DENKI-SEIKO (Electric Furnace Steel), vol. 76 (2005), No. 4, p. 279 – 286.
Paper

The Development of High Hardness and Toughness Matrix Type High Speed Tool Steels: DRM™

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*This English article is an abridged version of the original Japanese one.

Synopsis

The best way to attain high toughness in carbon-high hard tool steels is to refine carbides. Besides powder metallurgy, carbides control by alloy designing and production process is the key technology. This time we have developed three matrix type tool steels, DRM steels, and have clarified their superiority to conventional type steels not only in fundamental study but in practical use.

This series are composed of three steels, DRM1 to 3 which are used with the maximum hardness of 58, 62 and 66 HRC, respectively. These steels are characterized by their more finely dispersed carbides free from coarse primary ones, higher toughness and fatigue strength than conventional type steels. DRM1 is mainly used for hot and warm forging tools with the hardness of 56 to 58 HRC. DRM2 is applied to warm and cold forging tools with higher hardness of 58 to 62 HRC. DRM3, highest hardness one, is the best grade for cold toolings.

These DRM steels have shown longer life and contributed to total cost reduction mainly in forging tools of automobile and machinery components. They are further expected to expand their application fields.

1. Preface

Plastic forming is one of the important elemental technologies and forging is one of them. Dies play an important role in forging processes. In order to respond to the recent customers request for cost reduction or shorter lead-time, plastic forming technology has developed rapidly by applying net-shape or near-net-shape. For that reason, warm or cold forging processes have been chosen more widely. This progress made die use conditions harsher by complicating products dimensions or decreasing forging temperature. Therefore dies have been required to be harder and tougher to be more durable against higher contact pressure, sliding wear and impact load[1), 2)].

In order to meet these severe requests, we have developed matrix-type high speed steel, "DRM (Dream)", featuring high hardness and high toughness for wide variety of application. In this paper development concept and features of DRM steel as well as actual application cases are introduced.

2. Background of development

Dies, especially heading tools forming automotive parts, require high hardness and high toughness. However since hardness and toughness are conflicting with each other, tough hot work die steels do not have enough strength resulting in deformation of dies, or high strengthened high speed tool steels (hereinafter HSS) easily generate die cracks so that high-precision forging or prolonged die life was very difficult. There is a material which can fill the gap between hot work die steels and HSS, called matrix-type HSS. Matrix-type HSS is a material which improves HSS by suppressing primary coarse carbides generation and adjusting its basic composition as its matrix composition. This reduction of carbides contributes to better toughness and fatigue strength while high hardness can also be secured because their matrix composition is the same as HSS's matrix one [3), 4)]. Various types of matrix-type HSS have been developed so far [5), 6)] and Daido Steel has developed our own matrix-type HSS, MH85 as cold or warm work die steel which require severe performance and has put them into the market. However with the recent change in die use environment, die service life cannot meet customers' requirements even by MH85. We investigated the cause of damages of those dies and found out that they were impact fracture or fatigue failure by high load, and wear because of lack of hardness as shown in Fig. 1. In order to solve these issues, die steels with higher toughness and hardness at the same time were needed to be developed. Powder HSS is one solution for this, but their production cost is expensive, thus we aimed to develop matrix-type HSS. That steel is "DRM (Daido's Revolutionary Matrix Type High Speed Tool Steels)" steel.

DRM has higher hardness and toughness than conventional matrix-type HSS and has three grades rather than two grades (MH85 and MH88) previously, so that user choice is more flexible depending on their applications. Figure 2 shows positioning map of DRM steels.

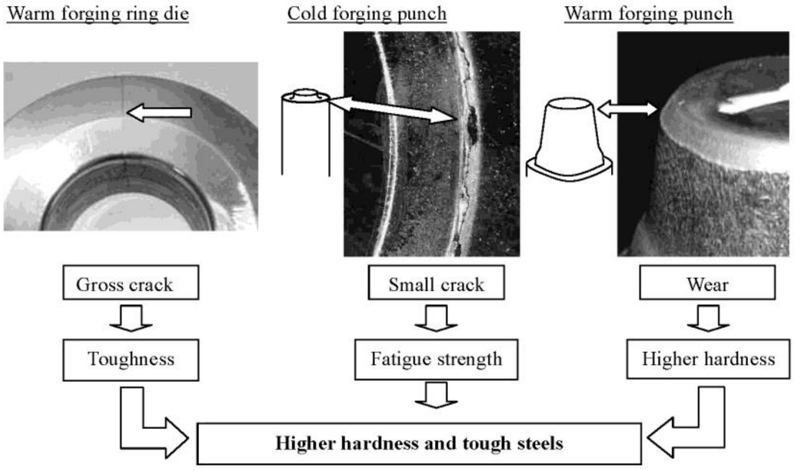

Fig. 1. Examples of failed forging tools and countermeasure to enlarge forging tools life

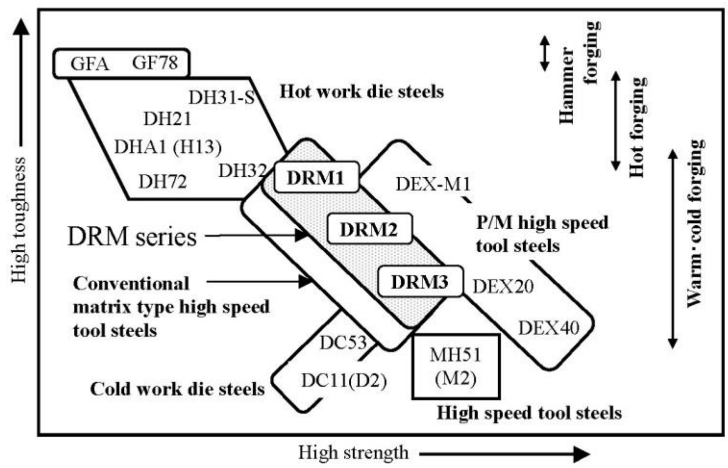

Fig. 2. Positioning of DRM steels in Daido tool steels

3. Development of DRM

3.1 Development Concept

The causes of damages of recent dies were found to be mainly impact fractures or fatigue failures by high load as described above. Therefore we observed fracture surfaces of impact test and fatigue test pieces of conventional matrix-type HSS and examined the form of the fractures. As a result, coarse primary carbides were found as shown in Fig. 3.

In addition, observation of microstructure of conventional matrix-type HSS were taken place and the existence of primary carbides, even though their amount is small, were confirmed as shown in Fig. 4. These carbides bring about suppression of toughness as shown in Fig. 5.

Moreover, decreasing size of carbides have been reported to raise fatigue strengths[7), 8)]. Therefore development target was to decrease those coarse carbides to the most and suppress fatigue and impact fractures. Two grades; MH85 and MH88 were available previously for hot, warm and cold work, but this time by strengthening each application's characteristic feature, deeper consideration was made so that the new steel will endure more severe environment.

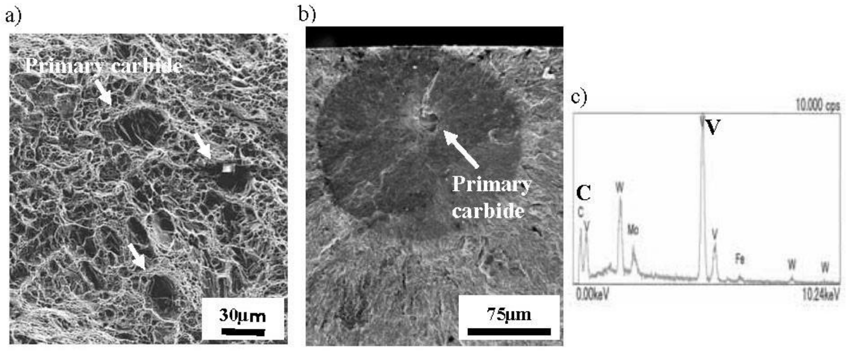

Fig. 3. SEM fractographs of conventional matrix-type HSS (MH85)
a) Charpy impact test specimen, b) Fatigue test specimen,
c) EDX-ray analysis of starting point in fractured surface of b)

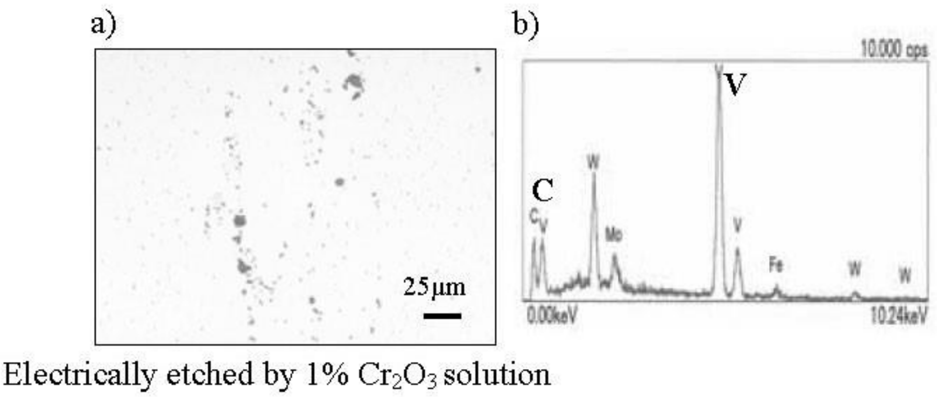

Fig. 4. Microphotograph of conventional matrix-type HSS (MH85)
a) Microphotograph, b) EDX-ray analysis result

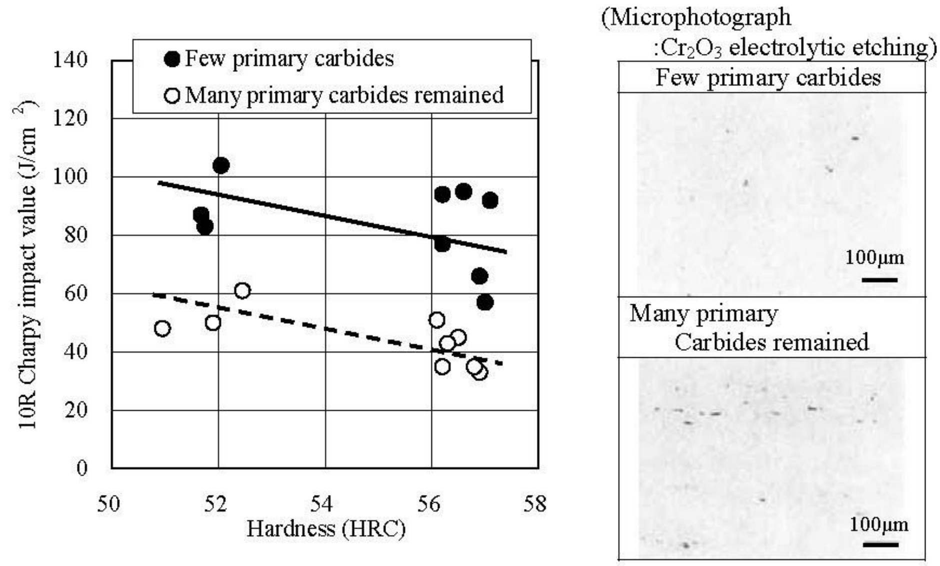

Fig. 5. Effect of the amount of primary carbides on Charpy impact values

3. 2 Alloy Design and Production Process

Following items were considered to achieve the development concept:

a. Alloy design to make most use of carbides: type of carbides, appropriate quantity

b. Production technology to refine coarse carbides: Dispersion in ingot-making and controlling solution or precipitation in forging or rolling

c. Grade lineup with excellent property corresponding to each hot, warm or cold work application

Basic philosophy of DRM1 and DRM2 is to design alloy composition where carbides can be dissolved easily during high temperature heating to reduce coarse carbides. Examination of composition was done using equilibrium calculation software, “Themo-calc” under the condition where single γ-phase at certain carbide amount was broad enough and those carbides are easily dissolved. The result is shown in Fig. 6. In spite that there is no single γ-phase region with AISI M2, the developed alloy has broad region of it.

In order to reduce original primary carbide size, re-melting is applied for the production of DRM steels. Applying re-melting enables molten steel in the pool to be refined and solidified rapidly, which results in clean and uniform steel with finely distributed carbides from the surface to the center and from the top to the bottom as well. Moreover, finely solidified primary carbides are remained to be fine by controlling the heating temperature prior to forging and re-heating temperature for final forging or rolling.

By applying these technologies we have newly developed two steels: DRM1 and 2.
Furthermore, by adding high hardness type high carbon steel [9], DRM3 which contains a little coarse primary carbides, we have completed DRM series：Daido’s Revolutionary Matrix type High Speed Tool Steels and launched to the market.　Principal chemistries of these steels are shown in Table 1.

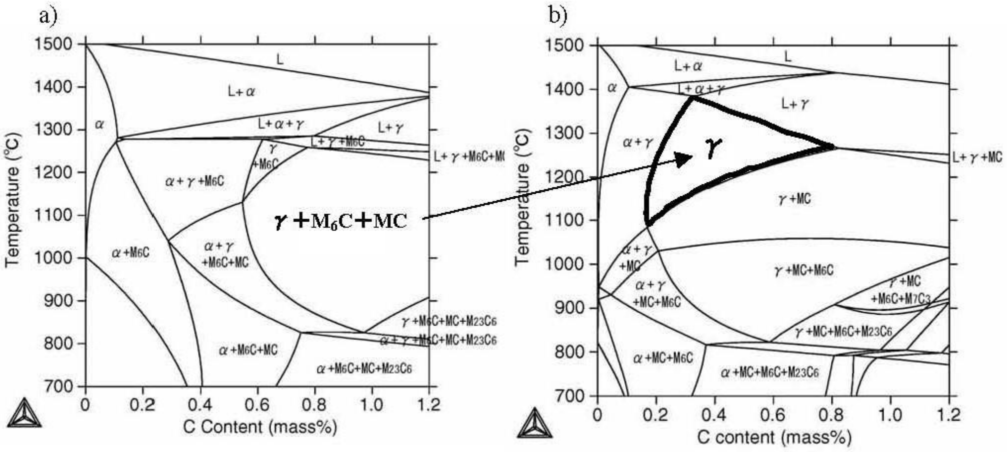

Fig. 6. Calculated phase diagrams

a) AISI M2, b) New matrix-type HSS

Table 1. Principal chemistries of DRM steels

Grade	C	Cr	Weq.*	V	Co
DRM1	0.6	4.2	5.0	1.5	Added
DRM2	0.7	5.5	6.0	1.0	-
DRM3	0.8	5.5	10.0	1.0	-

*Weq. = 2Mo + W

4. Special features of DRM steels

4.1 Features of DRM steels

Special features of DRM steels are shown in Table 2. DRM1 is applied mainly to hot and warm forging dies because of its high hot hardness. DRM2 is suitable for warm and cold forging dies. Due to its high fatigue strength cold forging dies is the most appropriate applicable field. DRM3 is cold forging die steel which can be applied where AISI D2 and M2 have problems in strength and toughness.

The primary feature of DRM steels is fine microstructure as shown in Fig. 7. DRM1 and 2 scarcely show the coarse carbides compared to conventional matrix-type HSS, MH85. DRM3 realizes uniformly dispersed carbides and contains less coarse carbides than AISI M2.

Table 2. Special features of DRM steels

Grade	Hardness (HRC)	Applications
DRM1	56 – 58	Hot and warm working tools: High hardness, hot forging tools
DRM2	58 – 62	Warm and cold working tools: High toughness, cold forging tools
DRM3	62 - 66	Cold working tools: When AISI D2 or M2 has problems with strength and toughness

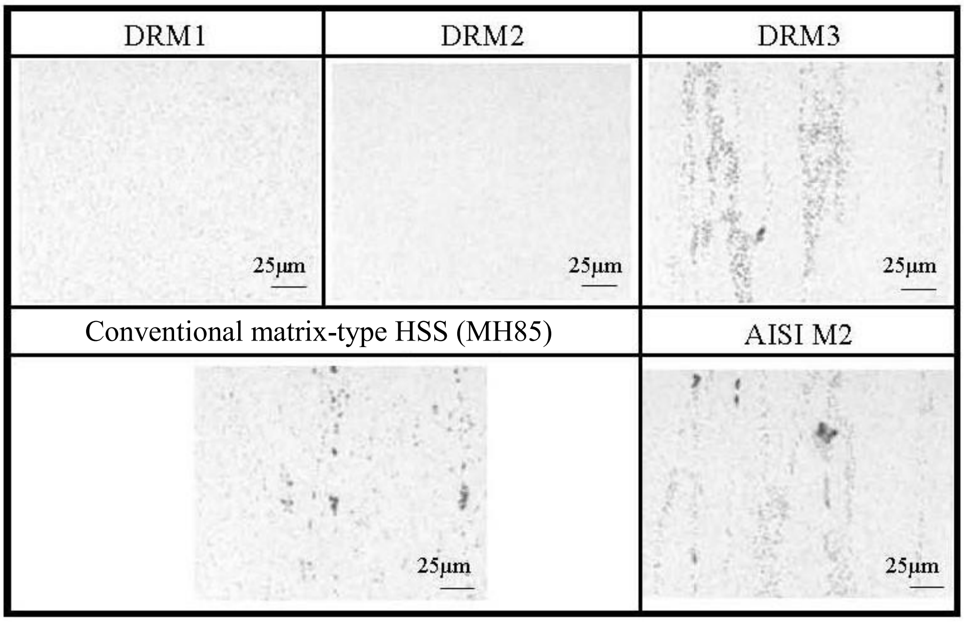

Fig. 7. Microphotographs of DRM steels as annealed

Sample: Taken from the center of 100mm dia. bar, Etchant: 1%Cr_2O_3 electrolytic etching

4. 2 Properties of DRM steels

Toughness properties are investigated by Charpy impact tests. The results are shown in Fig. 8. DRM1 and 2 exhibit higher values than those of cold work die steels such as AISI D2 and Daido's DC53 and conventional matrix-type HSS, MH85. Toughness of DRM3 is better than that of AISI M2.

Micro-fractographic photos taken from the Charpy impact specimens of DRM1 and MH85 are shown in Fig. 9. As we have intended, it is confirmed that coarse VC carbides were observed at the crack origin in MH85, but none of those were found in DRM1.

Fatigue test results, the relation between the applied stress and the numbers of cycles to fracture, are shown in Fig. 10. Rotating bending fatigue tests were carried out by using smooth specimens. DRM1 and 2 show higher fatigue strength than MH85. As confirmed in Charpy impact specimens, micro-fractography also reveals that there is no coarse carbides at fatigue crack origin in DRM1 and 2 as well.

Heat checking test and tempering softening resistance test were conducted to evaluate the thermal fatigue properties. The results of heat checking test are shown in Fig. 11. The maximum crack length of DRM1 and DRM2 is shallower than that of MH85 and AISI H13, which means the superiority of the new grades to conventional steels.

Tempering softening resistance is the other important property for forging die steels, and the test results are shown in Fig. 12. DRM1 shows higher hardness than MH85 and AISI H13. DRM2 is almost equivalent to MH85 but superior to AISI H13.

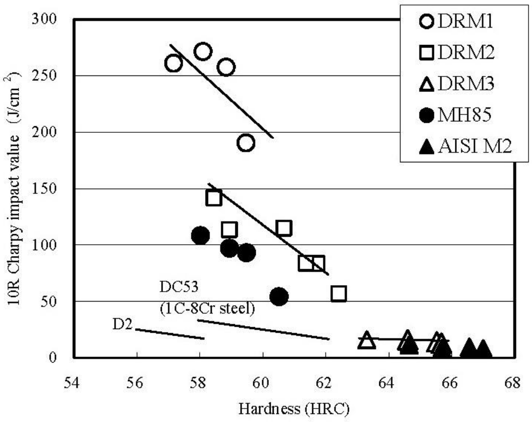

Fig. 8. Charpy impact values of DRM steels and conventional tool steels

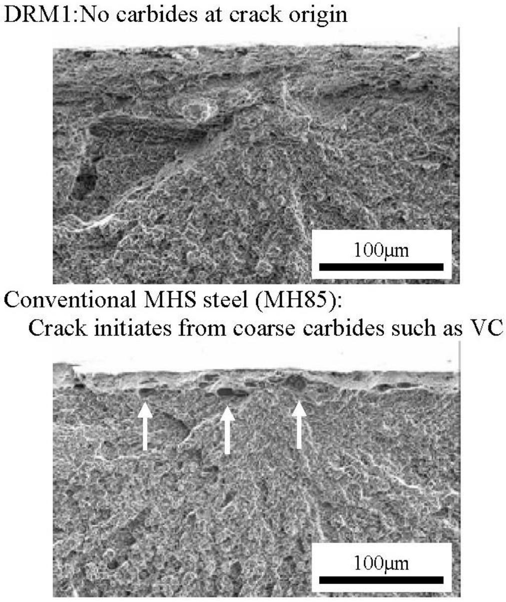

Fig. 9. SEM images of Charpy impact test specimens

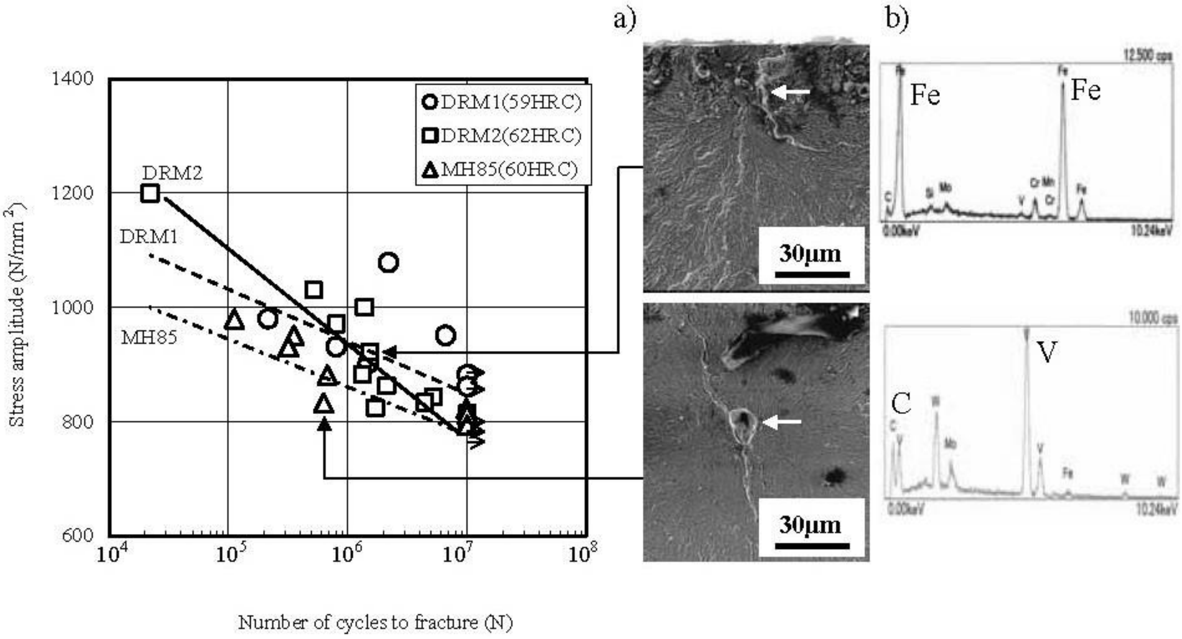

Fig. 10. Fatigue strength of DRM1, DRM2 and conventional matrix-type HSS (MH85)
a) SEM images of fatigue test specimens, b) EDX-ray analysis result

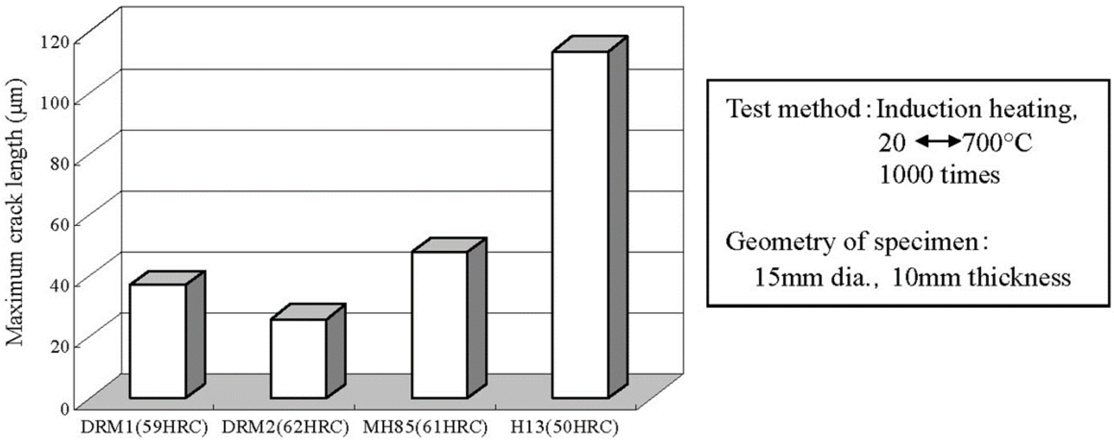

Fig. 11. Heat checking resistance of DRM1, DRM2 and conventional tool steels

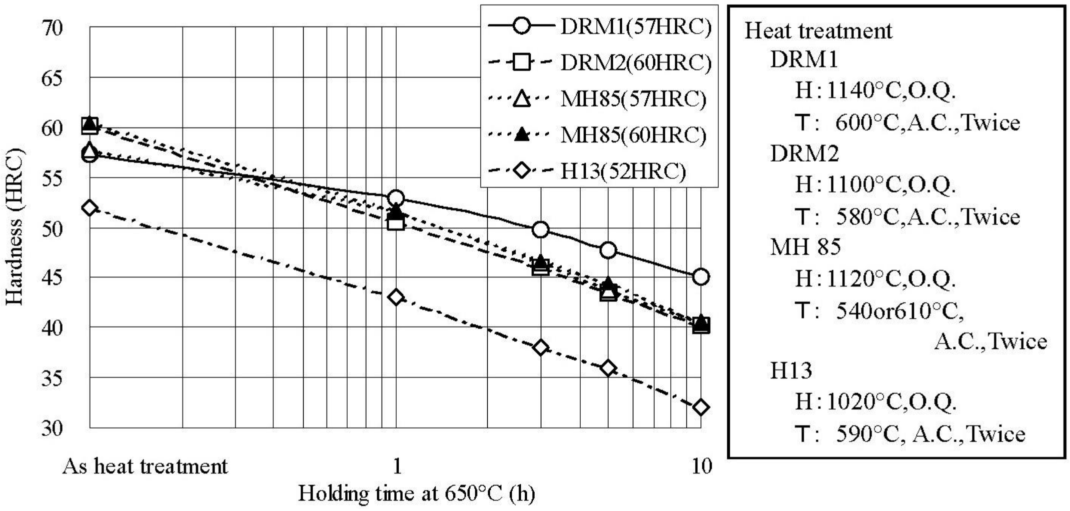

Fig. 12. Temper softening resistance of DRM1, DRM2 and conventional tool steels

5. Application Study

5. 1 Application of DRM1

Examples of the application of DRM1 are shown in Table 3. DRM1 shows longer life than MH85 and AISI H13 especially for dies the failure mode of which is crack. Furthermore, DRM1 is effective to prolong the life of the dies which have problems in the surface softening. The cause of the die life improvement from H13 is the greater tempering softening resistance by increasing the initial hardness [10].

Table 3. Applications of DRM1 steel

Application	Size(mm)	HRC	Life	Conventional grade
Outer race Forming punch	90 dia.	55±1	13,000S **	3Cr-2Mo: 12,000S** matrix-type HSS*: 12,700S**
Knockout pin	40 dia.	57±1	15,000S (No stelite)	matrix-type HSS*: 15,000S (Stelite welding overlay)
Back die	120 dia.	57±1	18,600S	matrix-type HSS*: 16,000S
Front die	140 dia.	57±1	6,700S 20,600S**	AISI M2: 2,400S
Pressing die	100 dia.	56±1	13,000S	AISI H13: 8,000S
Connecting rod forming die	45 X 130s	58±1	10,000S	AISI H13: 8,000S

*Conventional matrix-type high speed tool steel, **Salt nitriding

5. 2 Application of DRM2

Table 4 shows examples of the application of DRM2 indicating the longer life than conventional matrix-type HSS. Factors to prolong die life are prevention of yielding and fatigue by increasing the strength with remaining high toughness. DRM2 was applied to a mandrel used for cold forming and originally made of powder metallurgy high speed steel. The failure mode was fatigue fracture. Although the new grade shows almost the same life with fatigue fracture, it is superior to P/M steel from the viewpoint of material cost [10].

Table 4. Applications of DRM2 steel

Applications		Size(mm)	HRC	Life	Conventional grade
Cold	Knockout sleeve	20 dia.	59	≥ 18,000S	matrix-type HSS*: 14,000S
	Mandrel	30 dia.	61±1	12,000S	P/M HSS: 12,000S
	Punching die	15 dia.	60	Longer than M2	AISI M2
	Threading die	200 dia.	62	22,000S	matrix-type HSS*: 20,000S
Warm	Forming sleeve	50 dia.	58	60,000S	matrix-type HSS*: 50,000S
	Forming die	100 dia.	58	60,000S	matrix-type HSS*: 50,000S
	Warm punch	120 dia.	58	≥ 15,000S	Hot work die steel: 10,000S

5.3 Application of DRM3

Examples of the application of DRM3 are shown in Table 5. Longer life has been attained especially for the tools where AISI D2 and M2 fail with chipping. Since DRM3 has higher hardenability, prolonged life has been realized for large size dies like rolling-mill rolls where toughness deficiency may happen easily.

Table 5. Applications of DRM3 steel

Application	Size(mm)	HRC	Life	Conventional grade
Warm rolling die	75 X 85s	65	30,000S Chipping	AISI M2, 60HRC 10,000S, Chipping
CVJ **Cold forming die**	150 dia.	65	35,000S Chipping	8Cr type die steel 12,000S, Chipping
Cold forging **punch**	70 dia.	65	60,000S Chipping	AISI M2, 61HRC 10,000S, Chipping
Cold work roll	100 dia.	66	Three times Wear	AISI M2, 61HRC Wear
Emboss roll	200 dia.	65	Twice Wear	AISI M2, 61HRC Wear

6. Conclusion

We have developed new matrix-type high speed steels, DRM steels, aiming at high toughness and fatigue strength by decrease coarse primary carbides with maintaining the required amount of carbides [11]. This concept has been realized by the combination of alloy designing and state-of-the-art production technologies. These new grades, DRM steels, have shown their superiority to conventional steels in actual applications and are expected to expand their application fields by replacing conventional steels for hot, warm and cold forging tools.

DRM and DC53 are trademarks or registered trademarks of Daido Steel Co., Ltd.

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