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High Thermal Conductivity Steel and its Application to Die Casting Tools

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ABSTRACT

It is required in die casting operations not only to produce high enough quality products but also to shorten cycle time. Increased usage of light weight components produced by die casting, have made reduced cycle time a critical issue for die casters. To reduce cycle time, the application of high thermal conductivity materials to die casting tools is effective as well as reinforced internal cooling of molds. Although W alloys are high thermal conductivity metals, the price is too high to increase their applications. On the other hand, it has been widely known that low alloy type steels have higher thermal conductivity than the most popular 5%Cr-1%Mo type die casting mold steel H13. But, they are generally supplied as pre- hardened steel: the highest hardness is usually 40 HRC. DHA™-THRMO is a high thermal conductivity steel and high hardness of 48HRC is available by quenching and tempering. In this paper, examples of the application to die casting tools are introduced as well as the fundamental features of this grade.

INTRODUCTION

The roles of die casting molds are two folds. One is to inject and cast molten alloys in the cavity of molds to make required geometries. Another is to solidify molten alloys by removing the heat as heat exchanger. Needless to say, the latter is more important to produce good quality products with fine grain structure without internal defects in short cycle time. When automotive industries are considered, aluminum die casts are increasingly used for various components such as engine block and transmission case to produce light weight vehicles for improved fuel economy. Therefore, shorter cycle time is one of the key issues in automotive industries for cost reduction. Furthermore, fine cast microstructure with less defects in shorter time solidification contributes to further cost reduction and application of die cast products to wider variety automobile components.

To reduce cycle time by faster solidification of molten alloys various efforts have been strived to improve cooling efficiency. Among them are increased internal cooling by the increase in water lines and their proper layout. The distance between the top of water line and the mold surface is becoming shorter, for example. These efforts, however, have accompanied with early stage gross cracking from water lines, especially from the crossing of water lines and oxidized internal surface. Another solution is to apply high thermal conductivity materials such as Cu alloys and W alloys. Although thermal conductivity of these metals are much larger than tool steels, they have difficulties in actual applications as die casting molds mainly due to their high price and poorer mechanical properties than tool steels, resulting in limited applications.

Furthermore, high thermal conductivity steels are able to improve properties required in die casting molds, heat checking and soldering resistance, due to easier diffusing heat out in operations. Heat checking is thermal fatigue phenomenon caused by the repetition of heating and cooling on mold surface. The highest temperature decreases when high thermal conductivity molds are used, which results in improved heat checking resistance. The decreased surface temperature in operation is also effective to prevent erosion-corrosion on the surface. From these points, application of high thermal conductivity steels will be measures to prolong mold life.

THERMAL CONDUCTIVITY OF MATERIALS

Table 1 shows thermal conductivities of various materials. Compared with the most popular hot work die steel H13 used for die casting tools, lower alloy tool steels such as PX5 and NAK80 mainly used for plastic injection mold steels show larger thermal conductivity. This effect of alloying elements was already reported almost 55 years ago[1)]. Recently one of these low alloy tool steels, named HDS1, has applied to actual die casting molds for automotive and motor cycle components[2)]. The drawbacks of these low alloy steels were low hardness lower than 40 HRC due to low carbon and poor harden ability mainly due to low Cr content. Therefore, applicable tools were limited to small molds which thermal stress were not highly applied.

Non-ferrous materials which show much higher thermal conductivity are Cu-Be alloy and W alloy. The former is mainly used for plastic injection mold and the latter is for small pins and inserts for die casting systems. The most popular W alloy, Anviloy, shows almost three times higher thermal conductivity than H13, but it has draw backs such as expensive and brittle due to powder sintered material.

Table 1 Thermal conductivity of metals and steels.

Classification	Grade	Main chemistry (%)	Hardness (HRC)	Thermal conductivity (W／MK)
Low alloyed tool steel	PX5*	0.2C--2Cr-0.5Mo	30	42
	NAK80*	0.1C-3Ni-1Al-1Cu	40	42
	HDS1*	0.22C-1.5Mn-1.9Cr-1Mo	38	41
Hot work die steel	H13	0.38C-1Si-5.3Cr-1.2Mo-1V	40 - 50	27
Cu alloy	Cu-Be	2Be-Cu	33	130
W alloy	Anviloy	W-Mo-Fe-Ni	35-40	80-100

* Brand name of Daido Steel

FUNDAMENTAL PROPERTIES OF DHA-THERMO

Based on these backgrounds new high thermal conductivity hardened and tempered type hot work die steel was developed targeting to obtain higher hardness and improved hardenability[3)]. By testing the effects of alloying elements: Si, Mn, Cr, Mo, and V, on several properties: thermal conductivity, hardenability, toughness, the new steel named DHA-THERMO was developed. The hardenability was improved by adding the optimum amount of Mn and controlling Cr content to maintain high thermal conductivity.

THERMAL CONDUCTIVITY

Thermal conductivity at room temperature and elevated temperature are shown in Figure 1. At room temperature, thermal conductivity of DHA-THERMO is as 1.6 times larger than that of H13. Although the difference decreases with elevating test temperature, DHA-THERMO still maintains higher thermal conductivity than H13 at 500 ℃ which is the estimated surface temperature of the molds in general die casting operation.

TEMPERING HARDNESS

Hardness change with tempering temperature is shown in Figure 2. DHA-THERMO shows lower hardness than H13 when tempered at 300 to 600 ℃. At higher than 600 ℃, however, DHA-THERMO maintains higher hardness than H13. These behavior are derived from the chemistry, especially low Cr content. By selecting tempering temperature from 610 to 680 ℃, aimed hardness 40 to 47 HRC are available.

HARDENABILITY

Hardenability is evaluated by CCT (Continuous Cooling Transformation) diagram as shown in Figure 3. DHA-THERMO shows slightly inferior hardenability to H13 in terms of Bainitic hardenability. Figure 4 indicates the hardness distribution in different thickness of 200 mm dia. round bar when vacuum gas quenched with 4 Bar and tempered at 580 ℃. Hardness in the center part of 100 and 150 mm long bars are slightly lower than that of 60 mm long.

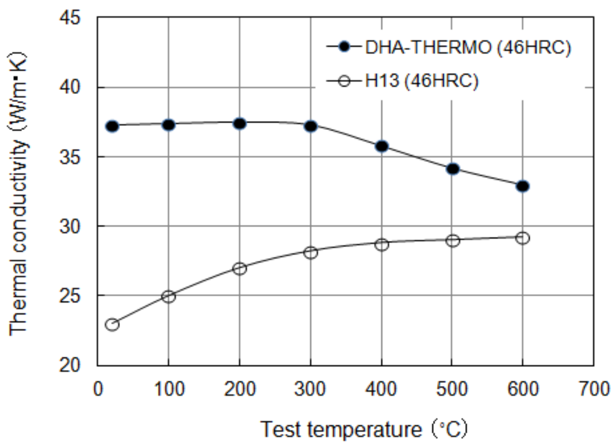


Figure 1 Thermal conductivity vs. test temperature.

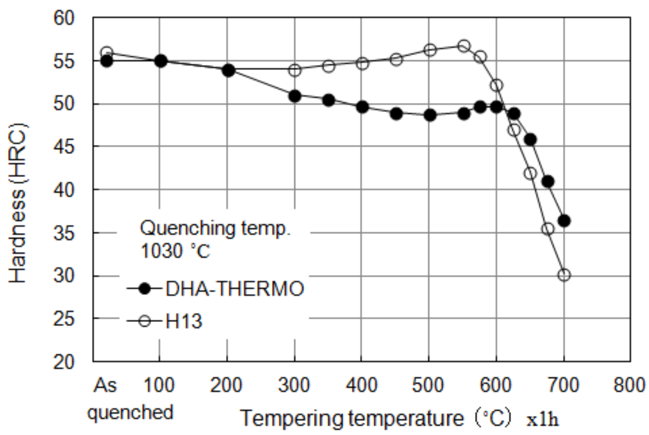


Figure 2 Hardness vs. tempering temperature.

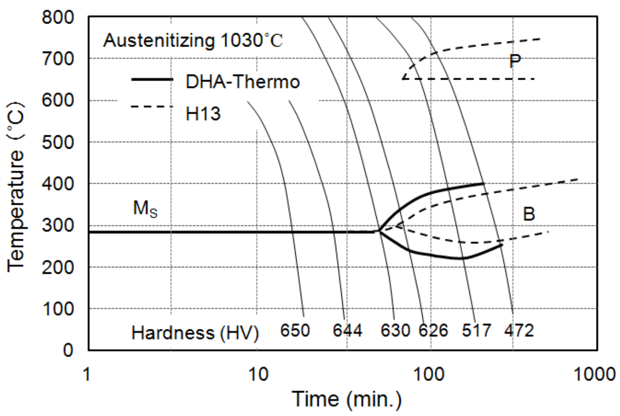


Figure 3 CCT diagram.

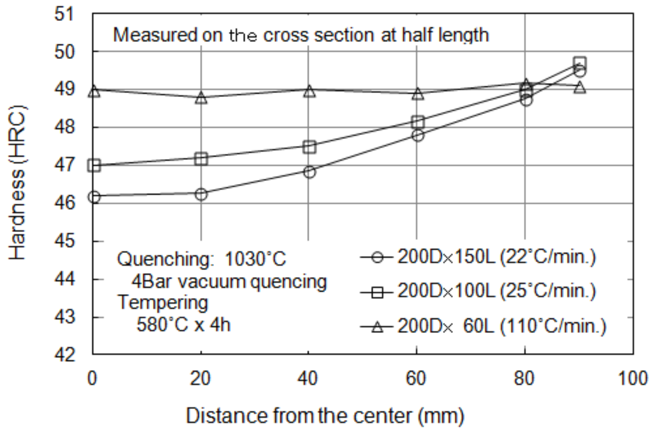


Figure 4 Examples of hardness in round bars 4Bar gas Quenched and tempered.

DIE CASTING TEST

By 135t small machine, actual die casting test was performed. Considering that the cooling of the biscuit that finally solidify is the key issue in operation, DHA-THERMO and H13 were applied to sprue core and temperature was measured. The applied position and testing conditions are shown in Figure 5 and Table 2, respectively. The temperature on the sprue core surface was measured and the microstructures of the biscuit part were observed.

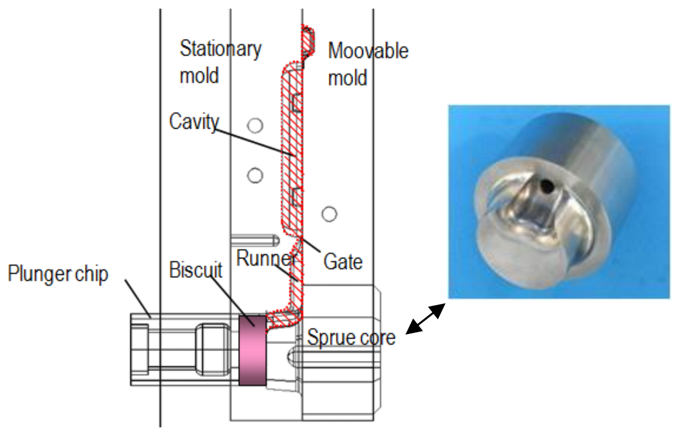
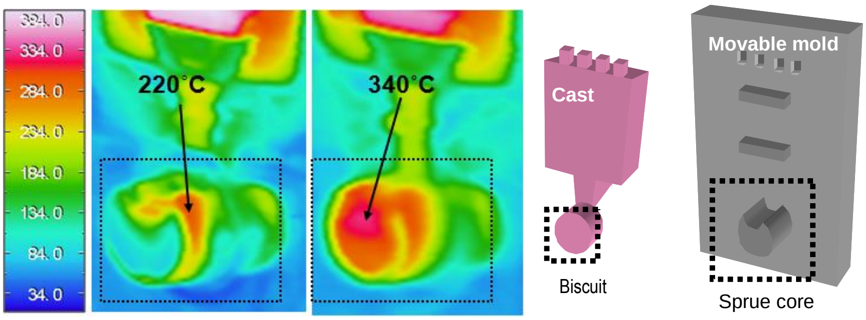


Figure 5 Application of DHA-THERMO in die casting test.

Table 2 Die casting test conditions.

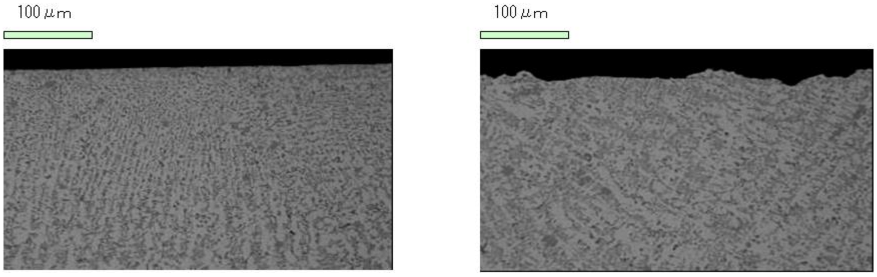
Die cast machine	135t (Toshiba)
Molten Aluminum	ADC12, 700°C
Die cast product	122mm x 122mm x14mm 650 ± g
Injection rate	0.2m/sec., 1.6m/sec.
Cycle time	Total 27 sec Solidification 9 sec Lubricant spray 3.5 sec.

The temperature distributions around biscuit parts measured by radiant thermograph are shown in Figure 6. Temperatures were measured after unclamping and just before lubricating. The sprue core made of DHA-THERMO showed lower temperature than that of H13 by 120 ℃. As shown in Figure 7, optical microstructure of the center surface of the biscuit which touched with DHA-THERMO sprue core was much finer than that of H13. It is derived from the faster molten aluminum solidification due to faster heat transfer through high thermal conductivity sprue core.



DHA-THERMO H13

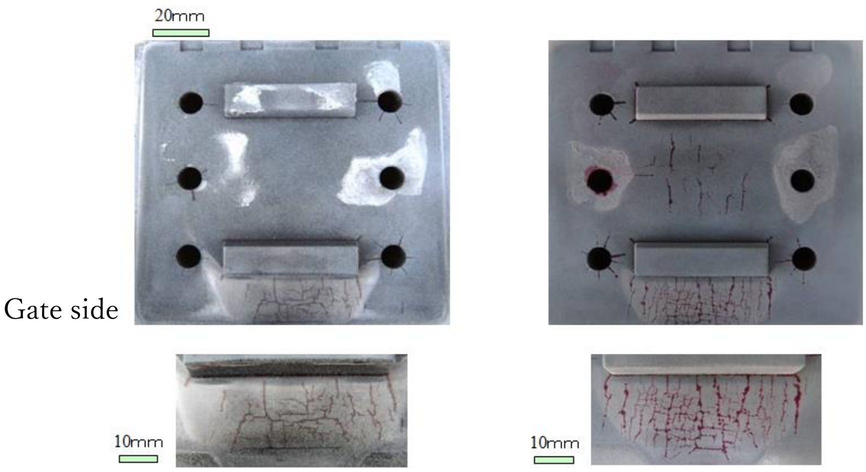
Figure 6 Surface temperature of sprue core.



DHA-THERMO H13

Figure 7 Optical micrographs taken from biscuit surface.

By using this die casting machine, heat check resistance was also tested. Figure 8 shows the heat checking appeared as of 10,000 shots on the surface of movable molds made of DHA-THERMO and H13. On H13 mold surface, heat checkings were observed remarkably at gate side and the center, especially. Compared to this, DHA-THERMO mold showed milder cracks at the gate and almost none at the center. This superiority of DHA-THERMO was derived from less thermal stress due to lower highest surface in the operation by larger heat transfer in the operation.



DHA-THERMO H13

Figure 8 Heat checking observed on the surface of movable molds as of 10,000 shots.

APPLICATION TO DIE CASTING TOOLS

DHA-THERMO has been applied to a wide variety die casting tools such as small insert, distributor, core pins and so forth, especially to the tools which need faster cooling. Representative successful examples are shown in Table 3. The advantages of DHA-THERMO over H13 are classified to three: quality improvement in Al die cast products, decrease in cycle time, and cost reduction of tools. Among the examples in Table 3, noteworthy items are shown in detail as follows.

Table 3 Examples of application.

Advantage	Tools	Applications	Conventional Grade	Hardness Coating	Results
Quality improvement of die cast products	Center pin	Motor cycle	H13,	49HRC Salt bath nitriding	Improved yield rate (Shrinkage reduced)
	Core pin	Motor cycle	H13	47HRC Salt bath nitriding	Improved yield rate (Shrinkage reduced)
	Split insert	Automobile	H13	42HRC Salt bath nitriding	Improved yield rate Surface temperature decrease
	Distributor	Automobile	High Mo type grade	45HRC Multi- layer coating	Improved yield rate Deeper chill layer
Reduction in cycle time	Distributor	Automobile	H13	47HRC	Decreased surface temperature by 45-80˚C
	Sprue core	Automobile	H13	45HRC	Reduction in cycle time by 18%
	Squeeze bush	Automobile	High Mo type grade	45HRC, Nitriding+shot peening	Improved cooling
	Distributor	Automobile	H13	45HRC Ferritic Nitrocarburizing	Reduction in cycle time
Cost reduction	Core pin	Automobile	W alloy (Anvilloy)	50HRC	Same life as W alloy Substitute for expensive W alloy

QUALITY IMPROVEMENT OF DIE CAST PRODUCTS

DHA-THERMO was applied to the center pin. Cast component was motor cycle Al wheel. Compared with the conventional pin made of H13 heat treated to 49 HRC and salt bath nitride, the yield ratio of cast products remarkably increased by the decrease in shrinkage. Another example in die casting of motor cycle components is core pins for cylinder cover mold. Conventional pins were H13, 47 HRC and salt bath nitrided. Hardness and nitriding process for DHA-THERMO were the same. By substituting for H13, yield ratio was dramatically improved by 50 %. The part of the Al cast product where internal quality was much improved is shown in Figure 9.

DHA- THERMO was used as split insert for automobile components. H13 used to be applied with the hardness 42 HRC and salt bath nitrided. The surface temperature decreased by 30℃ and the leakage rate by shrinkage decreased from 5 % to 0 %. Microstructure near surface was fine.

The other example used as distributor showed the fine optical microstructure as same as shown in Figure 7. The chill layer of the biscuit by using DHA-THERMO was 80 % deeper than by H13.

Figure 9 A part of Al die cast product where internal soundness was improved by the application of DHA-THERMO core pins.

REDUCTION IN CYCLE TIME

One case study showed remarkable decrease in the surface temperature of a distributor sized 90 mm dia. x 60 mm. Current steel was H13 with the hardness 47 HRC. By applying DHA-THERMO, surface temperature decrease much lower than H13 just after taking out products from the mold.

The second one is the application to sprue core sized 132 mm dia. DHA-THERMO reduced cycle time by 18 %. Furthermore, the drop of the products due to un-solidified biscuit was completely prevented.

COST REDUCTION

As shown in Table 1, the thermal conductivity of W alloy is much larger than tool steels. When rapid cooling is required, W alloy is limitedly used because of its high price. If the steel base core pins run almost in the same way, it will be very cost efficient solution. DHA-THERMO was applied in trial to one of core pins which Anvilloy was generally used. Two pins were heat treated to 50 HRC and tested without coating: one run 16,500 shots and cracked, another endured to planned life 20,000 shots without trouble. The average life of Anvilloy was 15,000 to 20,000 shots.

The core pin used to 16,500 shots was shown in Figure 10. It cracked from the bottom of the corner at the stage of different diameter. This part was soldered as well. These failure modes, cracking and soldering, are common for hot work die steels.

The DHA-THERMO pin worked as well as the Anvilloy pin and lasted to the same life. DHA-THERMO proved to be capable of being an inexpensive substitute of W alloy. As for the toughness, W alloy is inferior to hot work die steels.

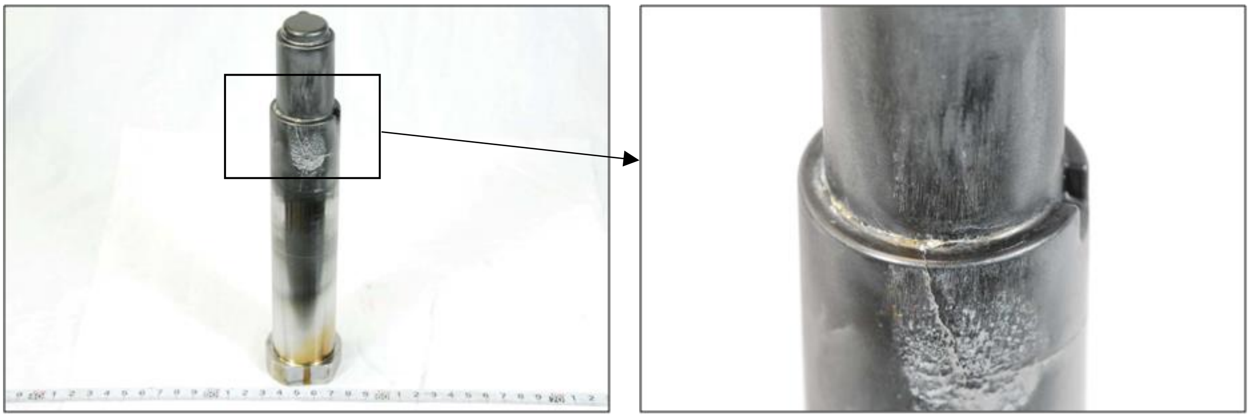


Figure 10 An example of core pin and failed area.

OTHER

Beside the application shown above, DHA-THERMO is used for a wide variety core pins produced by core pin suppliers. Advantages of this grade over H13 are all of three factors: quality improvement of products, shorter cycle time and cost reduction. Furthermore, it is reported that galling is suppressed due to decreased maximum temperature in operation.

It should be noted here that when the diameter of the pin is too small to machine water line in the center, DHA-THERMO doesn't work as the same as the pins with water line in them.

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