LINDQUIST STEELS, INC.
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DH31-EX

NADCA Approved 2011

Ultra High Strength, tough, and high heat check resistance hot work die steel.

DH31-EX, produced exclusively by Diado Steel Ltd., is a hot working die steel with the best balance or strength and toughness that shows comparable softening resistance to SKD7 (~AISI H10) and twice the hardenability as that of SKD61 (~AISI H13). DH31-EX won NADCA approval in June 2011.

Features:

- **High Hardenability**
  High toughness is obtained even in large sized dies.
- **High Strength**
  High softening resistance at elevated temperature contributes to high wear resistance.
- **High Toughness**
  DH31-EX has higher toughness than that of SKD61.
- **High Heat Check Resistance**
  Excellent heat check resistance leads to longer tool life.

Applications:

- Aluminum die cast dies, especially for large die sizes & long life use
- Aluminum die cast parts such as pins & plunger sleeves
- Hot forging dies
- Hot pressing dies
- Aluminum extrusion dies

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Examples of Applications:

Field	Application mold	DH31-S		Conventional		
		Hardness (HRC)	Life (Shot)	Grade	Hardness (HRC)	Life (Shot)
Die cast	Water jacket	36 Ion nitriding	24000	DH21	36 Ion nitriding	10000
	Cylinder head cover	50 (HIT)	>40000	SKD61	47	18000
Hot forging	Rear axcel	48	8000	SKD62	43	2000
	Rear spindle	48 Ion nitriding	11000	SKD62	45 Ion nitriding	4000

Chemical Composition:

Daido	C	Si	Mn	Cr	Mo	V
DH31-S	Patent pending					

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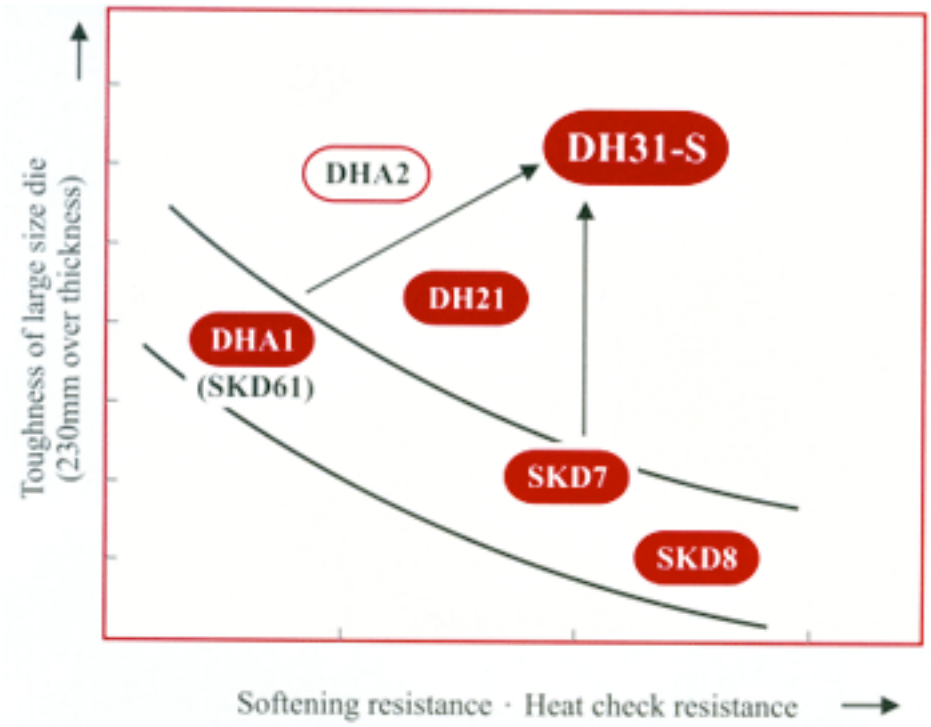
The Concept of Development:

DH31-EX is a hot working die steel with the best balance of strength and toughness showing the comparable softening resistance to SKD7 and twice hardenability as that of SKD61.



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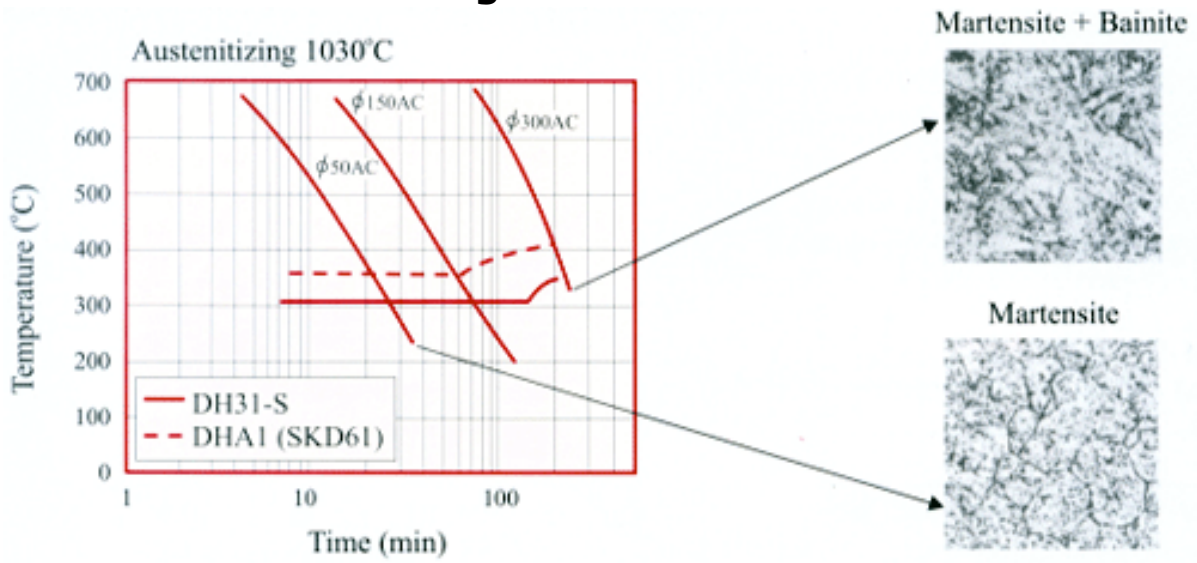
Hardenability:

High toughness is obtained even in large size dies due to high hardenability.

- **Continuous cooling transformation curve**



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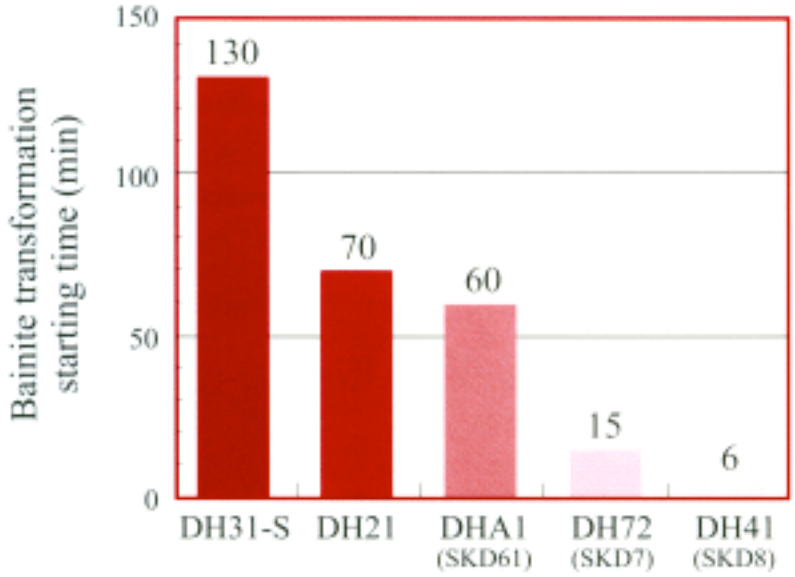
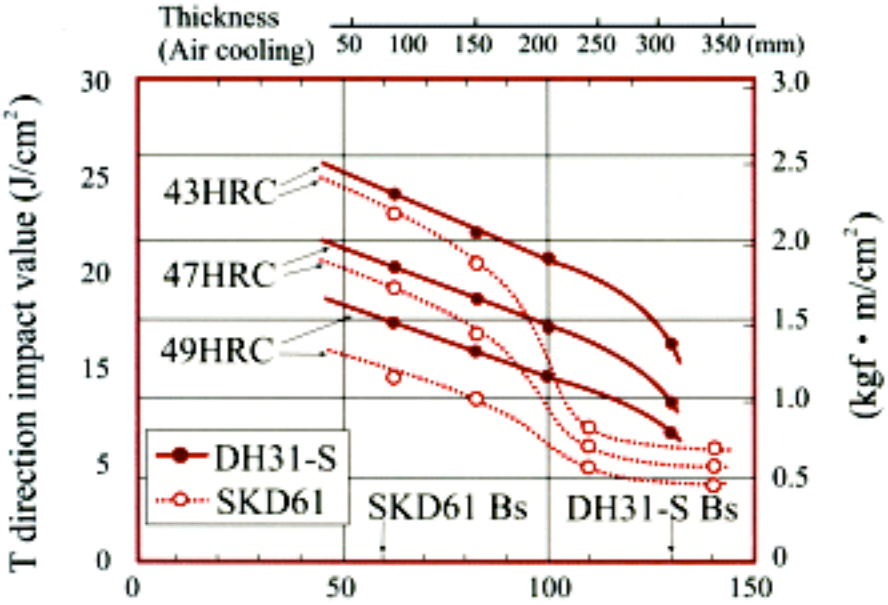
Bainite hardenability

As Bainite transformation starting time is twice as that of SKD61, 130min., quenching operations is easily and safely carried out without troubling such as toughness deterioration in large size dies.



Quenching cooling time vs. toughness

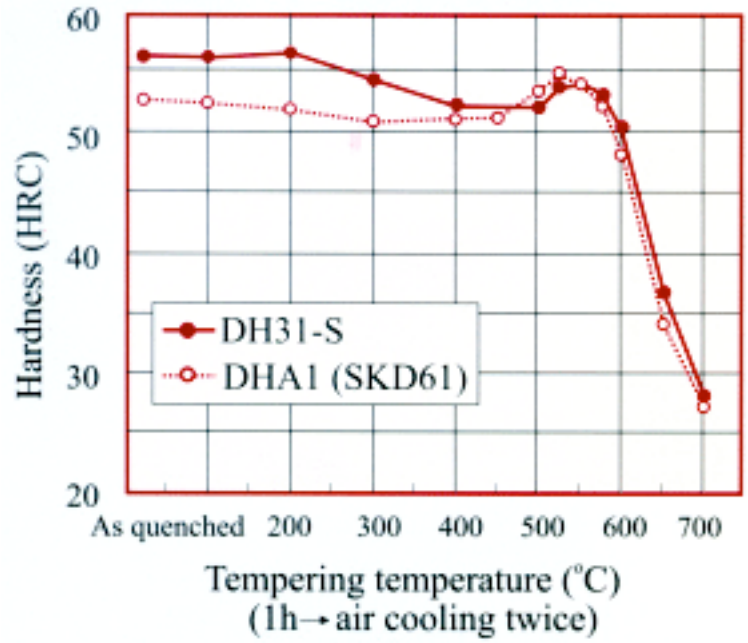


Cooling time of mid portion from 1030°C to 300°C (min)

- **TP size: Ø440**
- **Quenching temp: 1030°C**

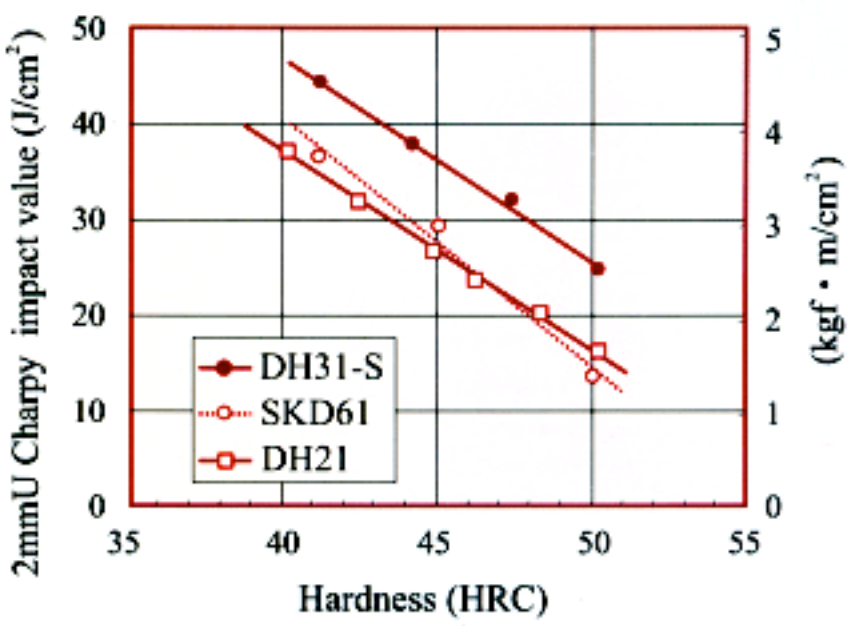
Characteristics:

- **Tempering hardness**



  - Quenching temp: 1030°C
  - T.P. size: 10H x 10W x 15L

- **Toughness**



  - Quenching temp: 1030°C x 30min. --> 150 Dia. Bar, AC
  - T.P. size: L

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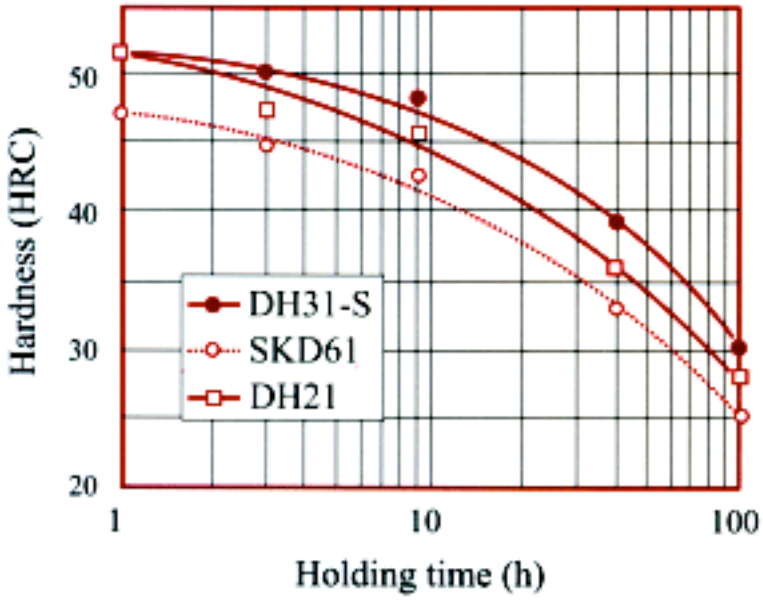
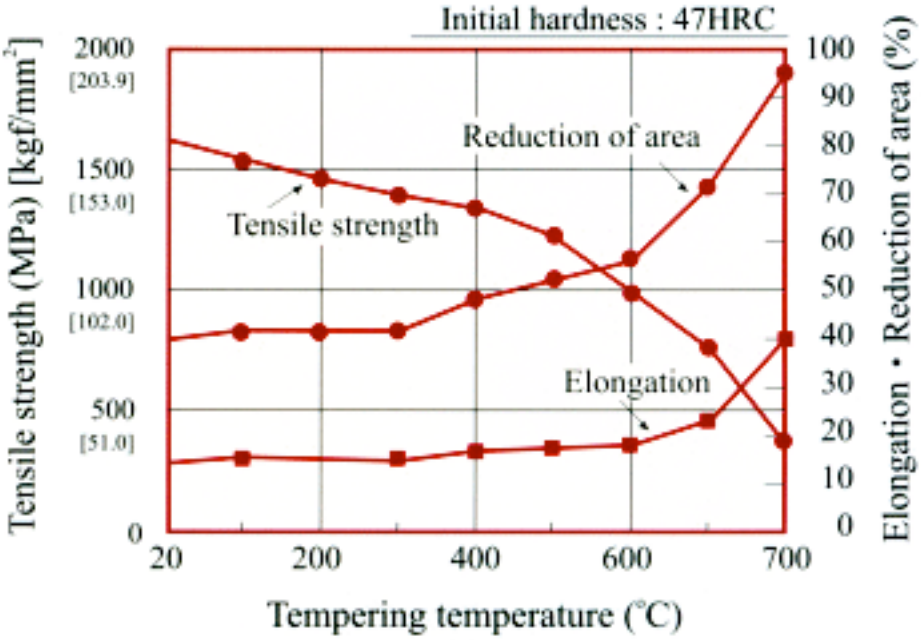
Softening resistance



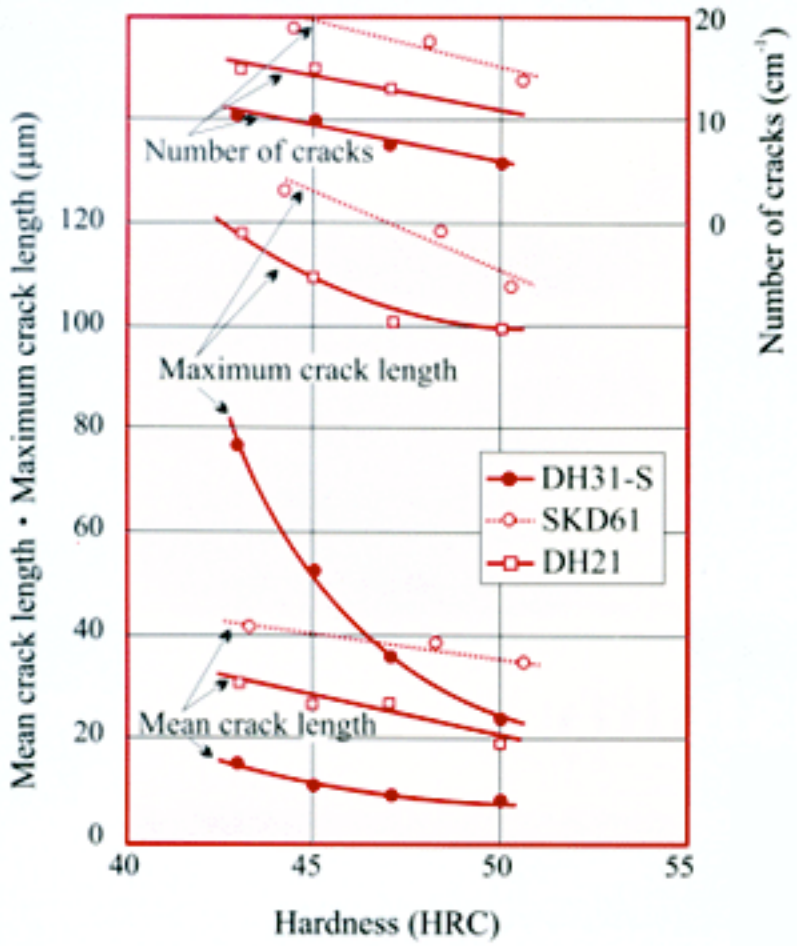
- Holding temp.: 600°C
- Quenching temp: 1030°C x 30min. --> 150 Dia. Bar, AC
- T.P. size: 10H x 10W x 15L

Elevated temperature tensile properties



- T.P. size: Ø 8 x 40L

- **Heat check resistance**



Heat check resistance is further improved by increasing hardness without deteriorating toughness.

An example to improve heat check resistance (200mmm thickness air cool quenched die)

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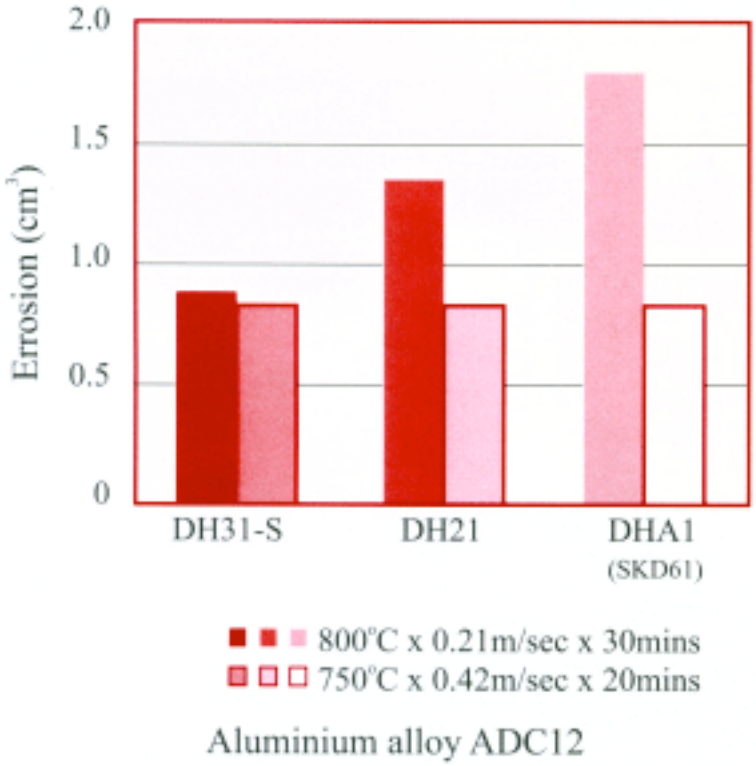
Grade	Hardness (HRC)	Charpy impact value* (J/cm^2) [$kgf \cdot m/cm^2$]	Mean crack length (μm)	Notes
DH31-S	50	12 [1.2]	8	same toughness
	43	19 [1.9]	16	same hardness
SKD61	40	12 [1.2]	43	

* T direction at center

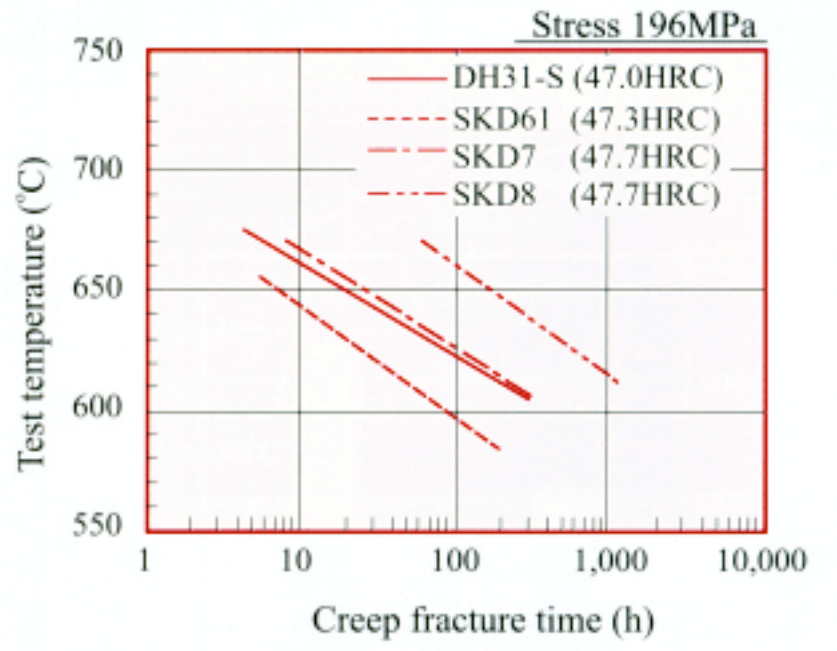
<Test procedures>

- Specimen: 15mm
- I/Heating: 20<-> 700C
- Number of cycles: 1000 times

Erosion resistance



Creep properties



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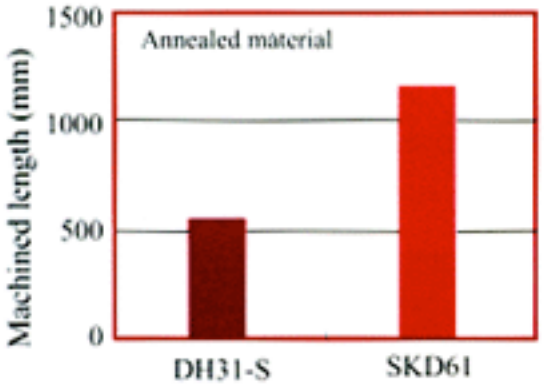
Machinability:

- DH31-EX shows good machinability as high strength-high tough grades.

● Test conditions

Tool	HSS/Square endmill
	Coating : Non, Number of cutter : Two
Size	10 ϕ
Speed	11m/min
Feed	0.2mm/Cutter
Depth	1mm
Fluid	Water soluble



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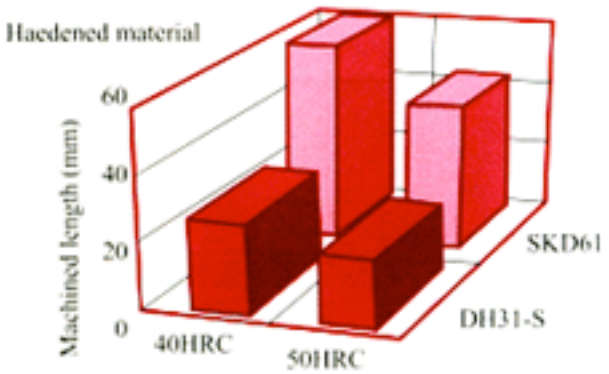
● Test conditions

Tool	Carbide/Square endmill
	Coating : TiAl, Number of cutter : Six
Size	10 ϕ
Speed	20m/min
Feed	0.03mm/Cutter
Depth	Axial ; 15mm Radial ; 0.5mm
Fluid	Air blow



- Recommended machining conditions

Annealed material	Smaller cutting speed and feed are preferable within the conditions for die steels recommended by tool makers.
Heat treated material	Use the tools for high hardness and hard machining materials. Cutting fluid further helps better operation. In square endmilling positive rake angle and larger twist angle are recommended.

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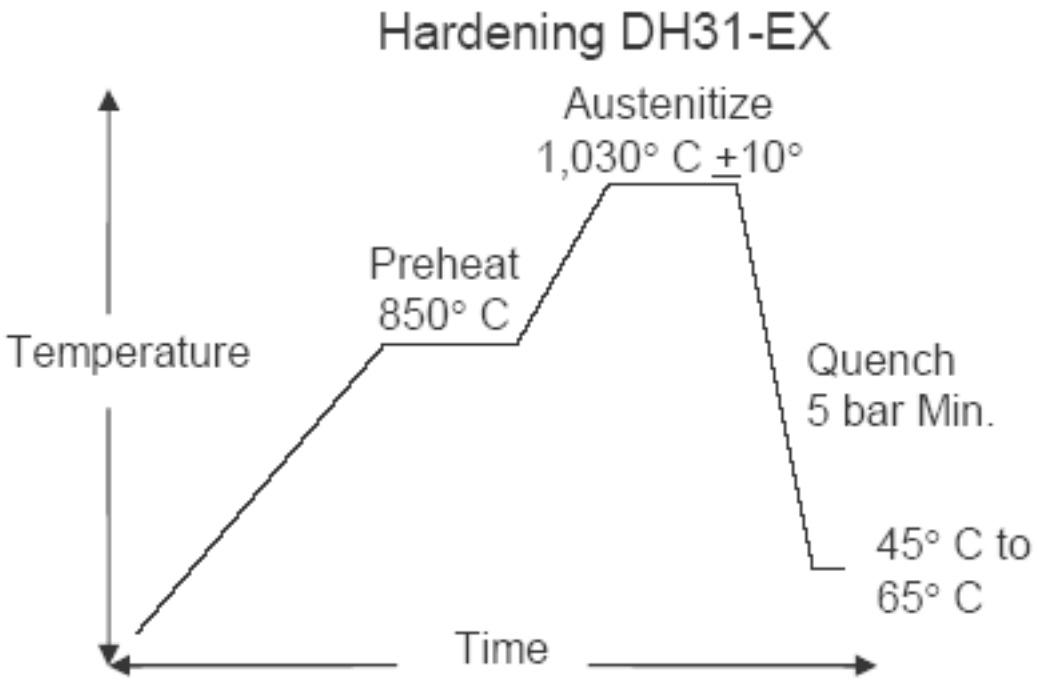
Heat Treat:

DH31-EX Heat Treat – is a double melted ESR, heat treatable air hardening premium hot work die steel. It has been forged on a 7,000 metric ton press to give it extra high toughness and heat check resistance. Its heat treat process is broken down into two segments, hardening & tempering. The hardening segment is best performed in a vacuum furnace with high pressure quench capabilities.



Vacuum Austenitize & Gas Quenching – DH31-EX should first be preheat at a rate of less than 220° C (400° F) per hour and held at 800° C (1,475° F) to 850° C (1,560° F) until the tools are uniformly heated from surface to core to within 60° C (100° F) and then increased to 1,030° C ±10° C (1,885° F±18° F) to austenitize otherwise known as soaking the tool.

When distortion in heating is concerned for large or complicated geometry parts, a double pre-heating is recommended: The first pre-heat is at 550° C (1,020° F) to 650° C (1,200° F) and the second at 800° C (1,470° F) to 850° C (1,560° F). The temperature should be allowed to equalize from the surface to the center of the part in each step before proceeding up to the austenitizing temperature.

Once the part reaches 1030° C (1,885° F) and is fully equalized in temperature, the holding time is 30 minutes. In cases where it is difficult to measure the temperature of the center of the part, the holding time from when the atmosphere reaches to 1030° C should be as shown in the Table considering the delay of the rise in the center temperature. As the time required for equalization of the temperature is ruled by furnace size, loading weight, heating method and so on, holding time is allowed to justify by the recommendation in the Table.

Maximum thickness Inch (mm)	Holding time (Min)
4" and under (100mm)	20 – 30 min/inch of thickness (longer than 1h)
Over 4" (100mm)	10 – 20 min/inch of thickness (longer than 2h)

After austenitizing, the part will need to be quenched in inert high pressure gas (generally in nitrogen) to rapidly cool with at least 5 times atmosphere pressure (5 bar), however 10 bar pressure is recommended. The cooling rate at the center of the part should be at least 3° C (6° F) per minute in the temperature range of 500° C (930° F) to 200° C (390° F). Preferably the cooling rate should be higher than 5° C (9° F) per minute for obtaining better toughness.

An interrupted quench is preformed by temporarily halting the cooling process between 450° C and 400° C (840° F and 750° F) to allow the temperature throughout the part to equalize within

110° C (200° F) before continuing the rapid quench. This interrupted quench is recommended to reduce the distortion in quenching. The part should be immediately tempered once it has reached 65° C to (150° F) to 45° C (120° F).

Using Thermocouples - It is important that efforts be taken to measure temperatures at the center of the part throughout the heat treat process. Inserting a thermocouple in the center of the part insures that the entire part has reached the desired temperature before proceeding to the step in the heat treat process. The initial design should allow for the insertion of a thermocouple when possible. Water lines often make excellent locations for thermocouples. Be sure to pack thermocouple holes with a refractory fiber material to help prevent false readings. If the geometry of the part does not accommodate such a feature, it is recommended that a dummy part of similar shape and mass with a thermocouple mounted in the center be used as a temperature control.

There are two ways to use this control information. The first way is to run the part side by side with the dummy part using it to measure the temperature at the center of the part throughout the heat treat process. Realizing that this may not be practical when heat treating large parts, the second way is to cycle the dummy part through the heat treating process while documenting the times it takes for the tool to reach the desired temperatures and use that data to run the actual part. Thermocouples are useful in both the hardening and tempering processes.

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Other Quenching Methods - As an alternative to vacuum furnace with gas quench, an atmosphere controlled furnace can be used for austenitizing. The holding time is recommended to be a little longer than that of a vacuum furnace. In this case salt bath or oil bath is used as quenching media to obtain quenching rate higher than 3° C per minute in the range of 500° (930° F) to 200° C (390° F).

Generally, the quench rate should be as rapid as possible to obtain optimum balance of strength and toughness. Quenching too fast, however, may cause distortion and cracking. In controlling the cooling rate by vacuum furnace quenching, it must be considered not only gas pressure, but also gas flow, its rate, heat exchanger efficiency, gas running path and so on.

Tempering – Preferably, tempering is performed in air convection or atmosphere type furnace however can also be vacuum tempered when aided by the use of thermocouples and special care is taken to monitor temperatures. Triple tempering is recommended for die-casting molds and minimum twice for forging and extrusion tools.

The first tempering temperature is 550° C (1,022° F) to 650° C (1,200° F). 580° C (1,075° F) to 600° C (1,110° F) is generally applied for die casting molds. Second tempering is carried out at 550° C (1,022° F) to 650° C (1,200° F) depending on the required hardness. If the resulting hardness is higher than specified, hardness, it can be decreased by a third tempering. When the hardness meets the specification by second tempering, the third tempering is done at 30° C (54° F) to 50° C (90° F) lower than that of the second.

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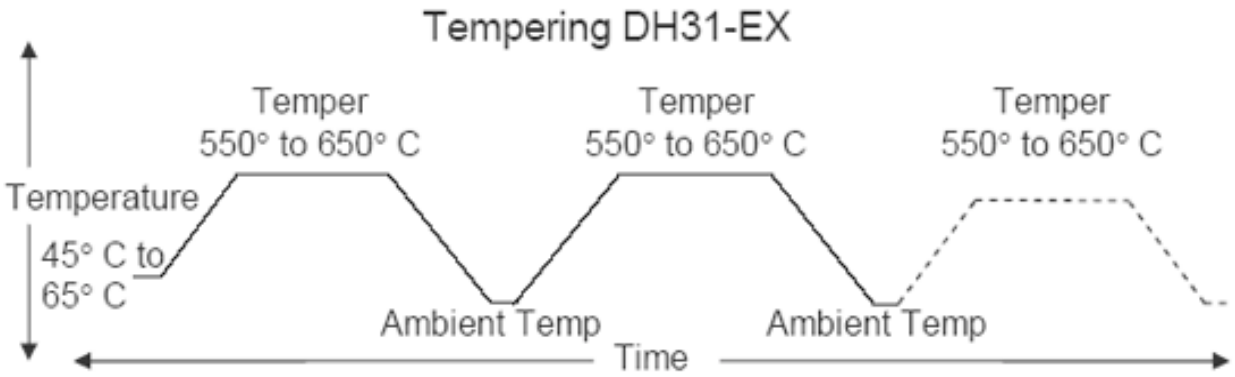

Tempering temperature for each aimed hardness is shown in the table hereunder.

Celsius	Fahrenheit	HRC
600° C	1,110° F	HRC 46-50
615° C	1,140° F	HRC 42-46
630° C	1,165° F	HRC 38-42

Holding time after atmosphere temperature reaches aimed temperature is 60 minute per 25mm (1 inch) in thickness in cross section with a minimum tempering time of 2 hours.

Note: As with any tool steel, actual heat treat results may vary depending on the circumstances of each application. Therefore the information pertaining to this document is given as a starting point and may require modification based on the size of a given load, fixturing, and equipment capabilities therefore some adjustments in the process may need to be developed and fine tuned base on you combination of circumstances to achieve optimum. Empirical data from heat treating other hot work grades of similar size in specific equipment can be helpful in developing optimum heat treat process for DH31- EX.

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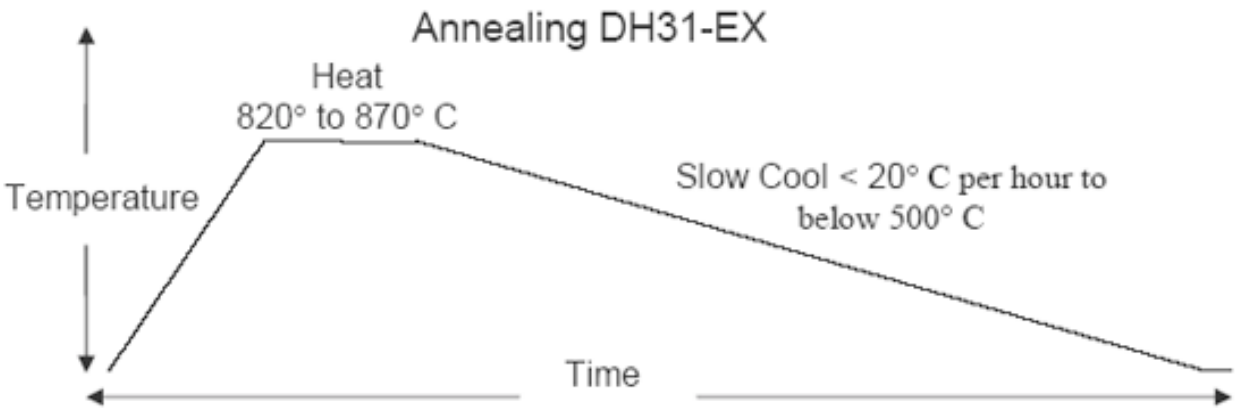
Annealing and re-hardening – If re-hardening is needed, it is necessary to first re-anneal the part.



Annealing – DH31-EX can be annealed by uniformly heating the part to between 820° C (1,508° F) and 870° C (1,598° F), and hold for 2 hours followed by a slow cooling at no more than 20° C (36° F) degrees per hour to until the temperature of the part has dropped below 595° C (1,100° F). The part can then be furnace cooled or left in still air to room temperature to complete the annealing process. The part is now ready to be re-hardened.

Heat Treatment Conditions:

Condition for heat treatment (°C)			Transformation temp (°C)		Hardness	
Annealing	Hardening	Tempering	Ac	Ms	Supply condition (HB)	Q.T. (HRC)
820-870 slow cooling	100-1050 air • gas • oil cooling	550-650 air cooling	805-885	315	≤235	≤53

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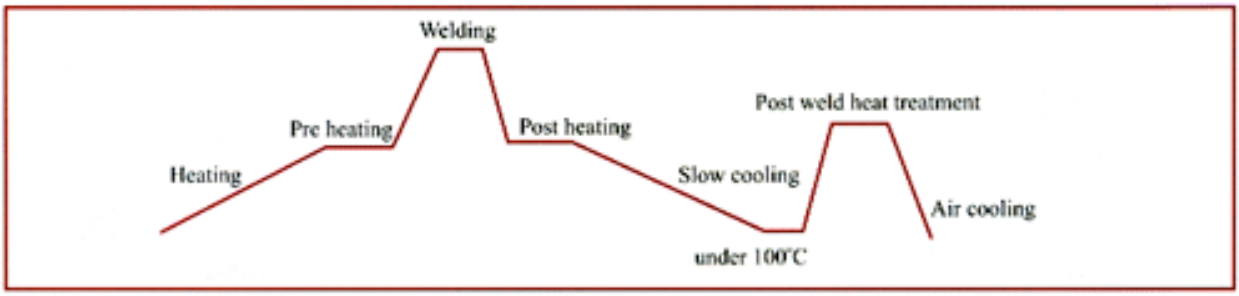
Repair Welding Conditions:

- TIG manual welding condition

Electrode diameter (mm)	Welding current (A)※	Argon gas flow (ℓ /min)	Nozzle diameter (mm)	Arc length (mm)
1.0	15-80	4-8	9	1.5-2.0
1.6	70-150	6-9	9	2.4-3.2
2.4	150-250	7-10	9-11	3.6-4.8
3.2	250-400	10-15	9-11	4.8-6.4

※DC

Work	Electrode	Pre and Post heating	Post weld heat treatment
Annealed	SKD61	400-500°C x 0.5h	500-550°C x 1h-3h
Hardened	MAS1C	300-400°C x 0.5h	450-500°C x 1h-3h



Physical Properties:

Coefficient of thermal expansion

Temperature	20-100°C	20-200°C	20-300°C	20-400°C	20-500°C	20-600°C	20-700°C
x 10⁻⁶/K	11.0	11.4	11.8	11.8	12.1	12.4	12.6

Thermal conductivity

Temperature	20°C	100°C	200°C	400°C	600°C	700°C
W/m•K [cal/cm•sec•°C]	26.0 [0.0621]	26.7 [0.0638]	27.5 [0.0657]	28.4 [0.0679]	29.2 [0.0698]	27.9 [0.0667]

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Specific heat

Temperature	20°C	100°C	200°C	400°C	600°C	700°C
J/kg·K [cal/g·°C]	435 [0.104]	452 [0.108]	478 [0.114]	554 [0.132]	707 [0.169]	883 [0.211]

Density

Temperature	20°C
Kg/m^3 $[g/cm^3]$	7800 [7.80]

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