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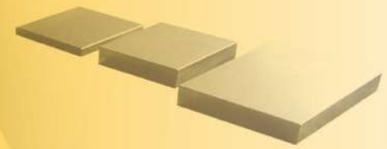
GMTC Gloria Material Technology Corp.

Hot Work Steel
TS-GHX1



TSG 台鋼集團 TAIWAN STEEL GROUP

The Story of Brand Name

T Localized Product in Taiwan
Along with Taiwan Steel Group
Firm Belief of Rewarding Taiwan

G Co-prosperity Group and Honor Team with Glory

H Hot Working Steel

X "Extra" represents high-class re-melting technique and product with superior features and excellent quality.

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TSG High-class Hot Work Steel : TS-GHX1

1. Chemical Composition

Brand	C	Si	Mn	Ni	Cr	Mo	V	Other
TS-GHX1	0.32 ~ 0.40	0.10 ~ 0.50	0.30 ~ 0.80	-	4.70 ~ 5.85	2.00 ~ 3.30	0.40 ~ 0.70	-

2. General Application & Size Capability

Features & Application

- Excellent ductility
- High cleanliness steel
- Good resistance to temper softening
- High temperature strength
- Excellent Hardenability (Large die)
- Available for Nitriding treatment
- Less dimensional change during heat treatment

It is suitable for various die-casting, extrusion, warm and hot forging, plastic injection molds, tungsten carbide or high-speed steel mold sets, wear-resistant blocks and other parts.

GHX1 Size Capability & Hardness: HB < 200

[Round bar] Machined Size ◦ ≧ Dia. 300mm , ≦ Dia.510mm ◦

W	Max T	W	Max T	W	Max T
720	275	550	365	380	528
710	279	540	372	370	542
700	284	530	379	360	557
690	288	520	386	350	573
680	293	510	394	340	589
670	297	500	402	330	606
660	302	490	410	320	624
650	307	480	419	310	643
640	312	470	428	300	664
630	317	460	437	290	686
620	322	450	447	280	709
610	328	440	457	275	720
600	333	430	468		
590	339	420	479		
580	345	410	490		
570	352	400	503		
560	358	390	515		

[Flat] Machined Size
Please check the right side list, and confirm with salesman.

Al-extrusion : Al-7005

Aluminum Die Casting Part : ADC 10

Hot Forged : Carbon Steel & Stainless Steel

Magnesium Die Casting : AM 60B ◦

3. Physical & Mechanical Properties

Physical Properties :

Temperature	24°C	200°C	400°C	550°C	600°C
Density(Kg/m3)	7,830	7,750	7,700	7,650	7,600
Modulus of Elasticity (N/mm2)	203,703	-	-	-	-
Coefficient of Thermal Expansion (mm/mm°C from 20°C)	-	11.89×10^{-6}	12.66×10^{-6}	13.03×10^{-6}	13.12×10^{-6}
Thermal Conductivity(W/°C)	32.56	34.64	27.25	28.80	-
Specific Heat (J/g °C)	0.45	0.54	0.51	0.66	-

Mechanical Properties :

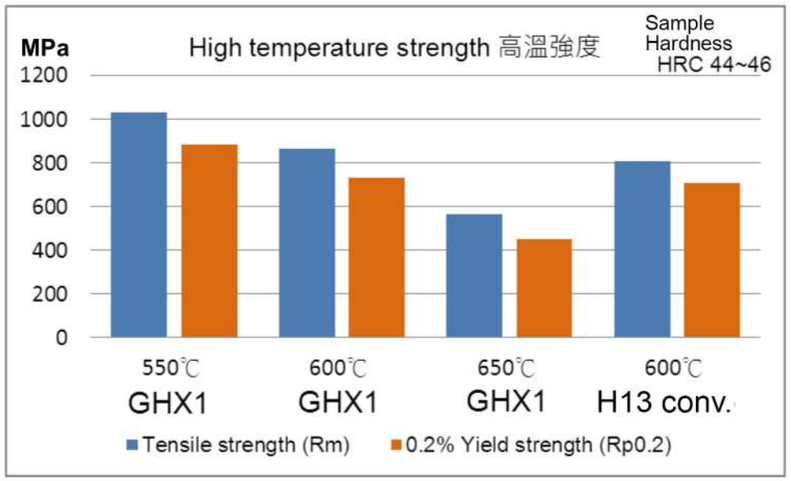
Grade	Hardness (HRC)	Tensile strength (R_m)	0.2% Yield strength ($Rp_{0.2}$)	Elongation (A5)	Reduction of Area (Z)
GHX1 Room temp.	44	1,480	1,210	13.0	55
	48	1,640	1,380	13.0	55
	52	1,900	1,560	12.5	52

4. Tensile Properties at Elevated Temperature :

GHX1

High Temp. Strength

Strength performance with different temperature under condition of H44~46 heat treatment
Rm:Tensile Strength
$Rp_{0.2}$: Yield Strength
A5: Elongation
Z: Reduction Ratio



Grade	Test temp.	Tensile strength (R_m)	Yield strength ($Rp_{0.2}$)	Elongation (A5)	Reduction of Area (Z)
GHX1	550°C	1030.8	886.0	26.0	74.5
GHX1	600°C	865.3	734.3	13.0	78.5
GHX1	650°C	565.4	451.6	-	-
H13 (conv.)	600°C	806.7	706.7	7	76.5

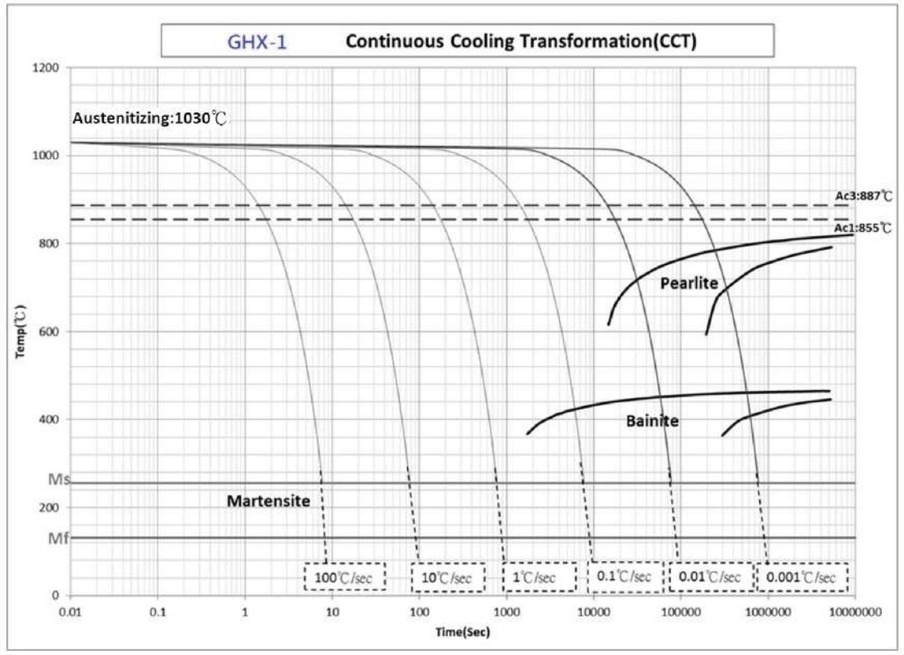
5. Heat Treatment :

GHX1

GHX1 Continuous Cooling Transformation Curves

Austenitizing Temperature ：1030°C

Soaking 30 Minutes



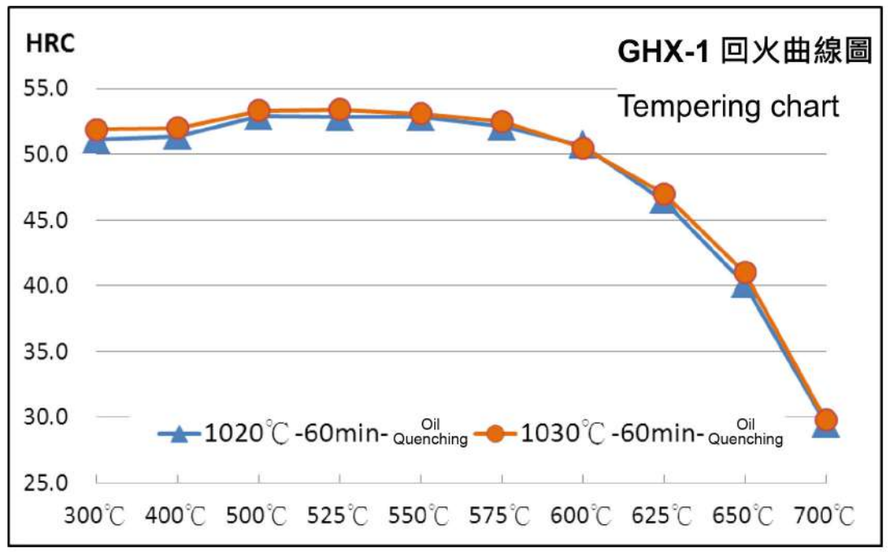
GHX1

Tempering Chart

Furnace holds temperature for 60 minutes (soaking in Muffle furnace, and then oil quenching).

Tempering once and 2 hours per time

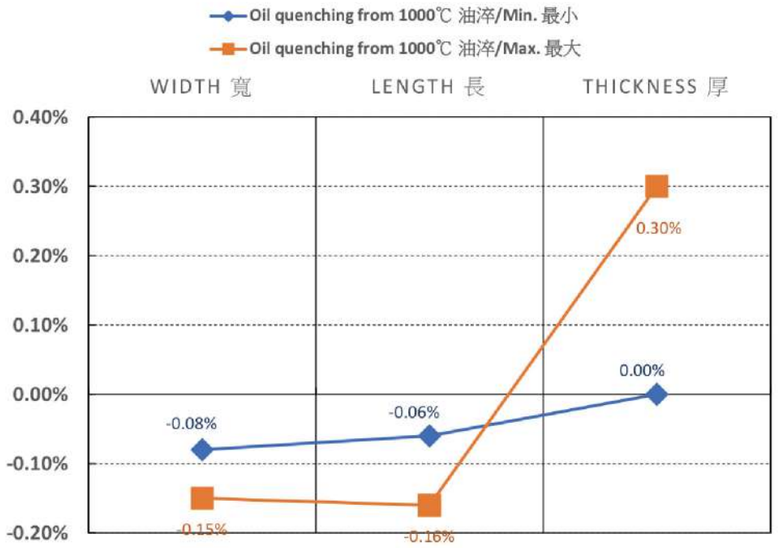
Dummy Block Size: 50 X 50 mm



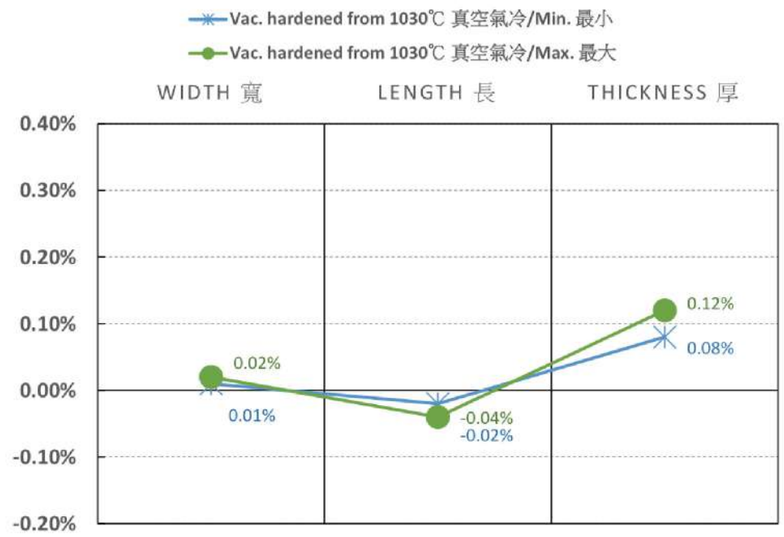
Dimensional Change during Heat Treatment (Quenching + Tempering)

Dimensional Change in Quenching (After Austenitizing / Solid Solution). Sample size : 100 X 100 X 25 (mm)

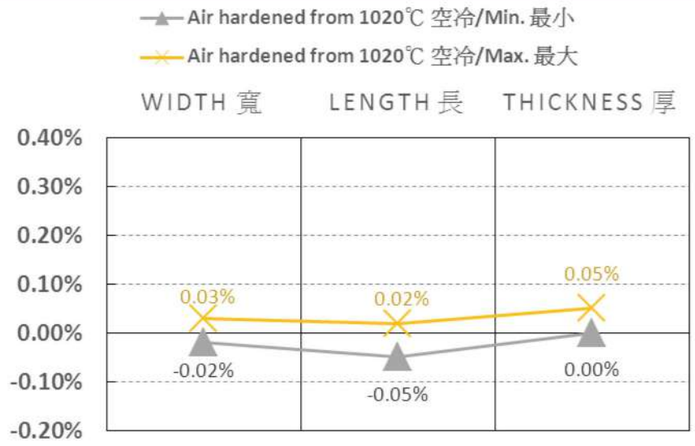
Oil Quenching



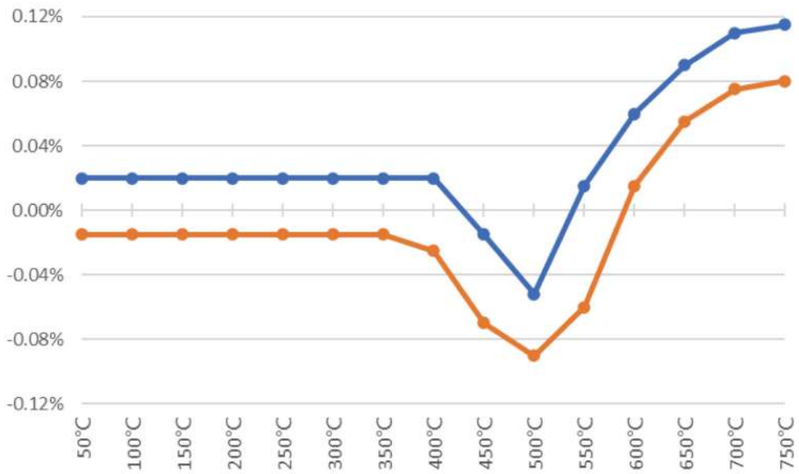
Vacuum Hardened



Air Hardened



The Change of Size while Tempering. **Blue line:** the change of upper limit. **Orange line:** the change of lower limit. The change of size should be in the region between two line.

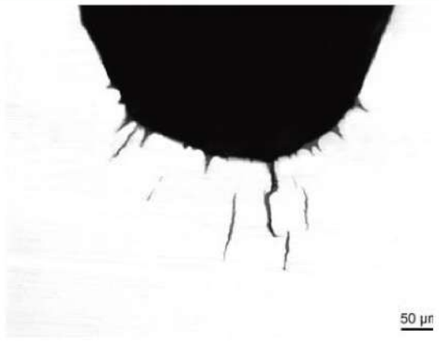


Others Heat Treatment	Without Heat Treatment (Soft / Annealing Material)	With Heat Treatment (Hardened Material / Material above HRC 30)
Soft Annealing	Heating steel to 850°C (to core part of bar as well) in protective atmosphere then slowly cooling (10°C/hr) to 650°C(some case to 600°C). Finally free air cooling to room temp.	the same as left content
Stress Relieving	Heating steel to 650°C (to core part of bar as well) and keep temperature with 2 hours after machining then do air cooling to room temperature.	Heating steel to temperature lower than last tempering about 15~30°C, keep it with 2 hours until core part of bar reaches to the temperature and do air cooling to room temperature.

The stress relieving temperature should lower 30~50°C when the steel tempering resistance isn't good.

6. Heat Checking Resistance / Thermal Fatigue(Net-working)

Enlarge 200x
The Test of Thermal Cycle on Fatigue (R Corner Crack)
Test Condition:
Impact Sample Shape: 2V
600°C-2 min Water-cooling
3s/cycle with 1000 cycles

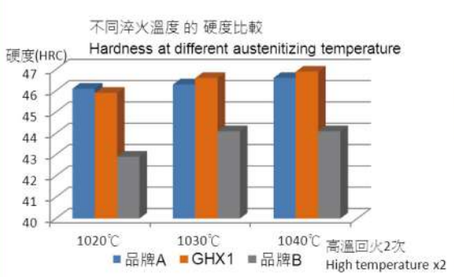
H13 conv.		GHX1	
			
Hardness	Transverse Impact Toughness	Hardness	Transverse Impact Toughness
HRC 45.6	16.6 (J)	HRC 45.6	26.0 (J)

7. Impact Toughness at Different Austenitizing Temperature

GHX1 is according to NADCA's standard with heat treatment to HRC 44~46. Comparison of Transverse Impact Toughness with Different Quench Temperature.

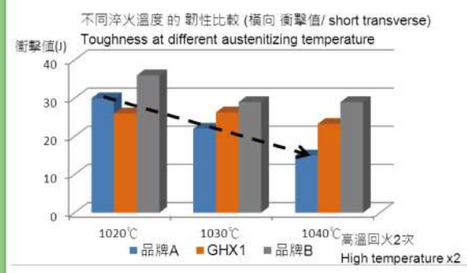
Mother Block Size:
310 X 600 mm

Sample Location:
Core Part



Hardness with Diff. Quench Temp.(Double Tempering)

Sample	A	GHX1	B
Quench temp	HRC	HRC	HRC
1020°C	46.1	45.9	42.9
1030°C	46.3	46.6	44.1
1040°C	46.6	46.9	44.1
Range	46.1~46.6	45.9~46.9	42.9~44.1



Toughness with Diff. Quench Temp.(Double Tempering)

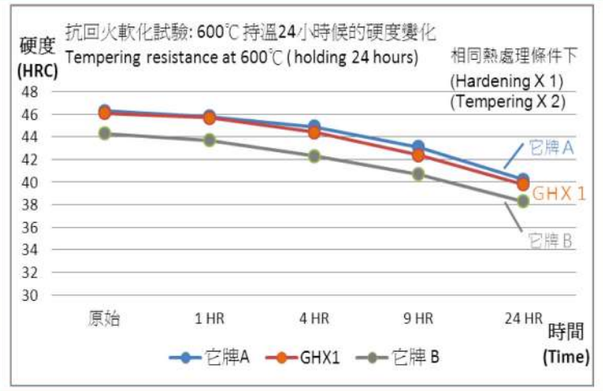
Sample	A	GHX1	B
Quench temp	impact(J)	impact(J)	impact(J)
1020°C	30	26	36
1030°C	22	26.3	29
1040°C	15	23.3	29

B sample's hardness is 2 HRC lower under the same tempering condition.

8. Tempering Resistance

Tempering Resistance	A	GHX1	B
(HRC)	46.3	46.1	44.3
1 hour	45.8	45.7	43.7
4 hour	44.9	44.4	42.3
9 hour	43.1	42.4	40.7
24 hour	40.2	39.8	38.3
HRC Change	-6.1	-6.3	-6.0

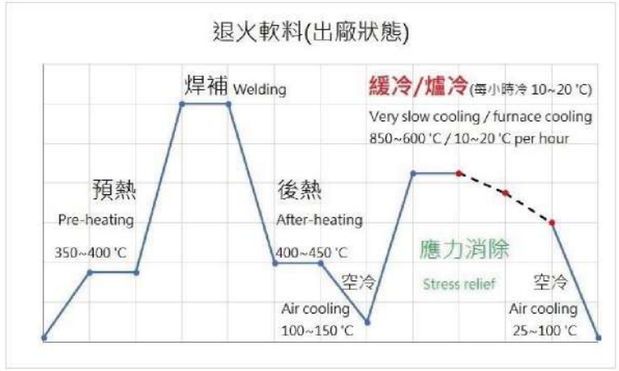
Three samples' hardness lower 6 HRC after 24 hours.

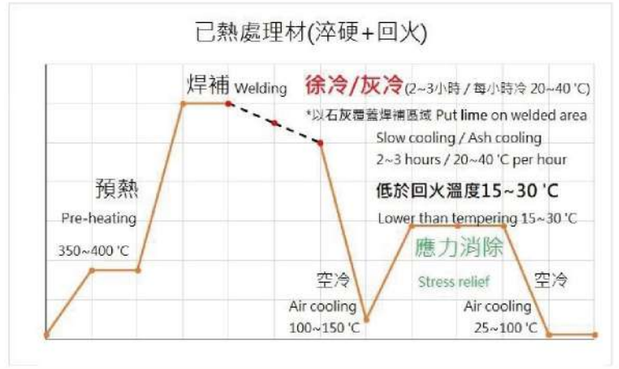


9. Welding

Welding Method	TIG			MMA	
Filler metal	UTP 73 G2	UTP 73 G3	UTP 73 G4	UTP 673	QRO 90
Hardness as Welded	55~58(HRC)	45~50(HRC)	38~42(HRC)	55~58(HRC)	48~53(HRC)

● Above welding rods were for TIG method

Steps of Welding	Soft Annealed Condition
Stress Relief : Soft annealed from 850°C(~2hours) to 600°C, cooling rate 10~20°C/per hour(in protected atmosphere furnace). Then free in air.	

Steps of Welding	Hardened Condition
Stress Relief : Tempering 15~30°C below the previous highest tempering temperature(min. 2 hours). Then free in air.	

● Notice

① Maximum interpass temperature < 475°C to avoid cracking.

② Post welding cooling(While the after-heating can't proceed)：20~40°C/per hour for the first 2~3 hours, then free in air.

10. Machining Data：The following cutting data was based on GHX1(HRC 44~46)

※ Information from public internet sources

Lathe Turning	Turning with Carbide		Milling	Milling with Carbide	
Parameter	Rough Turning	Fine Turning	Parameter	Rough Milling	Fine Milling
Cutting Speed (V_C)			Cutting Speed (V_C)		
m/min	40~60	70~90	m/min	50~90	90~130
f.p.m.	130~195	230~295	f.p.m.	160~295	295~425
Feed (f)			Feed (f_z)		
mm/rev.	0.2~0.4	0.05~0.2	mm/tooth	0.2~0.4	0.1~0.2
i.p.r.	0.008~0.016	0.002~0.008	Inch/tooth	0.008~0.016	0.004~0.008
Deep of Cut (a_P)			Deep of Cut (a_P)		
mm	1~2	0.5~1	mm	2~4	~2
inch	0.04~0.08	0.02~0.04	inch	0.08~0.16	~0.08
Carbide Designation			Carbide Designation		
ISO	P20~P30	P10	ISO	P20~P30	P10
US	C5~C6	C7	US	C5~C6	C7
Remark	Coated carbide	Coated carbide or mixed ceramic	Remark	Coated carbide	Coated carbide or mixed ceramic

Carbide Drilling	Type of Carbide Drilling			End milling	Type of End Milling		
Parameter	Indexable Insert(Carbide)	Solid Carbide	Carbide Tip(*)	Parameter	Indexable Insert(Carbide)	Solid Carbide	H.S.S. TiCN coated
Cutting Speed (V_C)				Cutting Speed (V_C)			
m/min	60~80	68~80	40~50	m/min	70~90	60~80	5~10
f.p.m.	195~260	195~260	130~160	f.p.m.	230~295	195~260	16~33
Feed (f)				Feed (f_z)			
mm/rev.	0.05~0.25	0.10~0.25	0.15~0.25	mm/tooth	0.08~0.20	0.03~0.20	0.05~0.35
i.p.r.	0.002~0.010	0.004~0.010	0.006~0.010	Inch/tooth	0.003~0.008	0.001~0.008	0.002~0.014
Drill Diameter				Carbide Designation			
mm	20~40	5~20	10~20	ISO	P10~P20	-	-
inch	0.8~1.6	0.2~0.8	0.4~0.8	US	C5~C6	-	-
Remark	(*) Drill with replaceable or brazed carbide tip.			Remark	Feed: Depending on radial depth of cut and cutter diameter.		

Drilling	High Speed Steel Twist Drill (TiCN coated)			
Drill Diameter				
mm	~5	5~10	10~15	15~20
Cutting Speed (V_C)				
m/min	4~6	4~6	4~6	4~6
f.p.m.	13~20	13~20	13~20	13~20
Feed (f)				
mm/rev.	0.05~0.10	0.10~0.15	0.15~0.20	0.20~0.30
i.p.r.	0.002~0.004	0.004~0.006	0.006~0.008	0.008~0.012
Remark				

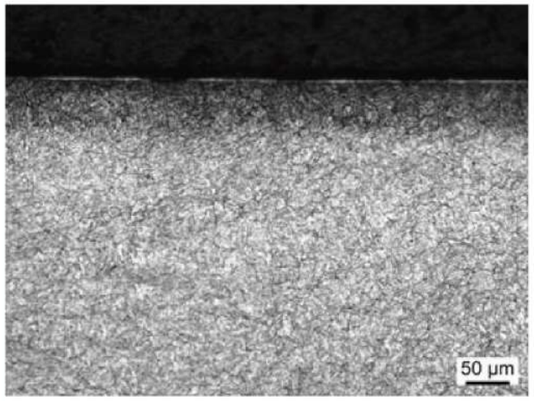
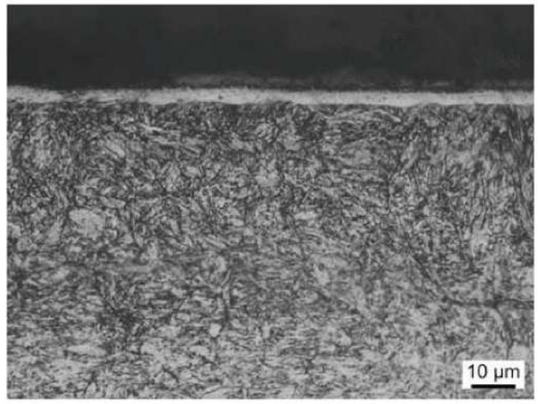
Grinding	Wheel Recommendation	
Type of Grinding	Soft Annealed Condition	Hardened Condition
Face Grinding (Straight wheel)	A 46 HV	A 46 HV
Face Grinding (Segmental wheel)	A 24 GV	A 36 GV
Cylindrical Grinding	A 46 LV	A 60 KV
Internal Grinding	A 46 JV	A 60 IV
Profile Grinding	A 100 LV	A 120 JV
Remark		

11. Nitriding (Surface Treatment) → Depth of nitriding shouldn't exceed 0.3mm in application of hot work steel.

Nitriding Process / Grade	Operation Temp.	Time (Hour)	Depth of Nitriding (mm)
Gas Nitriding	510°C	10	0.12
Gas Nitriding	510°C	30	0.20
Plasma Nitriding	480°C	10	0.12
Plasma Nitriding	480°C	30	0.18
Nitrocarburizing (in gas)	580°C	2.5	0.11
Nitrocarburizing (in salt bath)	580°C	1.0	0.06

12. Nitriding for Different Conditions(Vickers Hardness)

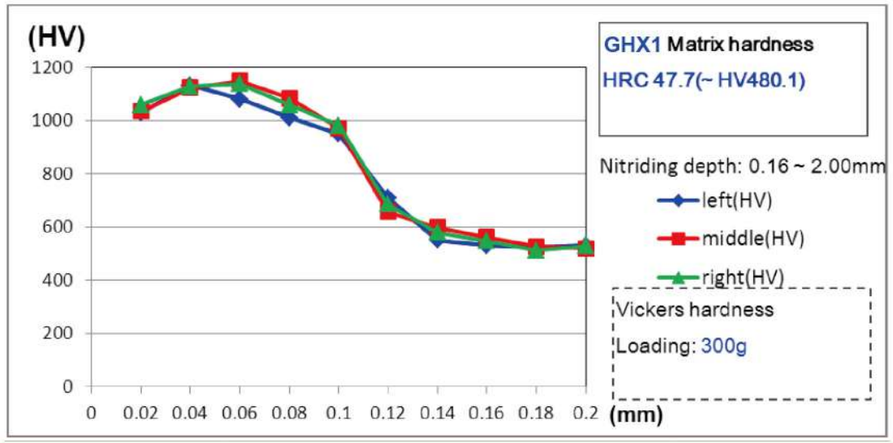
For Aluminum Die-casting Application：GHX1 (Matrix Avg.： Hv 477)												
Hv / mm	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.25	0.30
Left	1176	883	626	552	516	491	496	488	491	487	481	478
Middle	990	849	592	543	530	509	500	481	499	481	473	471
Right	1134	720	554	522	523	497	496	497	481	480	477	472

Gas Nitriding (Matrix：HRC47~48) 200X	Gas Nitriding (Matrix：HRC47~48) 1000X
	

- After die-casting mold is finished with gas nitriding, sandblasting process is generally followed to remove brittle white layer.
- Depth of case = distance from surface where hardness is 50 HV0.2 over the base hardness.

Definition : Base Hardness (HRC 47.5 ~ Hv 477) + 50 → Hv 527

For Aluminum Extrusion Application：Gas Nitriding



- After aluminum extrusion mold is finished with nitriding, abrasive flow machining is applied to remove brittle white layer.
- Aluminum extrusion mold, high hardness nitride layer(> Hv 1000), recommend depth< 0.09 mm.
- Hot forging mold, high hardness nitride layer (> Hv 1000), recommend depth < 0.02 mm.

13. Case Study of Al-Extrusion

Lifespan of H13(conv.) die for aviation structural components AL-7005：10~15 ingots.
After usage, mold will be cracked and scrapped. (Generally repair welding once)

Case 1：Application of Aluminum Extrusion Die　Extrusion Machine：2,100 tons
GHX1 (HRC 48.5), no nitriding. Lifespan of GHX1 Die: 58 ingots.

Usage Sequence	First	Second	Third	Fourth	Fifth	Summary
Date	2022-12-16	2023-01-09	2023-01-16	2023-02-07	2023-06-05	No Minor Crack
Al Ingot	10	15	11	15	7	58 (still usable)

CP Value 2.71 ~ 4.26	Lifespan/Ingot	Cost of Die/ Set (NT$)	Cost of Repair Welding (NT$ 3,000 per time) Total (NT$)	Cost of Shutdown (NT$ 10,000 per time) Total (NT$)	Cost of Mold Preparation (NT$ 5,000 per time) Total (NT$)	Usage of Die (NT$ Cost X Set)	Total cost (NT$)
GHX1	58	70,000	0	0	5,000	70,000 X1	75,000
H13(conv.) Min.	10	40,000	16,500	55,000	27,500	40,000 X5.5	319,500
H13(conv.) Max.	15	40,000	10,500	35,000	17,500	40,000 X3.5	203,000

- The cost written above is estimation for your reference, not actual data!

Case 2：Application of Aluminum Extrusion Die　Extrusion Machine：3,200 tons
GHX1 (HRC 48.5), no nitriding. Lifespan of GHX1 Die: 120 ingots.

Usage Sequence	First	Second	Third	Fourth	Fifth	Sixth	Summary
Date	2023-03-14	2023-04-10	2023-04-17	2023-04-20	2023-05-17	2023-06-05	No Minor Crack
Al Ingot	3 (trial)	18	8	25	35	31	120(still usable)

CP ratio 6.19 ~ 9.28	Lifespan/ Ingot	Cost of Die/ Set (NT$)	Cost of Repair Welding (NT$ 3,000 per time) Total (NT$)	Cost of Shutdown (NT$ 10,000 per time) Total (NT$)	Cost of Mold Preparation (NT$ 5,000 per time) Total (NT$)	Usage of Die (NT$ Cost X Set)	Total cost (NT$)
GHX1	120	70,000	0	0	5,000	70,000 X1	75,000
H13(conv.) Min.	10	40,000	36,000	120,000	60,000	40,000 X12	696,000
H13(conv.) Max.	15	40,000	24,000	80,000	40,000	40,000 X8	464,000

- The cost written above is estimation for your reference, not actual data!

GHX1 has to get the Thermal Fatigue Test certified by NADCA, the Certification Number is 305395; the final hardness measured is 44 HRC. From below testing result of thermal fatigue, GHX1 can bear over 20,000 cycles, while other H13 grades baseline's limit is 15,000.

Average maximum crack length ($\bar{L}$)