# THIRD GENERATION NICKEL BASE SINGLE CRYSTAL SUPERALLOY

# TMS-75 ( TMD-103 )

**(Developed under NIMS[1] / KHI[2] collaboration)**

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# TMS-75

It is a 3rd generation nickel-base single crystal superalloy containing 3wt% Cr and 5wt% Re. This alloy has a good balance of creep strengths from intermediate to high temperatures; creep rupture lives at 900°C/392MPa and 1040°C/137MPa are 961 hours and 1526 hours, respectively. In addition, TMS-75 exhibits good hot corrosion resistance.

# TMD-103

This DS alloy is a lower cost variant of TMS-75 for co-generation turbine blade application; its chemical composition is the same as that of TMS-75 with the exception of additional carbon and boron contents for grain boundary strengthening. Extensive testings have been successfully conducted at Kawasaki Heavy Industry (KHI) to certify its applications.

### Chemical composition, wt%

| Element | Co | Cr | Mo | W | Al | Ta | Hf | Re | C | B |
|---|---|---|---|---|---|---|---|---|---|---|
| TMS-75 | 12 | 3 | 2 | 6 | 6 | 6.0 | 0.1 | 5 | - | - |
| TMD-103 | 12 | 3 | 2 | 6 | 6 | 6.0 | 0.1 | 5 | 0.07 | 0.015 |

### Heat Treatment Condition (Typical) (TMS-75)

Solution; 1300℃/1h+1320℃/5h→R.T. *, Aging; 1150℃/4h→R.T. +870℃/20h→R.T.*

*Gas Fan Cooling (GFC)

Solidus Temperature : 1399℃(2530°F)
Solvus Temperature : 1283℃(2359°F)
Heat Window for Solution Treatment : 61℃( 116°F)

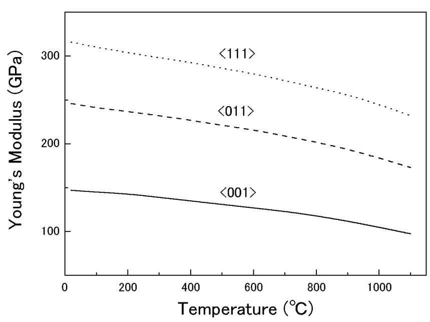
### Physical Constants and Thermal Properties (TMS-75)

**Density**…………………………………………… at R.T..…………8.894 g/cc

**Coefficient of Expansion**……………………….20 – 200℃………..11.7 x$10^{-6}$

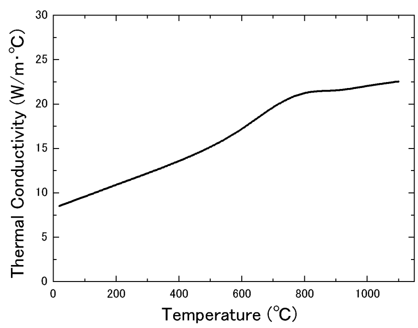
**Young's Modulus**

Rectangular parallelepiped resonance



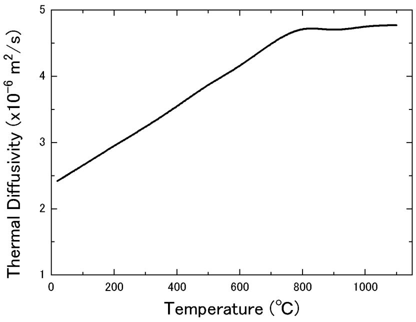

**Thermal Conductivity**

Laser-Flush Method



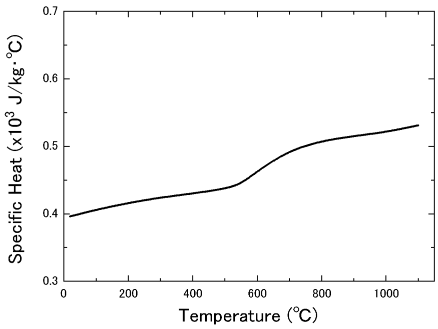
### Thermal Diffusivity

Laser-Flush Method




### Specific Heat

Adiabatic calorimeter (Nernst method)




## Typical Mechanical Properties

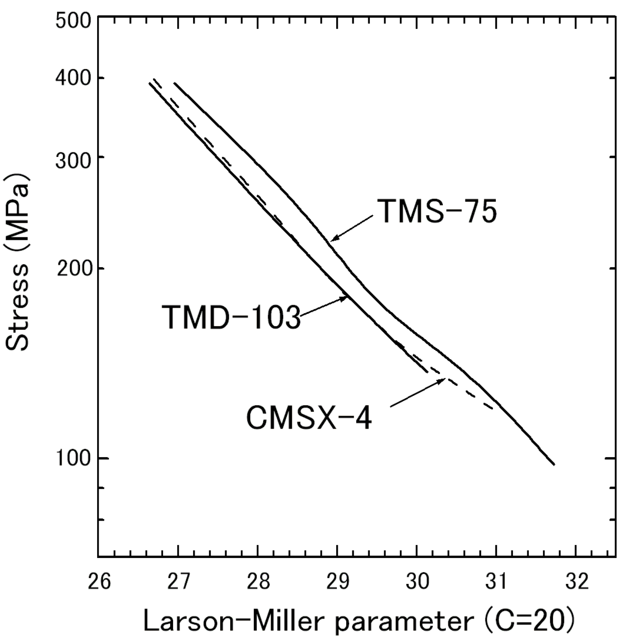
### Creep Rupture Strength (TMS-75)

| Conditions | | Rupture life τ | Elongation | Reduction of Area |
|---|---|---|---|---|
| Temperature, ℃(K) | Stress, MPa | h | % | % |
| 900 (1173) | 392 | 961 | 23.0 | 30.3 |
| 1000 (1273) | 245 | 329 | 27.9 | 34.0 |
| 1100 (1373) | 137.2 | 227 | 14.0 | 26.2 |
| 1150 (1423) | 98 | 196 | 11.9 | 39.1 |

### Creep Rupture Strength (TMD-103)

| Conditions | | Rupture life τ | Elongation | Reduction of Area |
|---|---|---|---|---|
| Temperature, ℃(K) | Stress, MPa | h | % | % |
| 900 (1173) | 392 | 519 | 10.8 | 17.9 |
| 1000 (1273) | 196 | 444 | 18.8 | 18.7 |
| 1040 (1313) | 137 | 884 | 18.6 | 32.3 |

### Larson-Miller Plot ( = T(20+log(τ))



**Tensile Strength (TMS-75)**

| Temperature ℃(K) | 0.2% Proof Stress MPa | UTS MPa | Elongation % | Reduction of Area % |
|---|---|---|---|---|
| R.T. | 854 | 898 | 7.0 | 14 |
| 550 (823) | 805 | 863 | 6.5 | 11 |
| 750(1023) | 972 | 1287 | 7.7 | 9 |
| 850(1123) | 893 | 1179 | 14 | 18 |
| 950(1223) | 564 | 932 | 20 | 24 |
| 1050(1323) | 513 | 717 | 16 | 41 |
| 1150(1423) | 266 | 417 | - | - |

**High Cycle Fatigue** ( Stress : Constant ) **(TMS-75)**

| Test Number | Temperature ℃(K) | Stress MPa | Strain Rate %/sec. | Cycles to Failure $N_f$ x$10^5$ |
|---|---|---|---|---|
| 1 | 1100 (1373) | 450 | | 2 |
| 2 | 1100 (1373) | 350 | | 7 |
| 3 | 1100 (1373) | 300 | | 10 |
| 4 | 1100 (1373) | 250 | | 40 |

**Low Cycle Fatigue** ( Strain : Constant ) **(TMS-75)**

| Test Number | Temperature ℃(K) | Strain Rate %/sec. | Total Strain $\Delta\varepsilon_t$, % | Stress (Initial) $\Delta\sigma_{Range}$, MPa | Cycles to Failure $N_f$ x$10^3$ |
|---|---|---|---|---|---|
| 1 | 900 (1173) | 0.1 | 0.7 | 784 | 103.7 |
| 2 | 900 (1173) | 0.1 | 1.0 | 1120 | 8.82 |
| 3 | 900 (1173) | 0.1 | 1.2 | 1344 | 1.75 |
| 4 | 950 (1223) | 0.1 | 1.0 | 1090 | 27.19 |
| 5 | 950 (1223) | 0.1 | 1.2 | 1308 | 4.65 |
| 6 | 1000 (1273) | 0.1 | 1.0 | 1050 | 3.05 |
| 7 | 1000 (1273) | 0.1 | 1.2 | 1260 | 1.65 |

**Low Cycle Fatigue** ( Stress : Constant ) **(TMS-75)**

| Test Number | Temperature ℃(K) | Stress MPa | Strain Rate %/sec. | Cycles to Failure $N_f$ x$10^3$ |
|---|---|---|---|---|
| 1 | 800 (1073) | 600 | | 7 |
| 2 | 800 (1073) | 450 | | 40 |
| 3 | 800 (1073) | 300 | | 350 |
| 4 | 1100 (1373) | 400 | | 1 |
| 5 | 1100 (1373) | 300 | | 3.5 |
| 4 | 1100 (1373) | 200 | | 20 |

## Oxidation Properties (TMS-75)

**Cyclic Oxidation in Air** (Condition: 20h/Cycle in Air)

| Temp. °C(K) \ Cycles | Weight Loss, $mg/cm^2$ | | |
|---|---|---|---|
| | 10Cycles | 20 Cycles | 30 Cycles |
| 1100 (1373) | 23.3 | 52.6 | 79.8 |
| 1100 (1373) | 0* | 5.1* | 13.8* |

* With Al-packed

## Patents

1) T.Kobayashi, Y.Koizumi, S.Nakazawa, H.Harada T.Yamagata; Nickel-based single crystal alloy and a method of manufacturing the same, Japanese Patent 314882 (2001).
2) T.Kobayashi, Y.Koizumi, S.Nakazawa, H.Harada T.Yamagata; Nickel-based single crystal alloy and a method of manufacturing the same, EPC Patent 913506 (2004).
3) T.Kobayashi, Y.Koizumi, S.Nakazawa, H.Harada T.Yamagata, A.Tamura, S.Nitta; Ni-Base directionally solidified alloy casting manufacturing method, Japanese Patent 2905473 (1999).
4) T.Kobayashi, Y.Koizumi, S.Nakazawa, H.Harada T.Yamagata, A.Tamura, S.Nitta; Ni-Base directionally solidified alloy casting manufacturing method, US patent 6224695 (2001).

## Related Articles


**Alloy Development**

1) H.Harada; Materials Design Approaches and Experiences as held during the TMS Fall Meeting; Indianapolis, IN, USA, 29-39 (2001).
2) H.Harada; Kogyo Zairyo (Engineering Materials). **47**, 1, 72-73 (1999).
3) T.Kobayashi, Y.Koizumi, S.Nakazawa, T.Yamagata and H.Harada; Advances in Turbine Materials, Design and Manufacturing; Newcastle upon Tyne, UK, 766-773 (1997).
4) T.Kobayashi, Y.Koizumi, H.Harada, T.Yamagata, A.Tamura and S.Nitta; 6th Liege conf. "Materials for Advanced Power Engineering 1998" 1079-1087 (1998).
5) T.Kobayashi, M.Sato, Y.Koizumi, H.Harada, T.Yamagata, A.Tamura and J.Fujioka; 9th International. Symposium on Superalloys 2000, Seven Springs,PA; USA, pp323-328 (2000).

**Creep Behaviors**

6) M.Maldini, H.Harada, Y.Koizumi, T.Kobayashi and V.Lupinc; Scripta Materialia. **43**, 7, 637-644 (2000).

**Thermal Fatigue**

7) H.Zhou, H.Harada, Y.Ro, T.Kobayashi and Y.Koizumi; Mat. Sci. Tech. **19**, 7, 847-852 (2003).
8) H.Zhou, H.Harada, Y.Ro, Y.Koizumi and T.Kobayashi; Fatigue: A David L. Davidson Symposium at the 2002 TMS Annual Meeting; Seattle, WA, USA, 203-215 (2002).

**Microstractural Analysis**

9) J.X.Zhang, T.Murakumo, Y.Koizumi and H.Harada; Journal of Materials Science, **38**, 24, 4883-4888, (2003).
10) J.X.Zhang, T.Murakumo, Y.Koizumi, T.Kobayashi and H.Harada; Metallurgical and Materials Transactions A, **33A**, 12, 3741-3746A (2002).
11) T.Yokokawa, M.Osawa, K.Nishida, Y.Koizumi, T.Kobayashi and H.Harada; Journal of the Japan Institute of Metals, **66**, 9, 873-876 (2002).
12) T. Yokokawa, M. Osawa, H. Murakami, T. Kobayashi, Y. Koizumi, T. Yamagata, H. Harada; 6th Liege conf. "Materials for Advanced Power Engineering 1998" 1121-1128 (1998).

**Coating System**

13) F.Wu, H.Murakami and H.Harada; Materials Transactions, **44**, 9, 1675-1678 (2003).
14) F.Wu, H.Murakami and A.Suzuki; Surface and Coatings Technology, **168**, 1, 62-69 (2003).
15) P.Kuppusami, H.Murakami and T.Ohmura; Surface Engineering: in Materials Science II at the 2003 TMS Annual Meeting; San Diego, CA, USA, 309-318 (2003).

## Application Examples

At Toshiba co. ltd., real machine tests have been successfully completed with a generator gas turbine employing the first stage blades made of TMS-75 single crystal superalloy.


**A 15MW-class turbine rotor installed TMS-75 blades.**

Inlet gas turbine temperature : 1300℃

Rotating speed : 3000 rpm

### High Temperature Materials 21 Project

On June 1, 1999, ex-NRIM (now NIMS) launched an R&D project, "High Temperature Materials 21 (HTM 21)" Project, (1999. 6--2008. 3). In this Project we develop high temperature materials for 1700℃ ultra-efficient gas turbines in power generations, small but efficient gas turbines for local power systems, next generation jet engines, high performance space rockets, and so on. These materials include Ni-base single crystal superalloys up to 5th generation alloys with new coating systems, as well as alloys with new concepts, e.g., platinum group metals (PGMs)-base refractory superalloys, Cr-base alloys, and so on. Materials design of empirical and theoretical approaches and microstructure analysis to support the alloy design and developments are also conducted with a major importance. We have world wide collaborations. to enhance the high temperature materials researches mentioned above (Director; Hiroshi Harada).