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Development and Applications of High Hardenability Special Quality Die Casting Mold Steels

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ABSTRACT

Toughness is becoming more important for die casting mold steels as well as heat checking resistance. High toughness is required to prevent gross cracking from water lines, especially from the crossing of these in large size mold such as transmission and crank cases of automobiles. The cause of decrease in toughness in large molds is Bainitic transformation during quenching. To prevent this high quenching cooling rate is required. But, the tradeoff is dimensional change. The right answer from mold steel design is highly hardenable mold steels. Based on these back grounds two die casting mold steels have been developed: DH31-EX™ and DHA™-WORLD. The former is 2367 modified double melted high Mo steel and the latter is H11 improved type steel. In spite of single melt steel, DHA-WORLD shows much higher toughness than H13 double melted steel even in large mold. These two steels have been applied to large automobile transmission cases in these three years, the largest one of which weighs 1700 lbs. These molds run in actual service without any gross cracking from water lines. This report will describe the features of these steels and the details of application.

INTRODUCTION

Trend of die casting industries, focusing on automotive industries, are summarized in Figure 1. Aluminum die casts are increasingly used for various components from engine to transaxle parts to manufacture light weight vehicles for improved fuel economy. Besides long life molds, to stand high applied stress shorter cycle time in die casting operation is key issue in automotive industries for cost reduction. For these purposes, high performance and reliable mold steels are required. NADCA specified steels are these kinds. Main failure modes of die casting molds are heat checking, gross crack and soldering. As far as heat checking is concerned, molds are used long to planned life by repeating repair in maintenance time. Gross crack, on the other hand, results in time consuming repairing, or being scrapped in the worst case. Usually crack initiates from deep heat checking and water lines, especially their crossing positions. Recent main measures to shorten cycle time are increased number of water lines and decreased distance between water lines and the mold surface. Therefore, the toughness inside, especially in large molds, becomes key property to rule mold life.

The low toughness of the mold core is caused by bainitic transformation in quenching. It has long been clarified that when molds quenched through bainitic transformation region, toughness drops after tempering[1]. Then, two measures are adopted to improve the toughness of molds: fast quenching and applying high hardenability steels. The transition of die casting mold steels in Japan is shown in Figure 2[2]. Initially, hot work die steels were standardized according to AISI steels, H13, H11 and H12. Among these three steels SKD61, equivalent to H13, is widely used as general purpose steel. Along with the development of automotive industries and the growth of die cast components, high performance steels have been developed. Low Si and high Mo type steels are ones of these and already registered as NADCA recommended steels as category C. Not only alloy designing, but also double melted clean steels have become popular as premium type steels and the importance of high quenching rate in low temperature range has been perceived. In this paper, as an example of measures from steel supplier, high hardenability die casting mold steels and their application to die casting molds of automotive large parts are introduced.

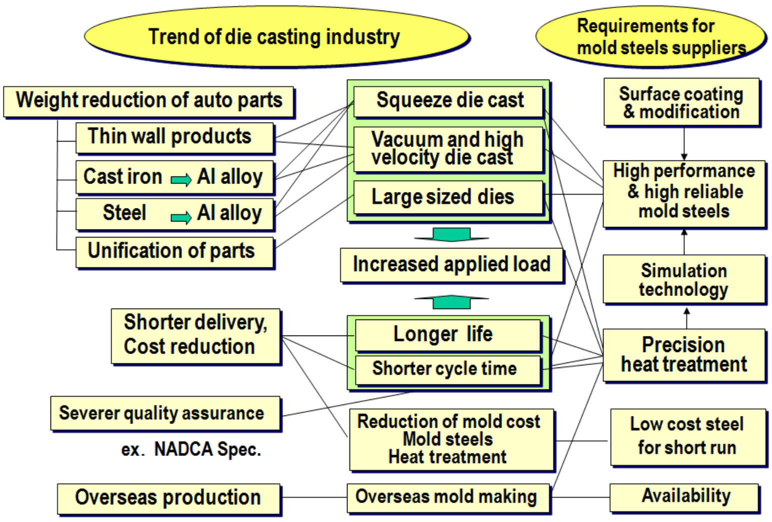


Figure 1 Trend of die casting industries and requirements for mold steel suppliers in Japan.

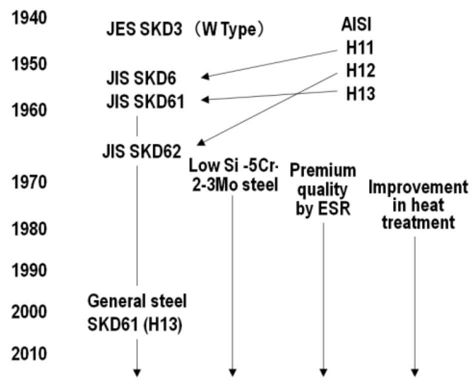


Figure 2 Change in die casting mold steels.

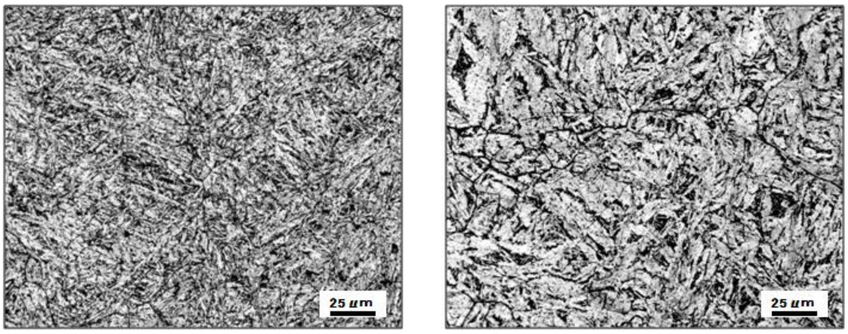
FUNDAMENTAL CHARACTERISTICS OF DEVELOPED STEELS

CHEMISTRY AND PRODUCTION PROCESS

Toughness of die casting mold steels are decided by quenching cooling rate especially in low temperature. Examples of optical micrographs taken from the thin and the thick part of a transmission case mold are shown in Figure 3. Charpy impact values (U notch) are shown together with photographs. Slowly quenched thick part shows coarse microstructure, acicular bainite structure, which results in lower Charpy values due to easy crack propagation.

Therefore, to harden through without bainitic transformation in large molds, it was intended to delay bainitic transformation in the chemistries of new steels. DH31-EX is improved 1.2367 type low Si- high Mo type steel and DHA-WORLD is improved H11 type steel. In both steels, to improve hardenability Mn and

Cr contents are closely controlled. Although DH31-EX is ESR melted steel, DHA-WORLD[3] is single melt steel to reduce production cost. But, by combining production technologies from alloy designing, clean steel-making to forging process, it is intended to give same properties as those of double melted steels.



37.1 J/cm^2 16.1 J/cm^2

Figure 3 Optical micrographs taken from the thin part (left) and the thick part (right) of a transmission case mold.

HARDENABILITY AND TOUGHNESS

CCT curves, continuous cooling transformation curves, of these two grades are shown in Figure 4 and 5. Compared to H13, bainitic transformation areas are shifted to longer time side. Bainitic transformation starting points of DHA-WORLD and DH31-EX are 2 hours, much longer than that of H13. The effect of cooling rate in low temperature range on U notch Charpy impact values is shown in Figure 6. Compared to H13, these new two grades show higher absorbed energy especially in slow quenching. Furthermore, Figure 7 shows the Charpy impact energy values of the samples taken from vacuum quenched large blocks sized 200 mm thick, 600 mm width, and 300 mm long. DH31-EX shows the highest values in wide hardness range. It is noted, here, that single melt DHA-WORLD shows almost equivalent to or better toughness than ESR melted H13.

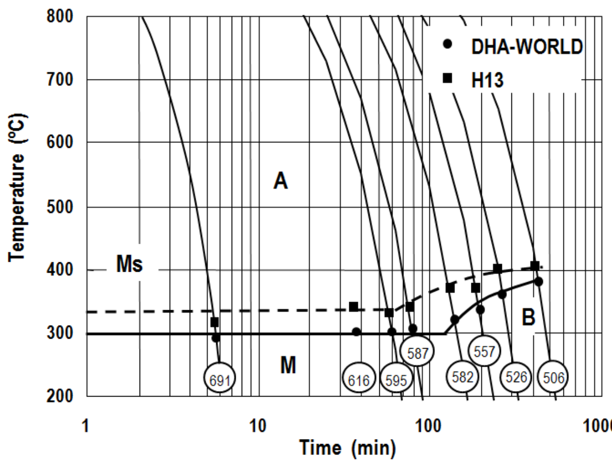


Figure 4 CCT diagram of DHA-WORLD.

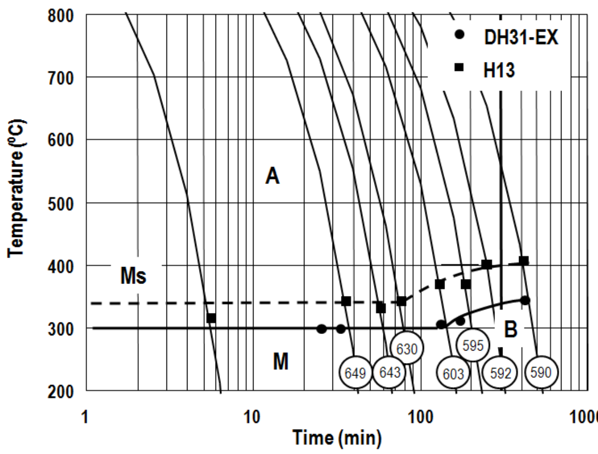


Figure 5 CCT diagram of DH31-EX.

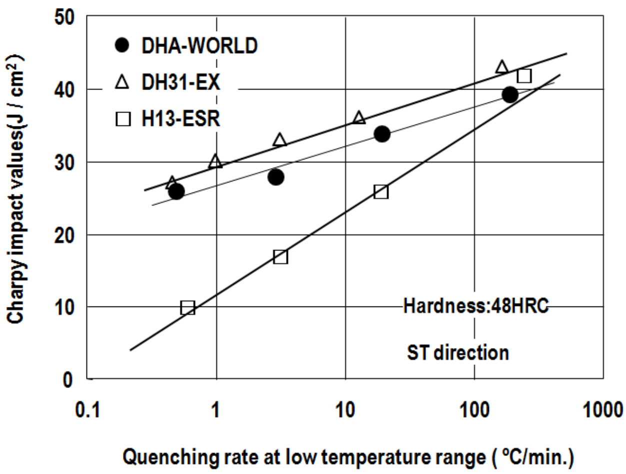


Figure 6 Effect of quenching cooling rate on Charpy Impact values (U notch).

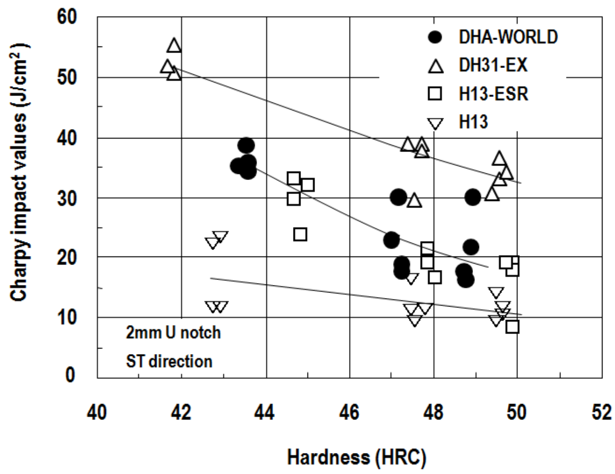
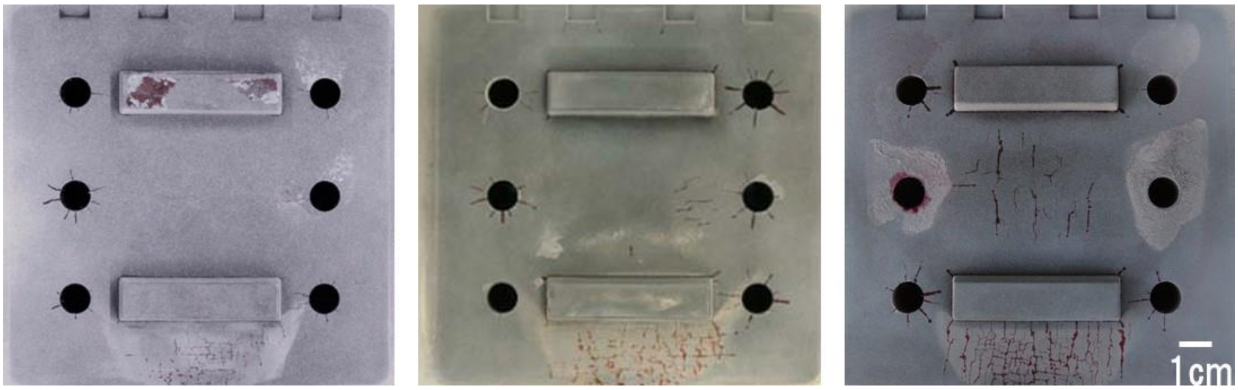


Figure 7 Charpy impact values of the specimens taken from vacuum quenched and tempered large block.

HEAT CHECKING RESISTANCE

An example of heat checking test results is shown in Figure 8[5]. This test was carried out by 135 ton 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 hardness was 42-43 HRC. The aluminum cast was 122 mm square x 12 mm thick weighting 600 g. Molten aluminum, ADC12, was ejected through gate with 54 m/sec and the cycle time was 28 sec including 3 sec. spray time. The molds surfaces as of 10,000 shots were shown in Figure 8. Compared to H13-ESR mold, DH31-EX and DHA-WORLD both showed less heat checking. Especially on the center surface, between two projections, neither cracks in DHA-WORLD nor DH31-EX. It is noted here DHA-WORLD, single melted and 1.25 % Mo steel, showed better heat checking resistance, which was caused by high thermal conductivity due to low Si content[6].



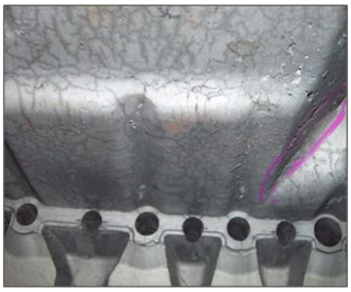
DHA-WORLD DH31-EX H13-ESR

Figure 8 Heat checking test result: The appearance of test specimens after 10,000 shots.

APPLICATION TO LARGE SIZE DIE CASTING MOLD

LIFE DETERMINING FACTORS IN LARGE MOLDS

Examples of large Al die cast automotive components are cases for transmission, torque converter and so forth. Generally, molds are used by repairing in periodical maintenance time to planned life such as 150,000 shots. Usually, heat checking, shallow chipping as shown in Figure 9 and soldering are removed and repair welded. But, in case of water leakage due to cracks propagated through the surface from water lines, it takes much time and cost to repair. Figure 10 shows an example of the gross crack resulted in water leakage and Figure 11 is the fracture surface around crack initiation site. The optical micrograph taken from the crack initiation site is shown in Figure 12. Needle like bainitic structure was observed, which indicated the low toughness inside resulting in crack initiation from the water line. Furthermore, the surface of water line was internally oxidized along austenite grain boundary, which assisted the crack to initiate.



Heat checking

Chipping

Figure 9 Examples of heat checking and chipping.

Figure 10 An example of gross crack.

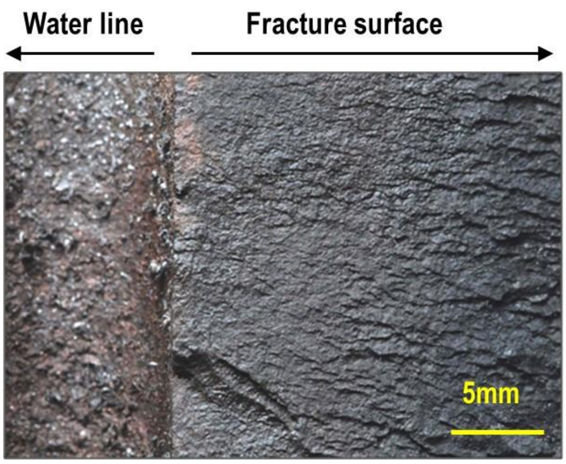


Figure 11 Fracture surface from water line

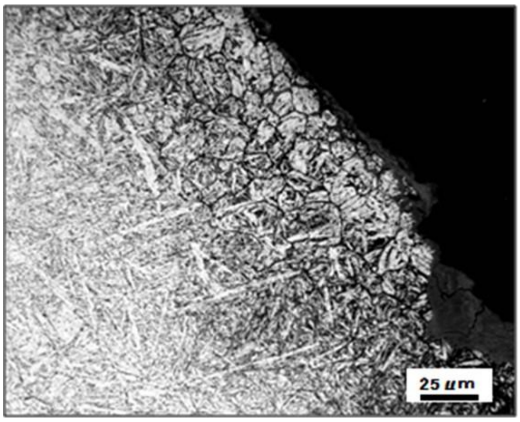


Figure 12 Optical micrograph taken from the cross section of water line

LARGE BLOCK TEST RESULTS

As the importance of toughness was perceived again by the previous analysis of actual mold, the superiority of developed steels to conventional ones were tested by using large blocks simulated core molds. Large test blocks of DHA-WORLD and H13 sized 550 mm width and 500 mm height were quenched from 1030 ℃ in oil and tempered to 42/44 HRC. Both steels showed uniform hardness around 43 HRC from surface to inside. On the other hand, Charpy impact values (U notch) were different each other as shown in Figure 13. In H13 block, the value in the center decreased to 10 J/cm^2. DHA-WORLD, whereas, maintained high values such as 30 J/cm^2 even in the center. Optical micrographs Figure 14 taken from the center parts of the specimens were showing clearly the difference: tempered martensite in DHA-WORLD and tempered bainite in H13.

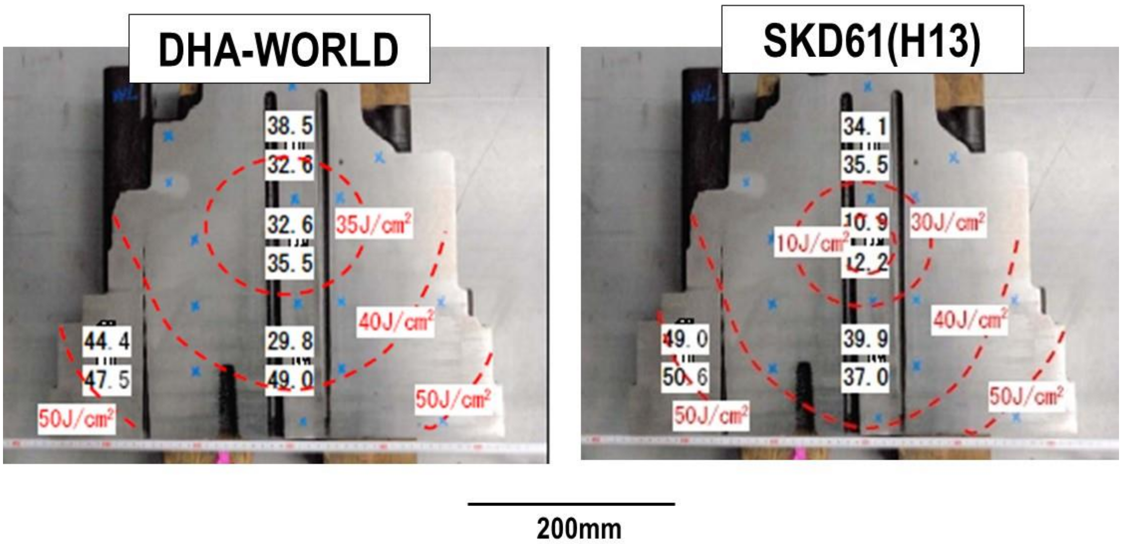
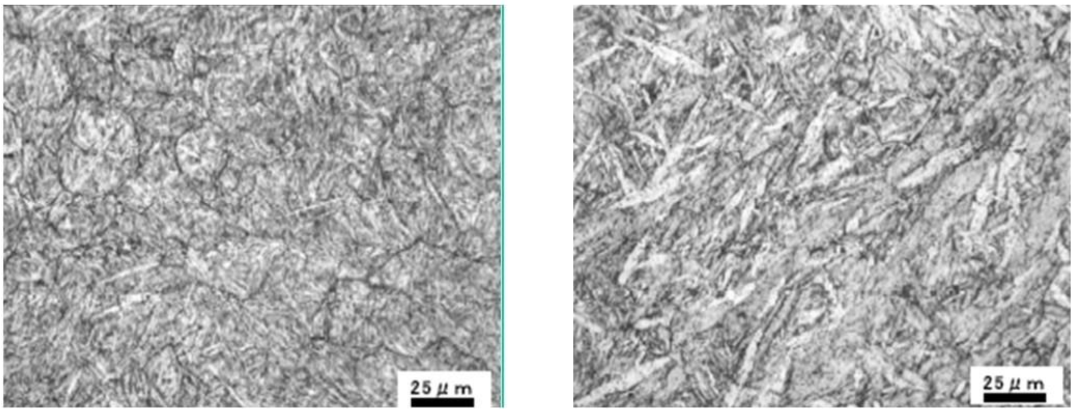


Figure13 Charpy impact values distribution in large test blocks tempered to 43 HRC.



DHA-WORLD SKD61 (H13)

Figure 14 Optical micrographs taken from the center part of the test blocks.

V NOTCH IMPACT PROPERTIES

Correlation between notch geometries, V and U, is to be stated in appendix.

APPLICATION TO TRANSMISSION CASE MOLD

Heat treatment of the mold

DHA-WORLD was at first applied to fixed cavity of transmission case mold. A large block sized 824 x 814 x 404 mm and weighting 2.1t was supplied and machined. Rough machined cavity mold was quenched by

11bar vacuum furnace, 36" x 36" x 48", by controlling gas pressure and its flow. The temperature inside was measured by setting thermocouples in a water line located in almost the center of the molds. Actual cooling rates at high and low temperature range were shown in Table 1. The rate in low temperature range was 3.6 ℃/min. When referred to the fundamental data shown in Fig. 6, this cooling rate was enough to obtain high enough Charpy values higher than 20 J/cm^2. This mold was tempered three times at 580, 610, and 570 ℃ to meet the specified hardness 43/45 HRC. Hardness obtained by tempering were plotted in the tempering curve as shown in Figure 15.

Table 1 Quenching cooling rate of the transmission case mold (°C/min).

Temperature range (°C)	Surface	Center	Target
1030-500	51.7	7.9	10.0
500-200	4.7	3.6	3.0

Table 2 Charpy impact values of the samples taken from the center of the mold

	Data			Ave.
	1	2	3	
Hardness: HRC	43.0	43.2	43.1	43.1
Charpy value: J/cm^2 (U notch)	39.9	25.5	39.9	35.1

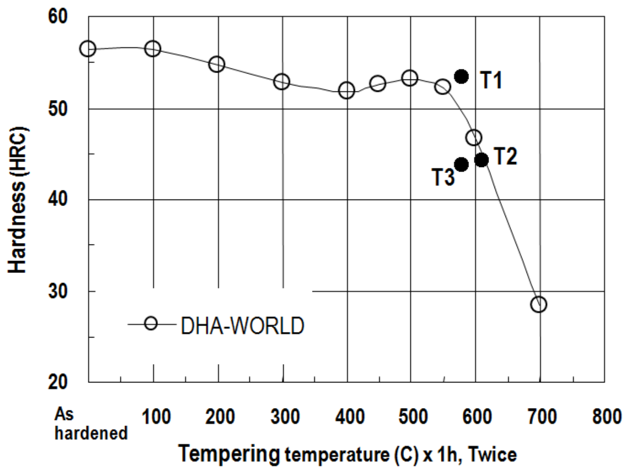


Figure15 Hardness obtained by tempering.

The hardness of the mold measured on the surface was in good agreement with fundamental tempering hardness curve. Furthermore, from the center part of the mold, three small samples were cut by EDM and Charpy test was carried out. As shown in Table 2, all values were higher than 20 J/cm^2: this value was empirically deduced criteria to prevent gross cracking in actual molds.

Optical micrographs of Charpy impact specimen was shown in Figure 16. Microstructure was fine and free from bainitic structure.

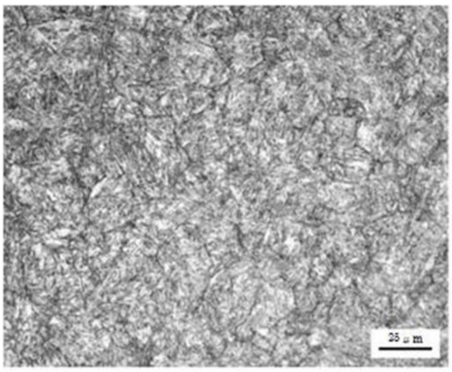
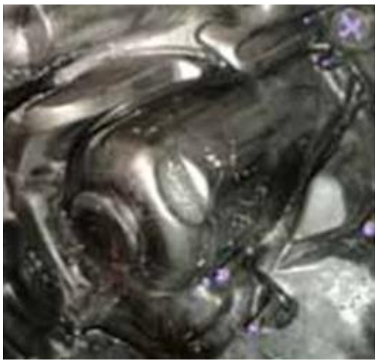


Figure 16 Optical micrograph taken from the center of the mold.

Results in die casting

After trial shot and some geometry modification, this mold was nitride and started to run in mass production in the beginning of 2010. As of 13,000 shots fine heat checking started to appear and heat checking became severer especially at the position near gate with increasing of shot number. But, without big cracks which triggered water leakage, this mold had reached to planned life 150,000 shots. The surface appearances of this mold as of 140,000 shots are shown in Figure 17. Small cracks were observed on the surface, but shallow one. DH31-EX was also used for ejector side and run through to 150,000 shots. Compare to DHA-WORLD, almost no heat checking at gate area in DH31-EX mold. An example of the surface is shown in Figure 17. Beside these molds, DHA-WORLD and DH31-EX have been applied to other molds for transmission cases.



DHA-WORLD: Fixed cavity

DH31-EX: Ejector side

Figure 17 Examples of mold surfaces of the molds.

CONCLUSIONS

Two hot work die steels, DH31-EX and DHA-WORLD, were developed to prevent gross cracking in large die casting molds by increasing the toughness. The features of these steels are high hardenability which provide high toughness even in large size molds. These two mold steels have been applied to automotive transmission cases and running well.

*DH31-EX and DHA are trademarks or registered trademarks of Daido Steel Co., Ltd.

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APPENDIX

In the discussion of die toughness of die casting mold steels, V notch Charpy specimen is popular in US, but U notch in Japan. For easier discussion the correlation of the Charpy impact energies were tested. From each coupon heat treated together with actual die casting molds by attaching on the surface, V notch and U notch Charpy specimens were taken side by side. Test steels used were H13, DHA-WORLD and DH3-EX. Coupons were taken from different size forged blocks, heat treated in different chances with different sized molds.

Figure Appendix 1 shows the correlation between the absorbed energies by V and U notched specimens. An approximate V notch value is 0.43 times U notch values.

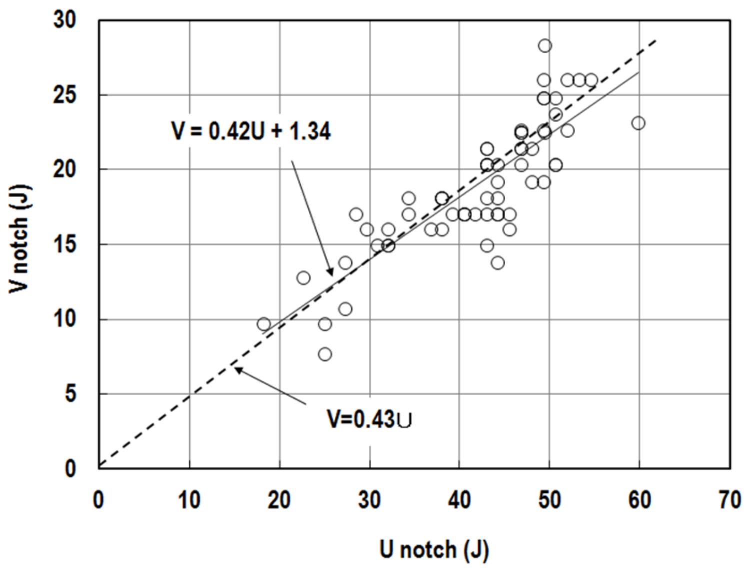

Figure Appendix-1 Correlation between V and U notch absorbed energy.

