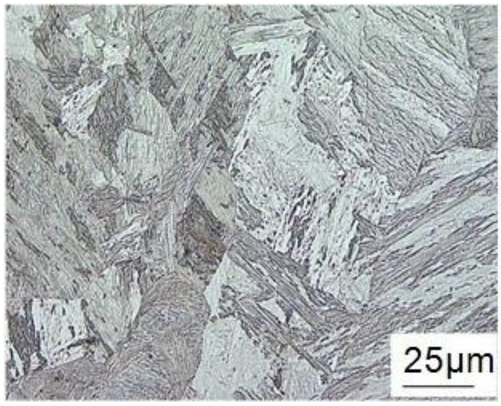

Fig. 5 Optical micrograph of welded DHW.

THERMAL CONDUCTIVITY

Thermal conductivity of DHW measured by laser flash method is shown in Fig. 6. DHW shows the same thermal conductivity of H13 and much higher than Maraging steel.

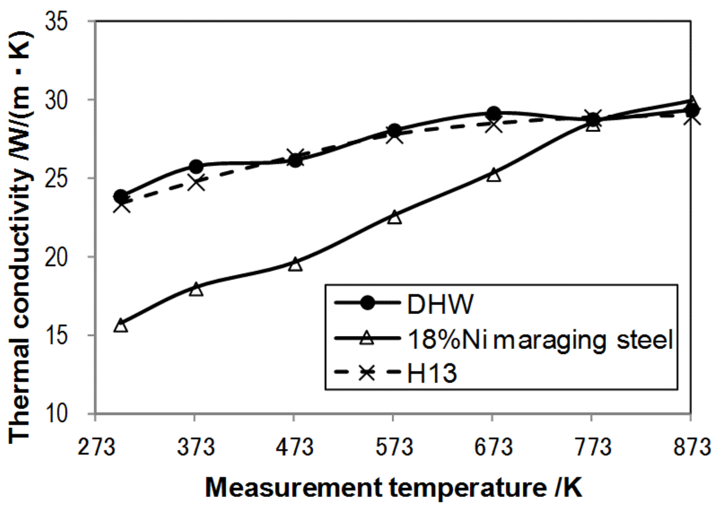

Fig. 6 Thermal conductivity of the part as welded.

HEAT CHECKING RESISTANCE

Heat checking was tested by the method schematically shown in Fig. 7. The specimen made of H13 sized 72 mm dia. And 50 mm thick was heat treated to 43 HRC in advance. A half of the disk surface was machined down by 1 mm and TIG welded and finished machined. Another half was remained as it was. The test piece surface was heated to 853 K (1076 ° F) by induction heating followed by water jet cooling. This was a cycle taking 17 sec. in total. For each 5000 cycles the surface was observed to evaluate the heat checking pattern severity. The test results are shown in Fig. 8. The left side half of the test piece is welded part and the right side is un-welded base steel. Gross cracks at the center of the test pieces were caused by HAZ (Heat Affected Zone). It was found that even at 25,000 cycles DHW remained almost the same heat checking pattern as that of Maraging steel at 5,000 cycles As far as this test method is concerned, DHW has about as five times heat check resistance as Maraging steel. This is considered due to high hardness and thermal conductivity as previously mentioned. DHW, furthermore, showed less cracks at 5,000 cycles than H13 weld metal and kept its superiority to 25,000 cycles.

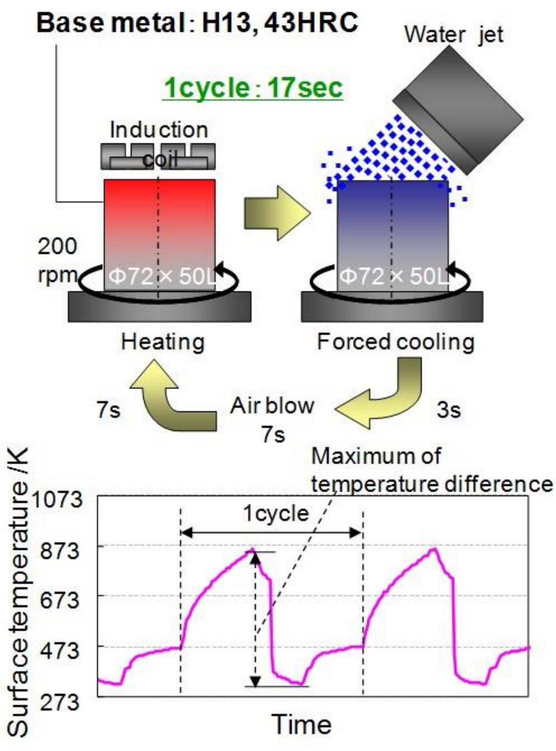

Fig. 7 Heat checking test procedures.

Another heat checking test results are shown in Fig. 9. This test was featured by using 135 ton actual die casting machine: TOSHIBA DC-135JT. Test mold weighting 18 kg has two projections sized 50 mm width and 7 mm height for easy crack initiation. The aluminum cast was 122 mm square and 12 mm thick weighting 600 g. Molten aluminum, ADC12, was injected to the mold through gate with 54 m/sec and the cycle time was 28 sec including 3 sec spray time[8]. The whole surface of the test mold was welded. The molds surfaces as of 10,000 shots were shown in Fig. 9. Around gate and holes areas, especially, the advantage of DHW in heat checking resistance over Maraging steel was clear. Not only by fundamental test, but also by actual die casting machine, DHW showed superior performance to other welding rod steels.

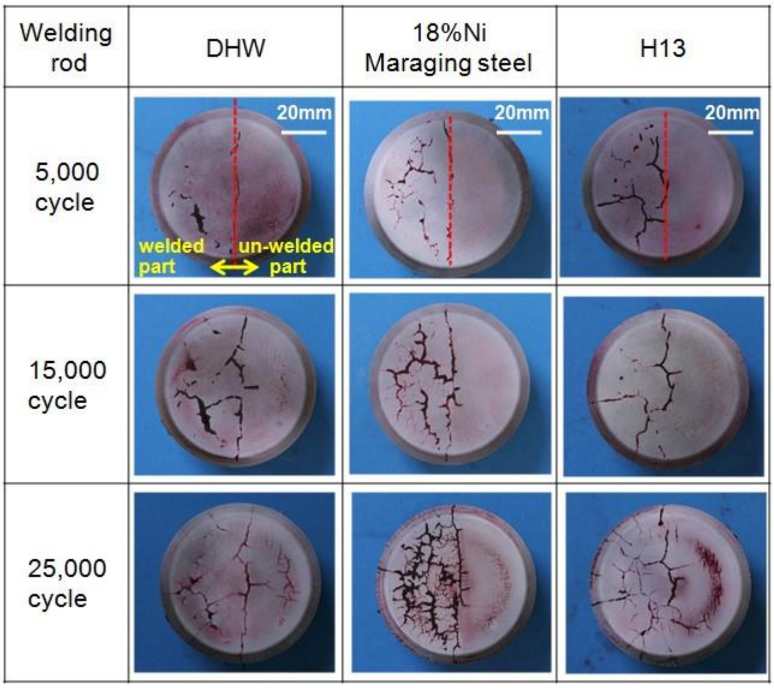

Fig. 8 Heat checking observed on the test specimens.

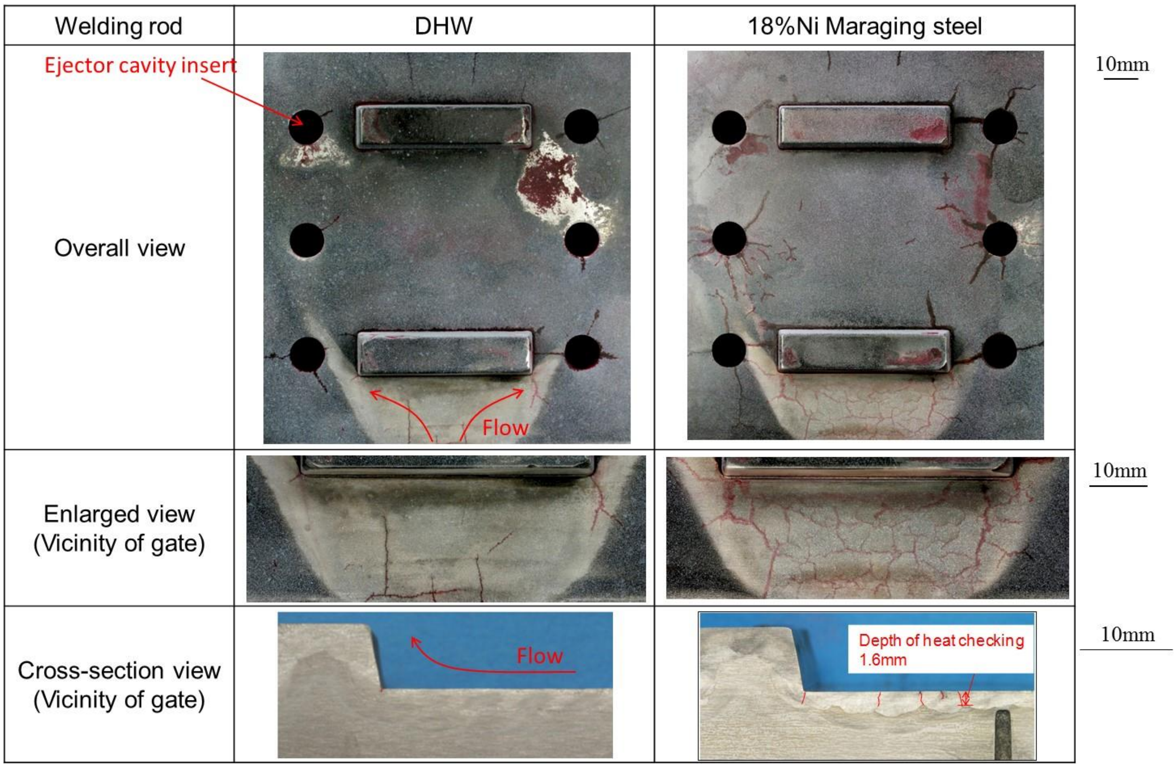

Fig. 9 Heat checking test result by actual die casting machine.

: The appearance of the mold surface after 10,000 shots

POST-HEATING

Generally, welded parts are post-heated to relieve the stress induced by repair welding, especially in large molds. In case of Maraging steel filler, post-heating plays a role as aging to increase its hardness. Here, the effect of post-heating temperature on the hardness in DHW and Maraging steel weld metals was studied as shown in Fig. 10. The holding time was 3 hours. It is found that the change in hardness of DHW is much smaller than in Maraging steel. And DHW maintains 450 HV up to 873 K (1112° F). Maraging steel shows higher hardness than DHW such as higher than 500 HV at post-heating temperature

723 to 873 K (842 to 1112° F). However, such high hardness results in deteriorated heat checking resistance.

NITRIDING

Most of die casting molds are nitrided to prolong its life by suppressing heat checking and soldering. In repairing such molds, heat checked areas are machined out, welded and finally nitrided again. Therefore, nitiriding capability of welded metal was studied. Test specimens were ferritic carbonitrided at 783 K (950° F) for 4 hours. Vickers hardness distribution from the surface of DHW is shown in Fig. 11. The hardness at 0.02 mm depth was about 1100 HV with the nitride layer of 0.1 mm deep. Thus, DHW shows the same hardness profile as H13 substrate does.

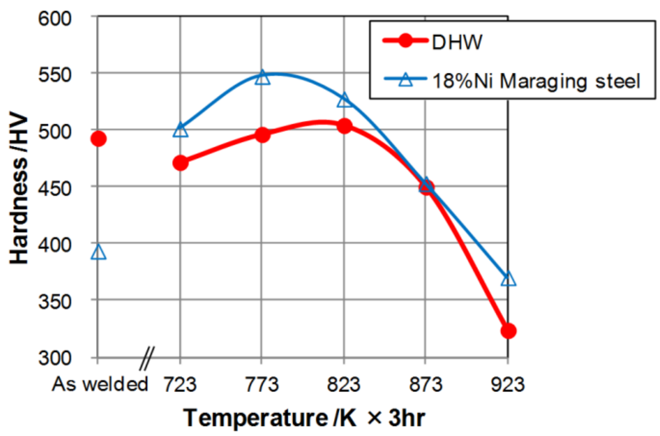

Fig. 10 Hardness with post-heating.

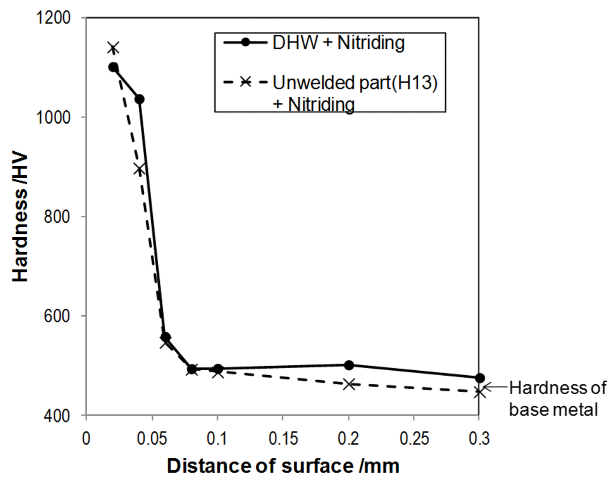

Fig.11 Hardness distribution after nitriding.

WELDING CHARACTERISTICS

Next, welding performance of DHW was studied by welding with the conditions previously shown in Table 2. Build-up characteristics was evaluated by observing the cross section of 25 x 55 x 10 mm specimen welded by single layer-single run and dual layers-five runs operation. Weld weight and excess weld metal height were measured as well. Figure 12 shows the relation of excess weld metal height with weld metal weight for both build up procedures. These values are in good correlation showing no difference in DHW and Maraging steel.

Furthermore, the shape and the size of droplets were monitored by high-speed video. The stationary pictures shown in Fig. 13 are shots when the welding rod began to melt and when the droplet just hanged down from the wire rod after distending. In these test conditions, the shape and the size of droplet of DHW was the same as those of Maraging steel. These welding test results reveal that DHW is available to repair welding with almost the same welding conditions as for Maraging steels.

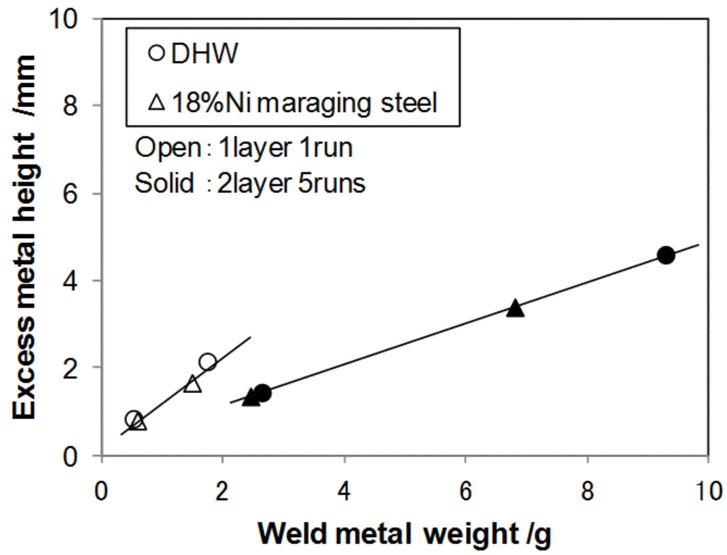

Fig. 12 Relationship between excess metal height and weld metal weight.

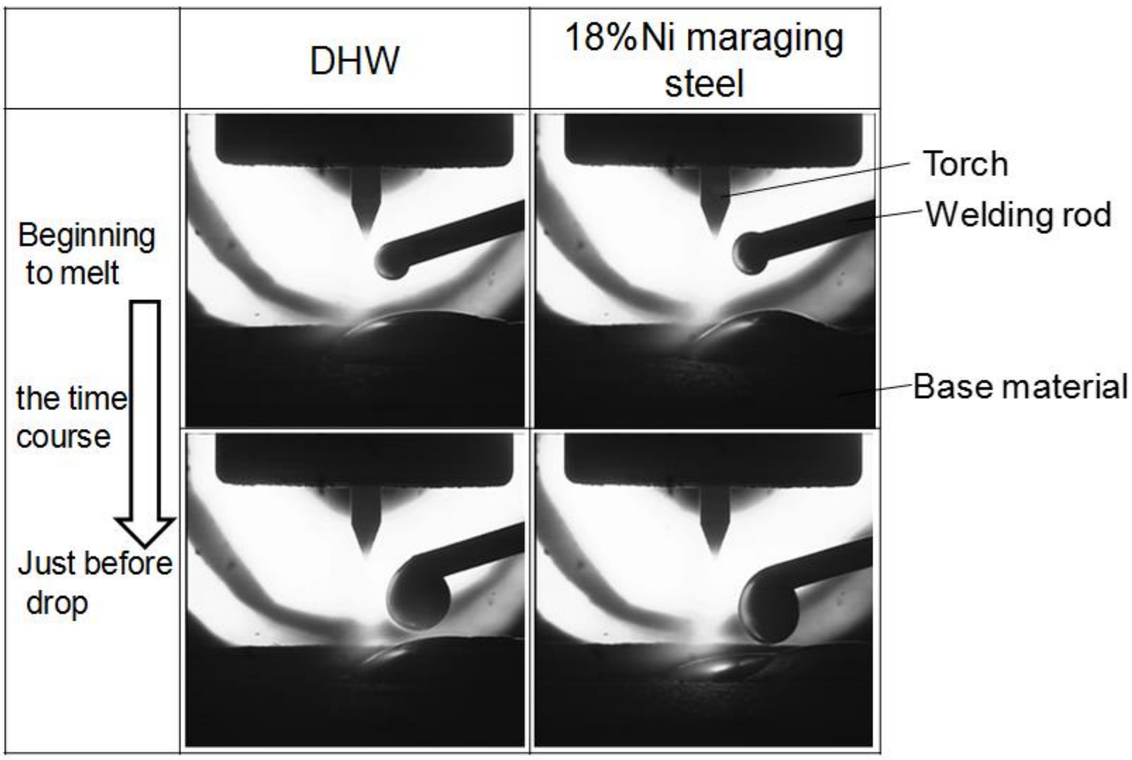

Fig. 13 An example of shots showing the behavior of droplets.

APPLICATION TO DIE CASTING MOLDS

The first beneficial example of the application to actual die casting molds is the prevention of heat cracking from the boundary between repair welded part and substrate. The stationary mold for oil pump parts used to be repaired by Maraging Steel, MAS1-C. Schematic figure in Fig. 14 shows the repair welded part and damaged mode in this cavity. Heat checking had usually appeared by 2,500 shots. The right figure in Fig. 14 compares the length, the width and the depth of the crack in the molds repaired by DHW and Maraging steel as of 5,000 shots. By applying DHW, the crack length was dramatically reduced from 50 mm to only 10 mm without developing in width and depth.

Another example of the application is the molds manufacturing the housing of power trains by 3,500 tons machine. The down time rate by repairing molds vs. accumulated shot number is shown in Fig. 15. Compared to that the down time rate by previous 18 % Ni Maraging steel rod used to be 5.3 %, substituted DHW showed almost a half ratio. This down time reduction is caused by the superior heat checking resistance of DHW to Maraging steel. For these die casting shops, DHW has been already applied to actual die casting operation.

Furthermore, since launching to Japanese market in 2014, DHW has been contributing to the cost reduction of die casting industries. Current available size is 1.0, 1.2, 1.6, 2.0, 2.4, 3.2 mm dia. rod and 0.2, 0.25, 0.3, 0.4, 0.5 mm fine wire (as of 2016).

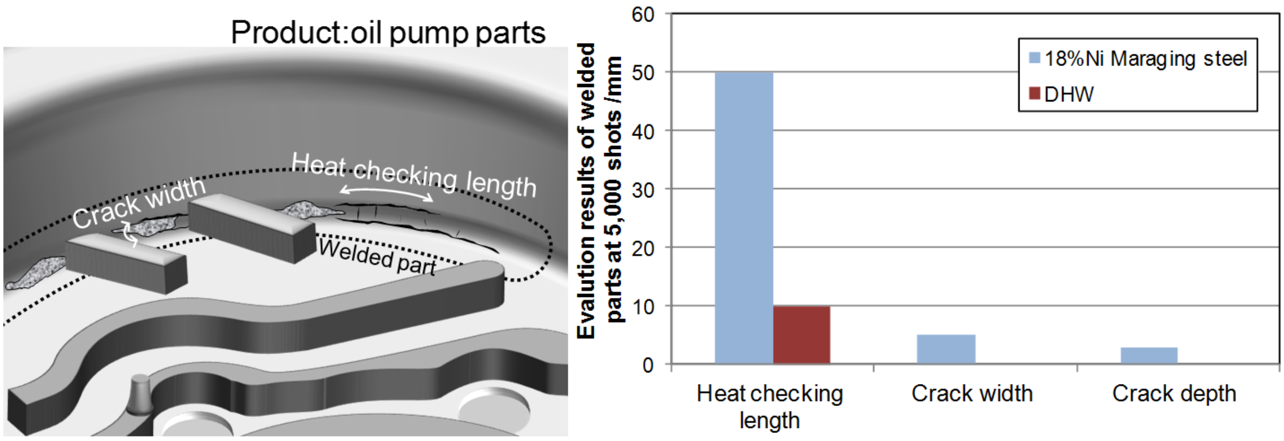

Fig. 14 An example of the application of DHW: Superior heat checking resistance.

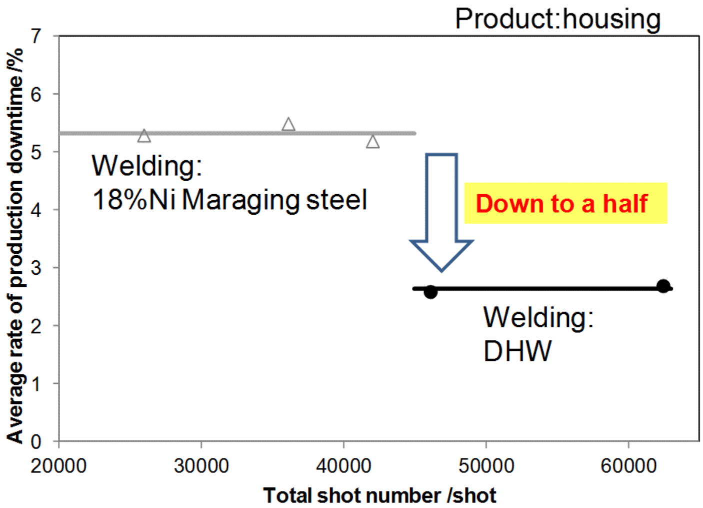

Fig. 15 An example of the application of DHW: reduced down time.

FUTURE POTENTIOAL APPLICATION TO ADDITIVE MANUFACTURING

Now, molds are generally repaired by welding, but additive manufacturing is also taken into consideration and already applied to actual die casting molds by using several methods such as cladding, laser micro-welding, electron beam welding, 3D printing and the like[9)]. Although Maraging steel is popular as surfacing material, it is worth to evaluate other alloys. This time, powdered DHW has been made as trial basis and tested.

DHW powder was sieved out to the size over 50 μm diameter and Maraging steel powder was supplied by the AM equipment manufacture. SEM observations of both powders are shown in Fig. 16. Experimental procedures are shown in Fig. 17. As powder based additive manufacturing, specimens sized 15 x 15 x 95 mm were made by selective laser melting. Sintered pieces and additionally post heated ones were machined to tensile test specimens and tested at room temperature. Post heating was carried out at 773K (923 ° F) for 3 hours.

Optical micrographs of the specimens as sintered are shown in Fig. 18. DHW showed finer microstructure than Maraging steel. As shown in Fig. 19, all the tensile strength data are proportional with hardness. As sintered, DHW exhibits 46 HRC with 1450 MPa that is general hardness when H13 is used as die casting molds. Actually these values agreed with those of heat treated H13 bulk steel. On the other hand, Maraging steel shows only 38 HRC with 1200 MPa as sintered. By post heating as aging process, its hardness increases up to 52 HRC.

Like this, it was confirmed that laser sintered DHW powder showed almost the same hardness and strength as those of TIG welded layer and hardened and tempered die casting molds. Now, other characteristics being under investigated, it is expected to utilize DHW for Additive Manufacturing.

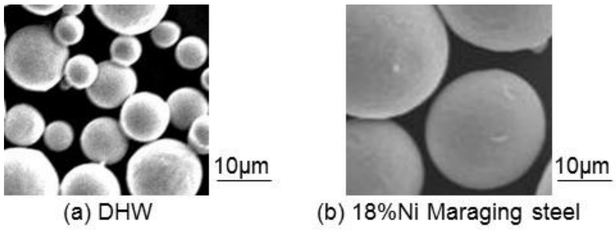

Fig. 16 SEM observation of powders used for laser sintering.

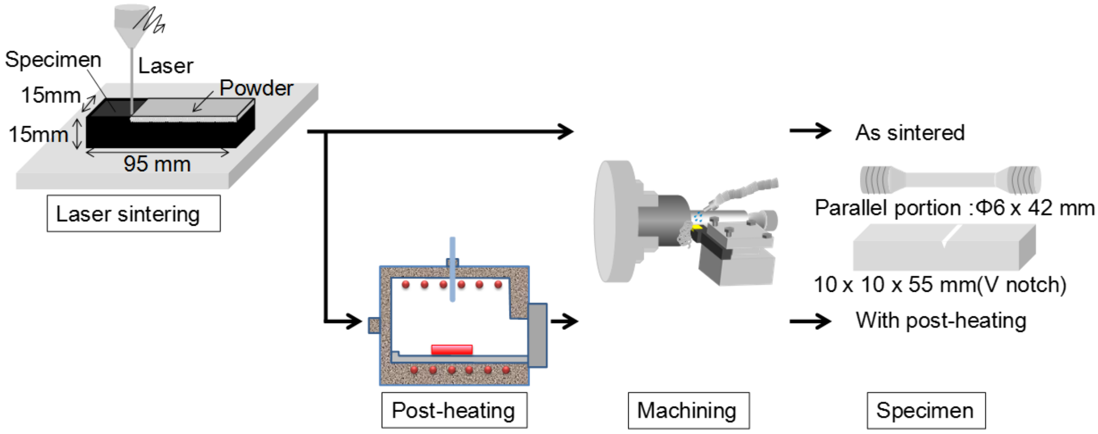

Fig. 17 Sampling procedures of tensile specimens.

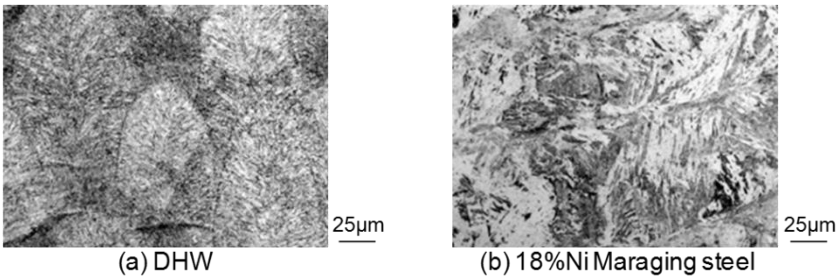

Fig. 18 Optical micrographs of as sintered powders.

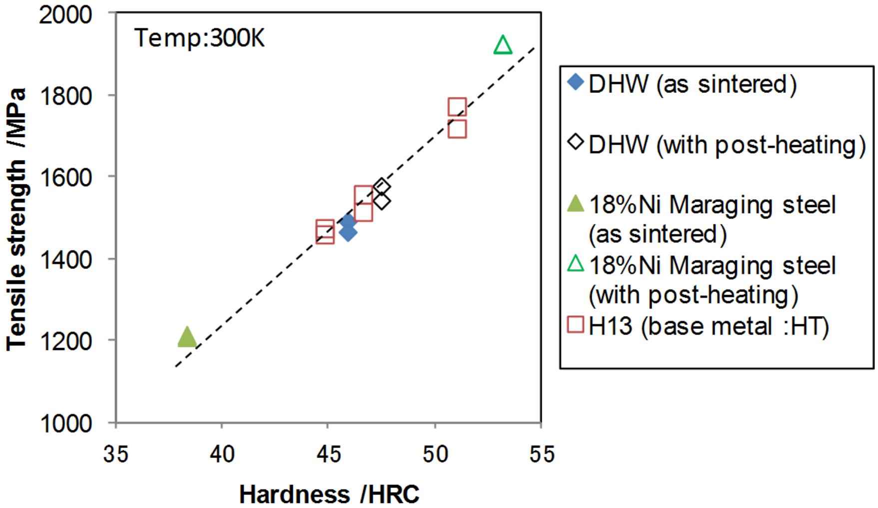

Fig. 19 Tensile strength at room temperature.

SUMMARY

DHW was developed to improve the heat checking resistance of welded parts. The features of DHW are the same hardness and thermal conductivity as general die casting molds, H13, without post-heating. Currently, DHW has been applied to die casting molds for automotive parts and running well. DHW is also expected to be widely used as environmental friendly material due to its Co free composition. Furthermore, DHW has a great potential as the materials for additive manufacturing.

*DHW is a trademark or registered trademark of Daido Steel Co., Ltd.

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