

Using the NTC thermistor

Technical Document

CONTENTS

1. Module internal structure and thermal flow	2
1-1. Module internal structure	2
1-2. Thermal flow within a module	3
<hr/>	
2. Basic characteristics of NTC thermistor	4
2-1. Resistance	4
2-2. B value	4
2-3. Thermal dissipation constant	5
2-4. Time response	5
<hr/>	
3. Temperature detection method of NTC thermistor	6

IGBT Modules have products with a NTC thermistor inside. The purpose of this thermistor is temperature detection in thermal equilibrium state such as during steady-state operation.

This document describes the basic characteristics of the thermistor and the temperature detection method.

1. Module internal structure and thermal flow

1.1 Module internal structure

As shown in Fig. 1, NTC thermistor is mounted at an adjoining location on the same DCB board as the chip for accurate temperature sensing.



Fig.1 Example of the internal structure of an IGBT module with a NTC thermistor

1.2 Thermal flow within a module

The thermal conduction is replaced by the equivalent circuit shown in Fig. 2.

Since there is a thermal resistance $R_{\text{th(j-NTC)}}$ between the chip and thermistor, the thermistor temperature T_{NTC} will be at a lower temperature than the junction temperature T_{vj} .

$R_{\text{th(j-NTC)}}$ depends on the thermal conductivity and thickness of the thermal grease, the thermal conductivity and dimensions of the heat sink, etc.

Also, there is a thermal resistance $R_{\text{th(c-NTC)}}$ between the case and thermistor, so the case temperature T_c and thermistor temperature T_{NTC} are not the same temperature.

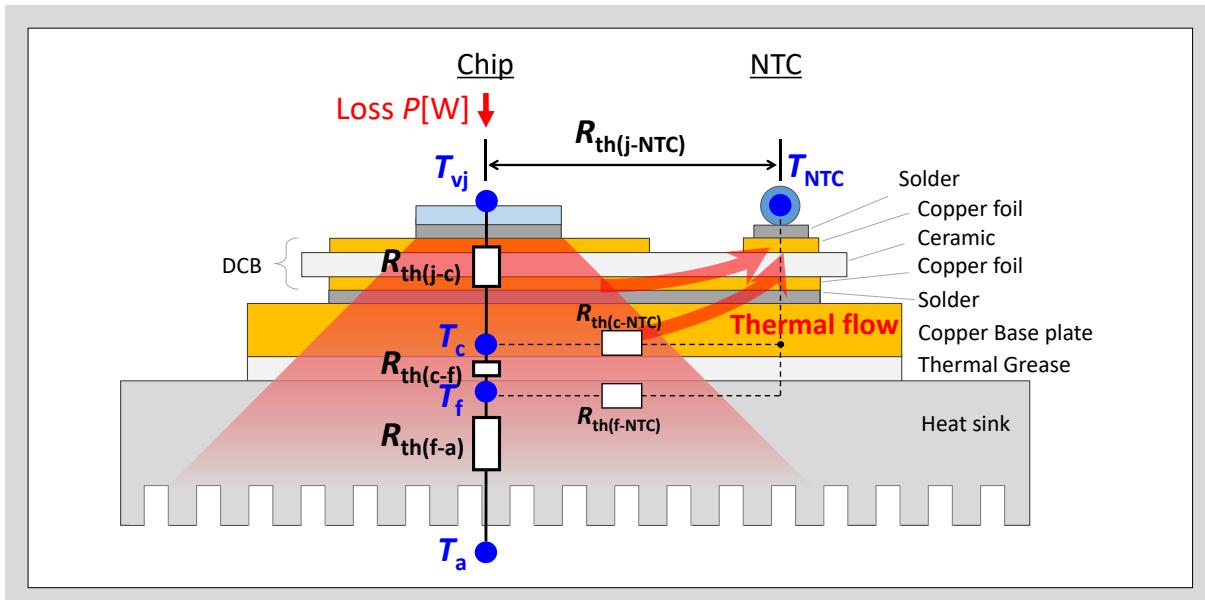


Fig.2 Image and equivalent circuit of thermal model

T_{vj} : Junction temperature

T_c : Case temperature (Copper base surface temperature directly below the chip)

T_f : Heatsink temperature (Heatsink temperature directly below the chip)

T_a : Ambient temperature

T_{NTC} : NTC thermistor temperature

P : Device generated losses

$R_{\text{th(j-c)}}$: Thermal resistance junction to case

$R_{\text{th(c-f)}}$: Thermal resistance case to heatsink

$R_{\text{th(f-a)}}$: Thermal resistance heatsink to ambient

$R_{\text{th(j-NTC)}}$: Thermal resistance junction to NTC thermistor

$R_{\text{th(c-NTC)}}$: Thermal resistance case to NTC thermistor

2. Basic characteristics of NTC thermistor

2.1 Resistance

The resistance of NTC thermistor decreases exponentially with temperature, as shown in Fig. 3. The resistance can be expressed by formula (1).

$$R_1 = R_0 \exp B \left(\frac{1}{T_1} - \frac{1}{T_0} \right) \quad \dots\dots(1)$$

R_0 : Resistance at absolute temperature

T_0 [K]

R_1 : Resistance at absolute temperature

T_1 [K]

B : B value

*Absolute temperature T [K]= t [°C]+273.15

Resistance under certain conditions are listed in the data sheet as shown in Table 1.

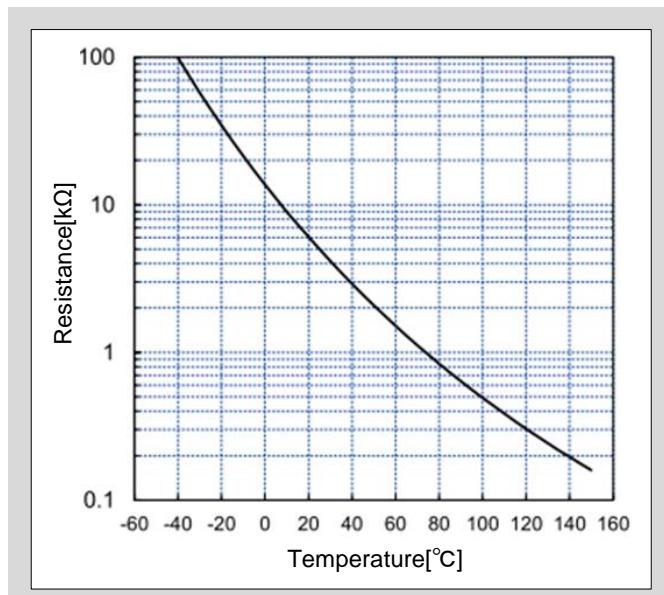


Fig.3 Temperature characteristics of NTC thermistor

2.2 B value

The B value indicates the slope of the change in resistance of the thermistor due to temperature change, and can be expressed by formula (2) based on formula (1).

$$B = l_n \left(\frac{R_1}{R_0} \right) / \left(\frac{1}{T_1} - \frac{1}{T_0} \right) \quad \dots\dots(2)$$

The B value changes slightly with temperature. Therefore, the B value differs depending on the defined temperature.

As shown in Table 1, the data sheet contains the value B(25/50) defined at 25°C and 50°C.

Table 1 Example of resistance value and B value of NTC thermistor (excerpt from data sheet)

Thermistor	Items	Symbols	Conditions	Characteristics			Units
				min.	typ.	max.	
Resistance		R	$T = 25^\circ\text{C}$	-	5000	-	Ω
			$T = 100^\circ\text{C}$	465	495	520	
B value		B	$T = 25/50^\circ\text{C}$	3305	3375	3450	K

2.3 Thermal dissipation constant

The thermal dissipation constant is a constant that represents the power required to raise the thermistor temperature by 1°C through self-heating in a thermal equilibrium state.

In the ambient temperature T_1 , when the power P (mW) is consumed and the thermistor temperature becomes T_2 , the relationship is expressed by formula (3).

$$P = C(T_2 - T_1) \quad \dots\dots(3)$$

C (mW/°C) is the thermal dissipation constant. Thermal dissipation constant varies depending on the thermistor shape, dimensions, condition of the object being measured, and atmosphere.

The thermal dissipation constant of NTC thermistor mounted inside Fuji IGBT modules is approximately 7mW/°C in actual measurements.

2.4 Time response

Since the thermistor has a thermal time constant, the thermistor temperature does not follow immediately even if the temperature rises due to the heat generated by IGBT chip.

The thermal time constant is the time required for the thermistor held in any temperature T_0 to change to the temperature T_1 when it is moved suddenly to a temperature T_1 atmosphere (temperature chamber, etc.). It is a constant that expresses the degree of thermal responsiveness of the thermistor.

Fig. 4 shows an example of the time response of an IGBT chip and the thermistor temperature. Note that this varies depending on the environment conditions of the IGBT module (such as the heat dissipation capacity of the heat sinks and the driving conditions of the IGBT module).

As shown in Fig. 4, there is a difference in the starting time of temperature rise between the IGBT chip and the thermistor time response.

In the time domain shorter than 100msec, only the chip temperature rises while the thermistor temperature hardly rises. As can be seen from the fact that the temperature difference between IGBT chip temperature and the thermistor increases, the thermistor temperature cannot follow the chip temperature change until the temperature difference becomes constant (saturation).

On the other hand, in the short circuit mode in which high current flows while a voltage is applied, the short circuit capability is about 10μs (Note that the short circuit capability varies depending on the series, voltage class, conditions of use, etc.), so that the thermistor temperature does not rise during this short circuit period.

In other words, it is difficult to perform short circuit protection by detecting the thermistor temperature. From this point of view, it is necessary to use overcurrent detector or $V_{CE(sat)}$ method for short circuit protection.

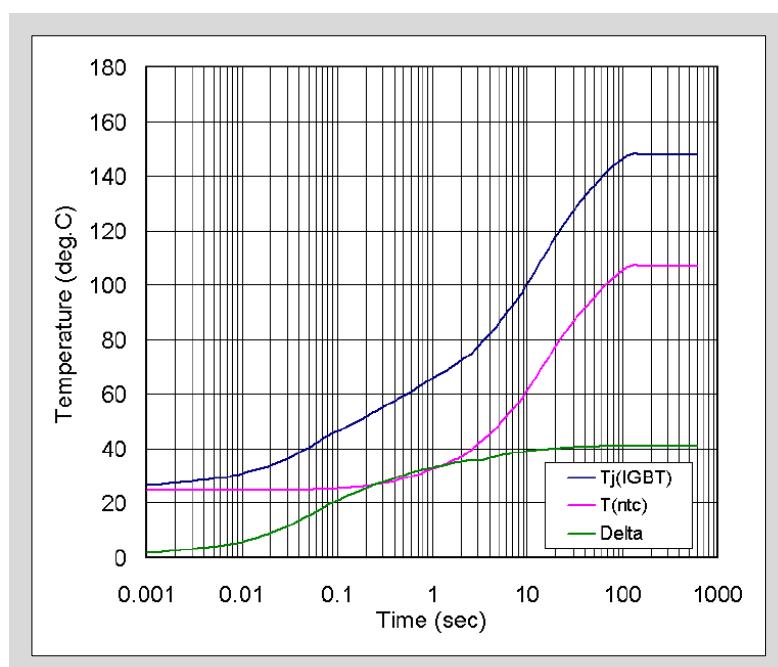


Fig.4 Junction temperature and time response of thermistor temperature

3. Temperature detection method of NTC thermistor

This section describes the temperature detection method of NTC thermistor.

Fig. 5 shows an example of a temperature detection circuit of NTC thermistor.

By configuring a voltage divider circuit between the NTC thermistor and the fixed resistor R, and converting the resistance R_{NTC} into a voltage V_{NTC} , the control circuit can detect the resistance that varies with the thermistor temperature as a voltage value.

The voltage value V_{NTC} of NTC thermistor is obtained by formula (4).

$$V_{\text{NTC}} = \frac{R_{\text{NTC}}}{R + R_{\text{NTC}}} V_{\text{in}} \quad \dots\dots(4)$$

R : Fixed resistor

R_{NTC} : Resistance of NTC thermistor

V_{NTC} : Voltage of NTC thermistor

V_{IN} : Input voltage

From formula (4) and formula (1) which shows the relationship between the resistance and temperature characteristics of NTC thermistor, T_{NTC} is obtained using formula (5).

Depending on the thermistor temperature, you can set actions such as increasing the fan wind speed or outputting an alarm to reduce the module temperature.

$$T_{\text{NTC}} = \frac{1}{(l_n \frac{R_{\text{NTC}}}{R_{25}} / B) + \frac{1}{T_1}} \quad \dots\dots(5)$$

$R_{25}=5000\Omega$: Resistance of NTC thermistor at $T_1=25^{\circ}\text{C}$

$T_1=298.15\text{K}$

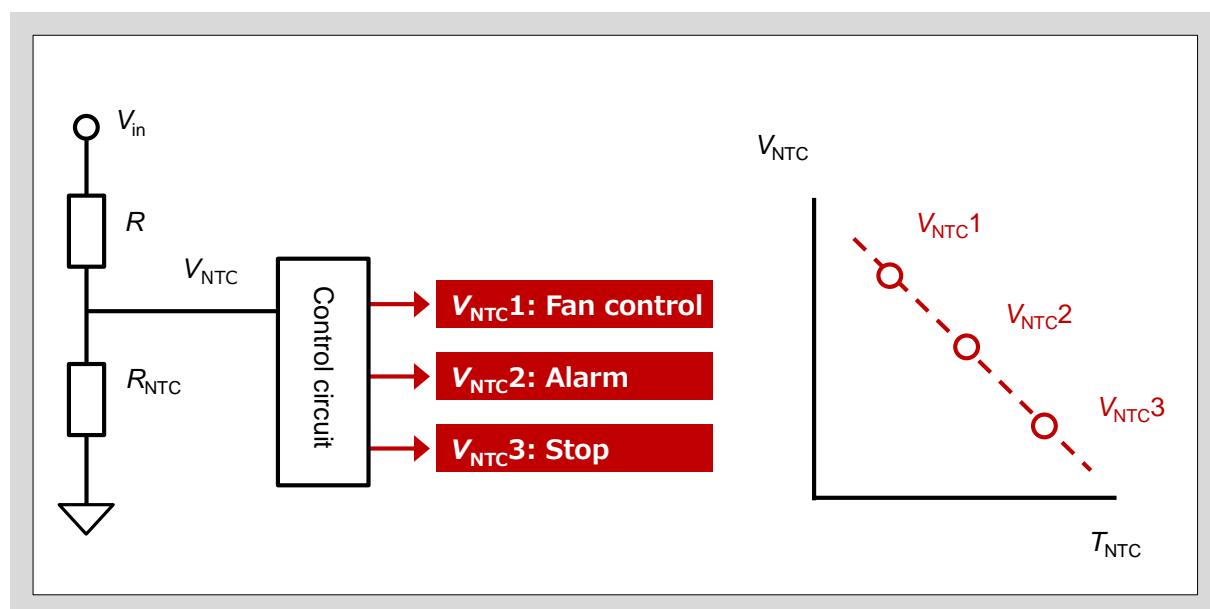


Fig.5 Example of a temperature detection circuit

As mentioned above, the B value varies with the temperature range.

Although the data sheet provides B(25/50), in order to calculate the temperature accurately, it is necessary to use the B value of the temperature range actually used.

The resistances and B value for -40°C~150°C (at 1°C intervals) are listed on page 8.

Also, if the current flowing through the thermistor is too small, the detected voltage will be small, and the accuracy of the measured value decreases. On the contrary, if the current is excessive, the self-heating of the thermistor becomes large, and in this case too, the measured value is not accurate. Therefore, it is important to select the resistor R considering the self-heating of the thermistor.

The thermal dissipation constant of NTC thermistor inside Fuji IGBT module is 7mW/°C in actual measurements. Assuming that the allowable temperature for self-heating of the thermistor is 1°C, the allowable power loss P_{\max} is 7mW.

When the thermistor temperature is assumed to be 100°C, the current flowing through the thermistor is obtained by formula (6).

$$I_{\max} = \sqrt{\frac{P_{\max}}{R_{100}}} \quad \dots\dots(6)$$

$R_{100}=495\Omega$: Resistance of NTC thermistor at $T_1=100^\circ\text{C}$

Therefore, a current of about $I_{\max}=3.76\text{mA}$ is appropriate for the thermistor.

The resistor R is obtained by formula (7).

$$V_{\text{in}} = I_{\max}(R + R_{100})$$

$$R = \frac{V_{\text{in}}}{I_{\max}} - R_{100} \quad \dots\dots(7)$$

When $V_{\text{in}}=5\text{V}$, $I_{\max}=3.76\text{mA}$, the fixed resistor R is approximately 835Ω .

For the E24 series, 820Ω is usually chosen.

Resistance and B value for NTC thermistor

Temp. [°C]	Rtyp [kΩ]	Rmin [kΩ]	Rmax [kΩ]	Bvalue [K]	Temp. [°C]	Rtyp [kΩ]	Rmin [kΩ]	Rmax [kΩ]	Bvalue [K]	Temp. [°C]	Rtyp [kΩ]	Rmin [kΩ]	Rmax [kΩ]	Bvalue [K]
-40	99.09	84.46	116.0	3194	26	4.816	4.376	5.288	3344	91	0.6229	0.5892	0.6569	3426
-39	93.69	79.96	109.5	3197	27	4.641	4.219	5.091	3334	92	0.6066	0.5741	0.6394	3427
-38	88.62	75.72	103.5	3199	28	4.472	4.069	4.903	3340	93	0.5909	0.5595	0.6225	3428
-37	83.86	71.74	97.78	3202	29	4.311	3.925	4.722	3339	94	0.5756	0.5453	0.6061	3430
-36	79.38	67.99	92.45	3205	30	4.156	3.787	4.549	3342	95	0.5608	0.5316	0.5903	3431
-35	75.17	64.46	87.44	3207	31	4.007	3.654	4.383	3346	96	0.5465	0.5182	0.5749	3432
-34	71.20	61.13	82.73	3210	32	3.865	3.527	4.224	3346	97	0.5326	0.5053	0.5600	3433
-33	67.48	58.00	78.31	3213	33	3.728	3.405	4.072	3350	98	0.5191	0.4927	0.5455	3434
-32	63.96	55.05	74.14	3215	34	3.597	3.288	3.926	3351	99	0.5060	0.4805	0.5315	3435
-31	60.66	52.26	70.23	3218	35	3.472	3.175	3.786	3351	100	0.4933	0.4687	0.5179	3436
-30	57.54	49.63	66.55	3220	36	3.351	3.067	3.652	3353	101	0.4810	0.4568	0.5052	3437
-29	54.61	47.15	63.08	3223	37	3.235	2.963	3.523	3355	102	0.4690	0.4452	0.4929	3438
-28	51.84	44.18	59.81	3225	38	3.124	2.863	3.400	3356	103	0.4574	0.4340	0.4809	3439
-27	49.23	42.60	56.74	3228	39	3.017	2.767	3.281	3358	104	0.4462	0.4231	0.4693	3440
-26	46.76	40.52	53.84	3230	40	2.914	2.675	3.168	3361	105	0.4352	0.4125	0.458	3441
-25	44.44	38.54	51.10	3233	41	2.816	2.586	3.058	3361	106	0.4246	0.4023	0.4471	3442
-24	42.24	36.68	48.53	3235	42	2.721	2.501	2.953	3363	107	0.4143	0.3923	0.4364	3443
-23	40.17	34.92	46.09	3238	43	2.63	2.419	2.853	3364	108	0.4043	0.3827	0.4261	3443
-22	38.21	33.25	43.80	3240	44	2.542	2.340	2.756	3367	109	0.3946	0.3733	0.416	3444
-21	36.35	31.67	41.63	3242	45	2.458	2.264	2.663	3368	111	0.376	0.3554	0.3968	3446
-20	34.60	30.18	39.58	3245	46	2.377	2.191	2.573	3369	112	0.3671	0.3468	0.3875	3447
-19	32.95	28.76	37.65	3247	47	2.299	2.120	2.487	3371	113	0.3584	0.3385	0.3786	3448
-18	31.38	27.42	35.82	3249	48	2.224	2.052	2.405	3373	114	0.35	0.3304	0.3698	3449
-17	29.89	26.15	34.09	3251	49	2.152	1.987	2.325	3374	115	0.3418	0.3225	0.3614	3450
-16	28.49	24.95	32.45	3254	50	2.083	1.924	2.249	3375	116	0.3338	0.3148	0.3531	3451
-15	27.16	23.81	30.91	3256	51	2.016	1.864	2.175	3376	117	0.3261	0.3074	0.3451	3452
-14	25.90	22.72	29.44	3259	52	1.952	1.806	2.104	3377	118	0.3186	0.3002	0.3373	3453
-13	24.70	21.70	28.06	3260	53	1.890	1.749	2.036	3379	119	0.3113	0.2932	0.3297	3453
-12	23.57	20.72	26.74	3263	54	1.830	1.695	1.971	3381	120	0.3042	0.2864	0.3223	3454
-11	22.50	19.80	25.50	3266	55	1.773	1.643	1.908	3381	121	0.2973	0.2797	0.3151	3455
-10	21.48	18.92	24.32	3268	56	1.717	1.593	1.847	3384	122	0.2905	0.2733	0.3081	3456
-9	20.51	18.09	23.20	3270	57	1.664	1.544	1.788	3384	123	0.284	0.267	0.3013	3457
-8	19.59	17.29	22.14	3271	58	1.612	1.497	1.732	3387	124	0.2776	0.2609	0.2947	3458
-7	18.72	16.54	21.14	3274	59	1.563	1.452	1.678	3387	125	0.2714	0.255	0.2882	3459
-6	17.89	15.82	20.18	3275	61	1.469	1.366	1.575	3390	126	0.2654	0.2492	0.2819	3459
-5	17.11	15.14	19.28	3279	62	1.424	1.326	1.526	3392	127	0.2595	0.2436	0.2758	3460
-4	16.36	14.50	18.42	3280	63	1.381	1.287	1.479	3393	128	0.2538	0.2381	0.2699	3461
-3	15.65	13.88	17.60	3282	64	1.340	1.249	1.434	3394	129	0.2483	0.2328	0.2641	3462
-2	14.98	13.29	16.83	3285	65	1.300	1.212	1.391	3395	130	0.2428	0.2277	0.2584	3463
-1	14.33	12.73	16.09	3286	66	1.261	1.177	1.348	3397	131	0.2376	0.2226	0.2529	3463
1	13.14	11.70	14.73	3291	67	1.224	1.143	1.308	3398	132	0.2324	0.2177	0.2475	3464
2	12.59	11.21	14.09	3294	68	1.188	1.110	1.269	3400	133	0.2274	0.2129	0.2423	3465
3	12.06	10.75	13.49	3295	69	1.153	1.078	1.231	3401	134	0.2226	0.2083	0.2372	3466
4	11.56	10.31	12.92	3298	70	1.120	1.047	1.194	3402	135	0.2178	0.2038	0.2323	3467
5	11.08	9.895	12.37	3299	71	1.087	1.018	1.159	3404	136	0.2132	0.1994	0.2274	3467
6	10.62	9.496	11.85	3300	72	1.056	0.9888	1.125	3405	137	0.2087	0.1951	0.2227	3468
7	10.19	9.115	11.36	3304	73	1.026	0.9610	1.092	3405	138	0.2043	0.1909	0.2181	3469
8	9.773	8.752	10.89	3305	74	0.9966	0.9342	1.061	3407	139	0.2	0.1868	0.2136	3470
9	9.378	8.405	10.44	3307	75	0.9683	0.9082	1.030	3408	140	0.1959	0.1829	0.2093	3470
11	8.641	7.758	9.600	3311	76	0.9410	0.8830	1.000	3409	141	0.1918	0.179	0.205	3471
12	8.297	7.455	9.211	3312	77	0.9146	0.8587	0.9717	3410	142	0.1878	0.1752	0.2008	3472
13	7.969	7.167	8.840	3314	78	0.8890	0.8362	0.9440	3412	143	0.184	0.1716	0.1968	3472
14	7.656	6.891	8.485	3316	79	0.8643	0.8124	0.9173	3413	144	0.1802	0.168	0.1928	3473
15	7.357	6.627	8.147	3318	81	0.8173	0.769	0.8664	3415	145	0.1765	0.1645	0.189	3474
16	7.071	6.375	7.824	3320	82	0.7949	0.7483	0.8422	3416	146	0.173	0.1611	0.1852	3474
17	6.798	6.133	7.516	3322	83	0.7732	0.7283	0.8188	3417	147	0.1695	0.1578	0.1815	3475
18	6.537	5.902	7.221	3324	84	0.7522	0.7090	0.7962	3419	148	0.1661	0.1546	0.178	3476
19	6.287	5.681	6.940	3325	85	0.7319	0.6902	0.7743	3420	149	0.1627	0.1514	0.1745	3477
21	5.820	5.267	6.414	3330	86	0.7123	0.6720	0.7531	3421	150	0.1595	0.1483	0.1711	3477
22	5.601	5.074	6.169	3330	87	0.6932	0.6544	0.7326	3422					
23	5.392	4.888	5.934	3332	88	0.6748	0.6373	0.7127	3423					
24	5.192	4.710	5.709	3338	89	0.6570	0.6208	0.6935	3424					
25	5.000	4.539	5.494	-	90	0.6397	0.6047	0.6749	3425					

Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of Sep. 2024.

The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this manual, be sure to obtain the latest specifications.

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