NAS301H

ASADA CORPORATION

http://www.asada-metal.com/

Asada Corporation is a specialized trading company
for wires and strips such as steels, wires, piano wires,
hard drawn steel wires, stainless steel wires etc.

NAS

HERCULEE

Herculee

Stainless steel wire for high-strength spring

Nippon Seisen Co., Ltd.

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Herculee

Stainless steel wire for high-strength spring

We respond to your variety of needs with our reliable technologies and flexible ideas.

With the recent trend toward downsizing products with low cost, materials having further strength and stronger ductility are being strongly called for, compared with the conventional stainless steel wire for spring.

In order to respond to such requirements, here, we have much pleasure in introducing our newly developed stainless steel wire for spring, that has super high-strength, excellent spring fatigue characteristic and permanent set resistance, as well as good coiling capability, compared with SUS304-WPB, by carefully examining specific composition, adopting our unique manufacturing method, and fully utilizing our long-cultivated technologies for manufacturing stainless steel wire for spring.

1. Characteristics

●High-strength

Having tensile strength equivalent to that of piano wire Class A, and Class B (SWP-A, -B)

●Excellent in fatigue strength

Enabling to design spring with higher stress compared with the conventional stainless steel wire for spring, and having excellent fatigue strength.

●Excellent in spring load characteristic

In the thin wire category, load characteristic of spring is at the equivalent level to piano wire that is more excellent than SUS304-WPB.

●Excellent in permanent set resistance characteristic

Excellent in permanent set resistance when spring is repeatedly used.

2. Chemical composition

The following table 1 shows chemical composition standard for Herculee.

Table 1 Chemical composition

Unit: %

	C	Si	Mn	P	S	Ni	Cr
Standard	0.15 or less	1.00 or less	2.00 or less	0.045 or less	0.030 or less	6.00 - 8.00	16.00 - 18.00

Herculee belonging to SUS301 type of 17Cr-7Ni, basics of austenite-based stainless steel, is a steel type excellent in its work hardening characteristic which allows cold work-induced martensitic deformation to occur more easily compared with SUS304 of standard steel type 18Cr-8Ni.

3. Specifications

The following Table 2 shows specifications for Herculee.

Table 2 Specifications

<table>
<tr><th rowspan="2">Standard wire diameter (mm)</th><th rowspan="2">Tolerance for wire diameter (mm)</th><th rowspan="2">Deviated diameter (mm)</th><th rowspan="2">Tensile strength (N/mm^2)</th><th colspan="2">Type of packing (inch)</th><th colspan="2">Standard mass (kg)</th></tr>
<tr><th>HNF</th><th>HUBNS</th><th>HNF</th><th>HUBNS</th></tr>
<tr><td>0.10</td><td rowspan="5">0
−0.004</td><td rowspan="5">0.004
or less</td><td rowspan="6">2550~2840</td><td rowspan="4">—</td><td rowspan="3">4C</td><td rowspan="4">—</td><td>0.8</td></tr>
<tr><td>0.12</td><td rowspan="2">1.0</td></tr>
<tr><td>0.14</td></tr>
<tr><td>0.16</td><td rowspan="6">6C</td><td>2.5</td></tr>
<tr><td>0.18</td><td rowspan="2">6C</td><td>5.0</td><td rowspan="2">3.0</td></tr>
<tr><td>0.20</td><td rowspan="10">0
−0.007</td><td rowspan="17">0.005
or less</td><td>7.0</td></tr>
<tr><td>0.23</td><td rowspan="4">2450~2750</td><td rowspan="4">8C</td><td rowspan="3">12.0</td><td>3.5</td></tr>
<tr><td>0.26</td><td rowspan="2">5.0</td></tr>
<tr><td>0.27</td></tr>
<tr><td>0.29</td><td rowspan="4">8C</td><td>15.0</td><td>8.0</td></tr>
<tr><td>0.30</td><td rowspan="4">2350~2650</td><td rowspan="3">10C</td><td>20.0</td><td rowspan="2">10.0</td></tr>
<tr><td>0.32</td><td rowspan="2">22.0</td></tr>
<tr><td>0.35</td><td rowspan="3">12.0</td></tr>
<tr><td>0.40</td><td rowspan="6">12C</td><td rowspan="2">12C</td><td rowspan="2">25.0</td></tr>
<tr><td>0.45</td><td rowspan="4">2300~2600</td></tr>
<tr><td>0.50</td><td rowspan="7">0
−0.010</td><td rowspan="5">—</td><td rowspan="4">30.0</td><td rowspan="5">—</td></tr>
<tr><td>0.55</td></tr>
<tr><td>0.60</td></tr>
<tr><td>0.65</td><td rowspan="5">2210~2500</td></tr>
<tr><td>0.75</td><td rowspan="4">16C</td><td rowspan="2">40.0</td></tr>
<tr><td>0.80</td><td rowspan="3">—</td><td rowspan="3">—</td></tr>
<tr><td>0.90</td><td rowspan="2">50.0</td></tr>
<tr><td>1.00</td><td rowspan="3">0
−0.015</td><td rowspan="3">0.007
or less</td></tr>
<tr><td>1.20</td><td>2110~2400</td><td rowspan="2">18C</td><td rowspan="2">—</td><td rowspan="2">60.0</td><td rowspan="2">—</td></tr>
<tr><td>1.40</td><td>2060~2350</td></tr>
<tr><td>1.60</td><td rowspan="6">0
−0.020</td><td rowspan="6">0.010
or less</td><td>2010~2300</td><td rowspan="2">22C</td><td rowspan="2">—</td><td rowspan="2">120.0</td><td rowspan="2">—</td></tr>
<tr><td>1.80</td><td>1960~2260</td></tr>
<tr><td>2.00</td><td>1910~2210</td><td rowspan="4">24C</td><td rowspan="4">—</td><td rowspan="3">130.0</td><td rowspan="4">—</td></tr>
<tr><td>2.30</td><td>1860~2160</td></tr>
<tr><td>2.60</td><td>1810~2110</td></tr>
<tr><td>2.90</td><td>1770~2060</td><td>150.0</td></tr>
</table>

Remarks : As to other specs than the standard specs, we'll discuss with you upon receiving your inquiry.
: As to less than 0.10 mm wire diameter, please see our pamphlet for "stainless steel wire SUPER FINE for super fine spring".

4. Characteristics

4-1. Work hardening characteristic

Figures 1 to 3 show changes in tensile characteristic and torsional characteristic of Herculee and SUS304 in wire drawing processing.
Herculee shows higher values compared with SUS304 when measured with the same reduction of area (more than 60%), such as its tensile strength running at more than 300 N/mm², and its torsional strength running at more than 150 N/mm².

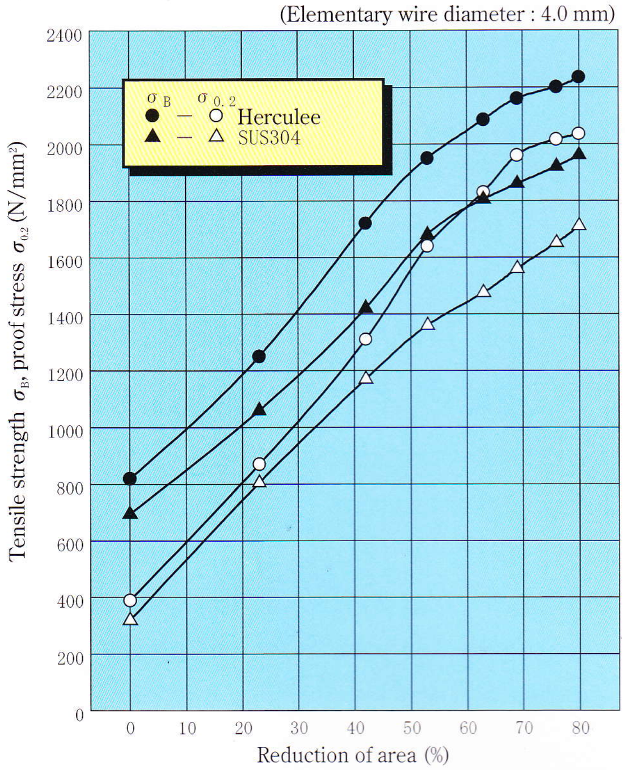

Fig. 1 Relation between reduction of area and σ_B and $\sigma_{0.2}$

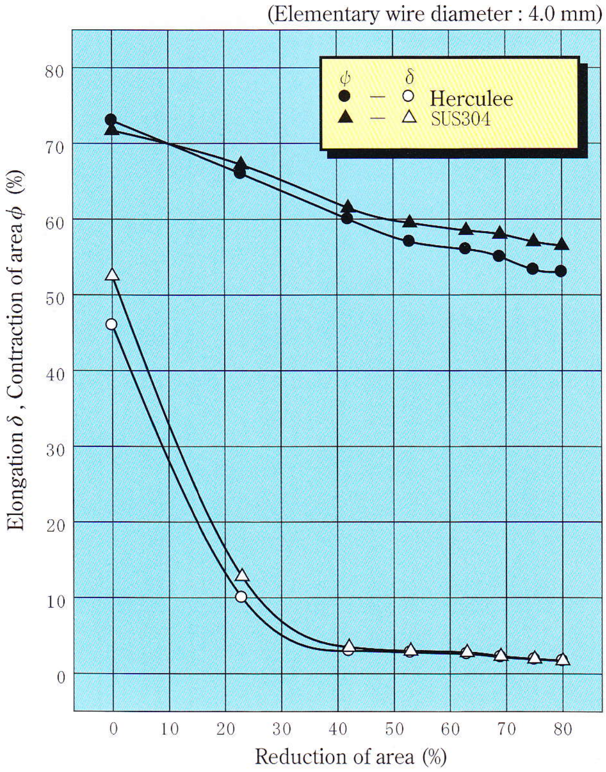

Fig. 2 Relation between reduction of area and δ and ϕ

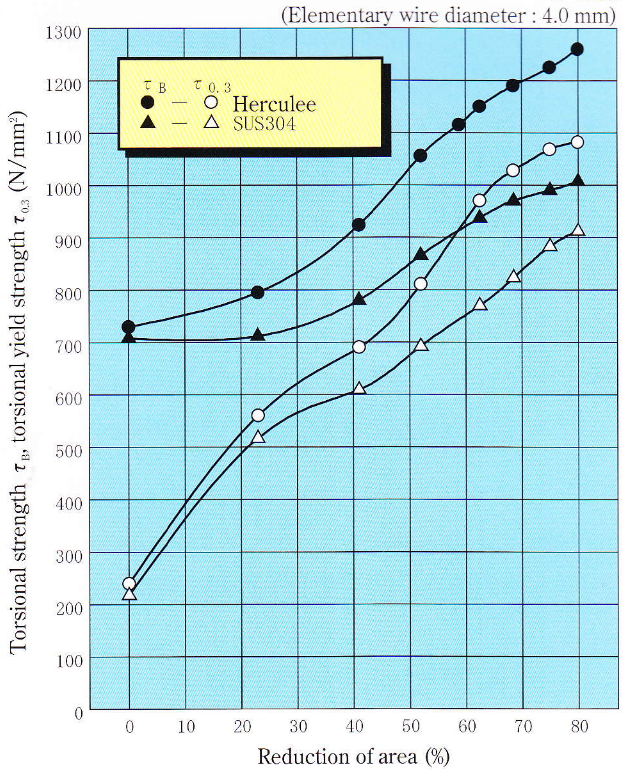

Fig. 3 Relation between reduction of area and τ_B and $\tau_{0.3}$

4-2 low-temperature annealing characteristic

Cold-work hardened wire like austenite-based stainless steel wire is treated with low-temperature annealing, after spring is formed, allowing wire to restore tensile strength, hardness and elastic limit through removal of residual stress, for the purpose of reducing permanent set and further improving strength against fatigue.

Figures 4 through 6 show changes in tensile characteristic and torsional characteristic of Herculee and SUS30, which have been treated with low-temperature annealing for 30 minutes at every 50℃ in the range of 300 to 500℃ after going through wire drawing process.

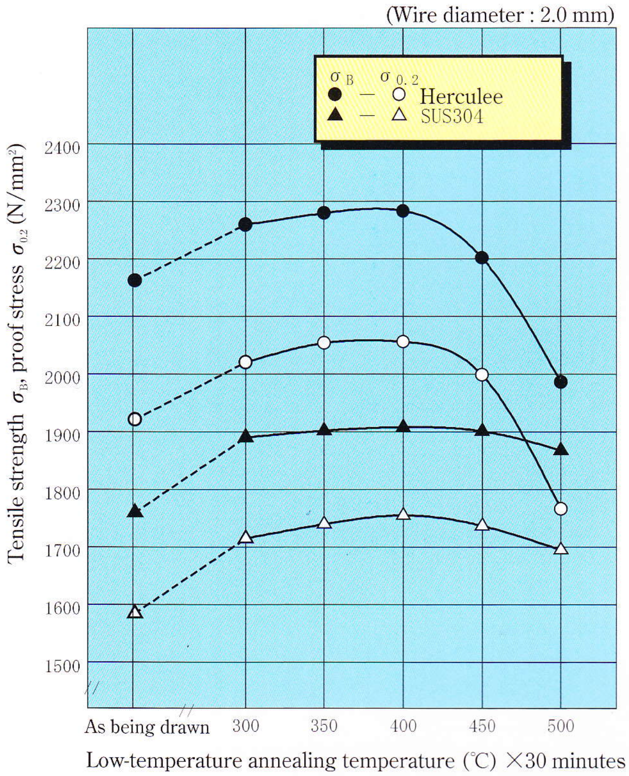

Fig. 4 Change in σ_B and $\sigma_{0.2}$ by low-temperature annealing

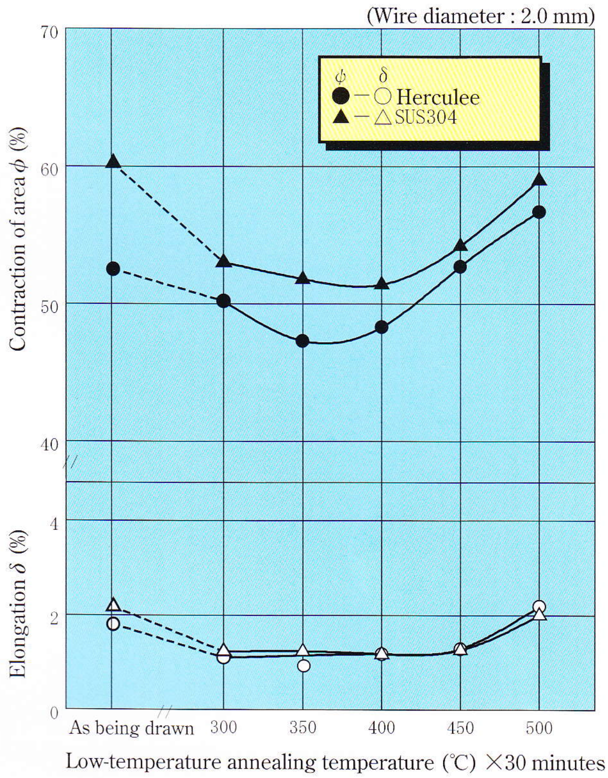

Fig. 5 Change in δ and ϕ by low-temperature annealing

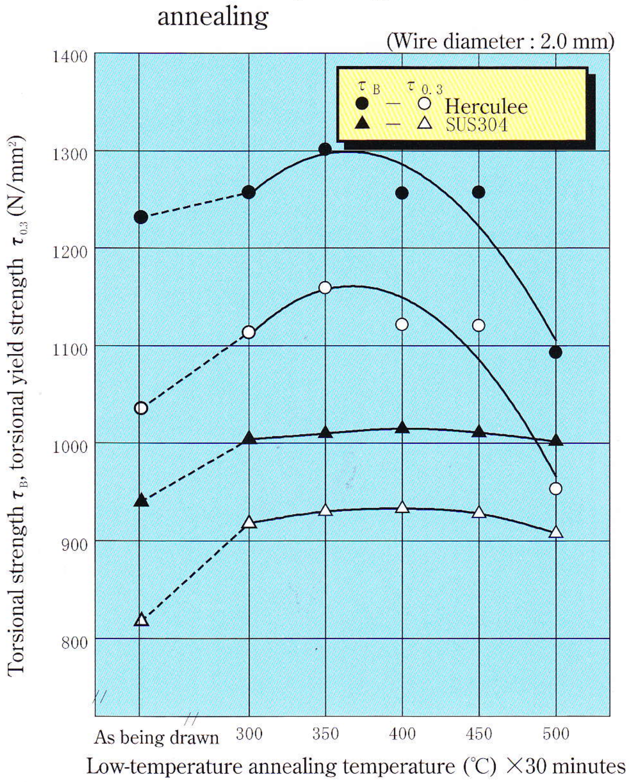

Fig. 6 Change in τ_B and $\tau_{0.3}$ by low-temperature annealing

Optimum condition of low-temperature annealing process for Herculee is 350℃×30 minutes, 50℃ lower than 400℃×minutes for SUS304.

Tensile strength and 0.2% proof stress of Herculee after low-temperature annealing process show more than about 300 N/mm² higher than those of SUS304, and torsional strength and torsional yield strength show more than about 200 N/mm² higher.

In short, Herculee has strength and elastic limit equivalent to piano wire (SWP-B), and at the same time, it provides enough elongation and contraction of area (See Fig. 5) for spring usage.

Tables 3 and 4 show tensile characteristic and torsional characteristic of Herculee and comparative steel types like SUS304 and piano, during wire drawing process and optimum low-temperature annealing process (wire diameters 2.0 mm and 0.4 mm).

Table 3 Changes in mechanical characteristic caused by low-temperature annealing (Wire diameter 2.0 mm)

Condition		Tensile strength σ_B (N/mm²)	Proof stress $\sigma_{0.2}$ (N/mm²)	Modulus of elasticity E (kN/mm²)	Torsional strength τ_B (N/mm²)	Torsional yield strength $\tau_{0.3}$ (N/mm²)	Modulus of rigidity G (kN/mm²)
Herculee	In wire drawing process	2157	1922	165.7	1236	1040	71.6
	Low-temperature annealing	2285	2059	171.6	1304	1157	73.5
SUS304	In wire drawing process	1765	1589	161.8	941	814	68.6
	Low-temperature annealing	1932	1755	166.7	1020	932	69.6
SWP-A	In wire drawing process	1893	1520	192.2	1089	863	78.5
	Low-temperature annealing	2040	1863	205.9	1177	1030	80.4
SWP-B	In wire drawing process	2118	1706	194.2	1226	995	78.5
	Low-temperature annealing	2285	2059	206.9	1324	1128	80.4

Table 4 Changes in mechanical characteristic caused by low-temperature annealing (Wire diameter 0.4 mm)

Condition		Tensile strength σ_B (N/mm²)	Proof stress $\sigma_{0.2}$ (N/mm²)	Modulus of elasticity E (kN/mm²)	Torsional strength τ_B (N/mm²)	Torsional yield strength $\tau_{0.3}$ (N/mm²)	Modulus of rigidity G (kN/mm²)
Herculee	In wire drawing process	2623	2346	189.7	1373	1196	77.6
	Low-temperature annealing	2705	2461	194.5	1399	1234	79.1
SUS304	In wire drawing process	2170	1931	173.5	1058	918	74.3
	Low-temperature annealing	2377	2139	179.2	1123	1025	75.1
SWP-A	In wire drawing process	2506	2284	185.7	1304	1006	77.9
	Low-temperature annealing	2546	2328	193.1	1321	1137	79.6
SWP-B	In wire drawing process	2610	2348	187.7	1340	1025	78.2
	Low-temperature annealing	2641	2411	194.4	1356	1151	79.8

Low-temperature annealing condition Herculee : 350℃×30 minutes
SUS304 : 400℃×30 minutes
SWP-A, SWP-B : 200℃×30 minutes

4-3. Tensile strength standard

Table 5 shows comparison between tensile strength standards for Herculee depending on specific wire diameters and (JIS standards) for SUS304-WPB, piano wire Class A (SWP-A) and piano wire Class B (SWP-B).

Tensile strength standards for Herculee on thin wire diameter side are slightly lower than standards for piano wire (SWP-A), and on thick wire diameter side, standards are almost equivalent to those for SWP-B.

Table 5 Tensile strength standard

Standard wire diameter (mm)	Tensile strength (N/mm^2)			
	Herculee	SUS304-WPB	SWP-A	SWP-B
0.10	2550～2840	2150～2400	2790～3090	3090～3380
0.12			2750～3040	3040～3330
0.14			2700～2990	2990～3290
0.16			2650～2940	2940～3240
0.18			2600～2890	2890～3190
0.20			2600～2840	2840～3090
0.23	2450～2750	2050～2300	2550～2790	2790～3040
0.26			2500～2750	2750～2990
0.29			2450～2700	2700～2940
0.32	2350～2650		2400～2650	2650～2890
0.35				
0.40			2350～2600	2600～2840
0.45	2300～2600	1950～2200	2300～2550	2550～2790
0.50				
0.55			2260～2500	2500～2750
0.60			2210～2450	2450～2700
0.65	2210～2500	1850～2100		
0.70			2160～2400	2400～2650
0.80			2110～2350	2350～2600
0.90			2110～2300	2300～2500
1.00			2060～2260	2260～2450
1.20	2110～2400	1750～2000	2010～2210	2210～2400
1.40	2060～2350		1960～2160	2160～2350
1.60	2010～2300	1650～1900	1910～2110	2110～2300
1.80	1960～2260		1860～2060	2060～2260
2.00	1910～2210		1810～2010	2010～2210
2.30	1860～2160	1550～1800	1770～1960	1960～2160
2.60	1810～2110			
2.90	1770～2060	1450～1700	1720～1910	1910～2110

Remarks: As to in-between wire diameter, use value for standard wire diameter larger than that.

4-4. Corrosion resistance

Table 6 shows the results of tests, including nitric acid immersion test, sulfuric acid immersion test, ferric chloride immersion test and salt spray test specified by JIS, that were conducted on Herculee and SUS304, where these wires have been treated with optimum low-temperature annealing after the process of drawing.

Table 6 Result of corrosion resistance test

Condition		Virgin material				Ni plated material
		Nitric acid immersion test	Sulfuric acid immersion test	Ferric chloride immersion test	Salt spray test	
		Corrosion weight loss ($g/m^2 \cdot hr$)			Rust development area ratio (%)	
In wire drawing process	Herculee	0.50	360	21	5～25	5～25
	SUS304	0.29	204	23	0～ 5	5～25
Low-temperature annealing	Herculee	0.56	443	23	25～50	25～50
	SUS304	0.34	288	26	5～25	25～50
Remarks		65% HNO_3 Boiling×48 hr JIS G 0573	5% H_2SO_4 Boiling×6 hr JIS G 0591	6%$FeCl_3$+1/20N HCl 35℃×24hr JIS G 0578	5%NaCl 35℃×240hr JIS Z 2371	

Low-temperature annealing condition Herculee: 350°C×30 minutes, SUS304: 400°C×30 minutes

Slight difference in corrosion resistance of Herculee is allowed compared to SUS304, due to different contents of C, Cr and Ni.
However, corrosion resistance of Ni plated wires that are frequently used for spring material, are generally equivalent to that of SUS304.

4-5. Fatigue characteristic of wire

Figure 7 and Table 7 show the result of S-N diagram by Nakamura-type repetition rotary bending test, conducted on Herculee and SUS304 wires that have been straightened after being drawn.

As to fatigue limit at the time of 10^7 times of repetitions, fatigue limit of Herculee is 564N/mm², 137N/mm² higher than that of SUS304.

(Wire diameter : 2.0 mm)

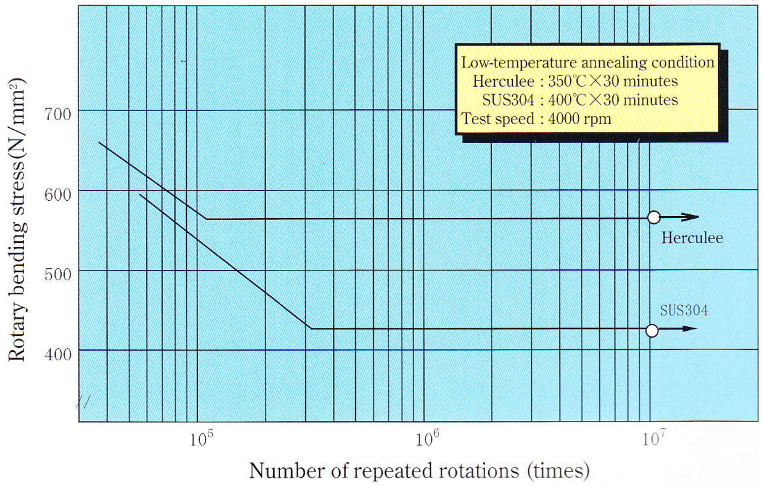

Fig. 7 Result of rotary bending test (Nakamura-type)

Table 7 Result of fatigue test of wire (Wire diameter 2.0 mm)

Condition	Fatigue strength (N/mm²)		Tensile strength (N/mm²)
	10^5 times	10^7 times	
Herculee	574	564	2206
SUS304	539	427	1824

Low-temperature annealing condition
Herculee: 350℃× 30 minutes
SUS304: 400℃× 30 minutes

4-6. Fatigue characteristic of spring

Fig. 8 shows the result of spring fatigue test conducted on compression-coiled spring (wire diameter 1.0 mm) of Herculee and SUS304. Table 8 shows specs for spring used in the test.

When fatigue limit at the time of 10^7 times of repetition is measured, with the average stress 490 N/mm² kept constant, Herculee shows 319 N/mm², satisfying about 50 N/mm² higher stress amplitude compared to SUS304.

(Wire diameter of spring : 1.0 mm)

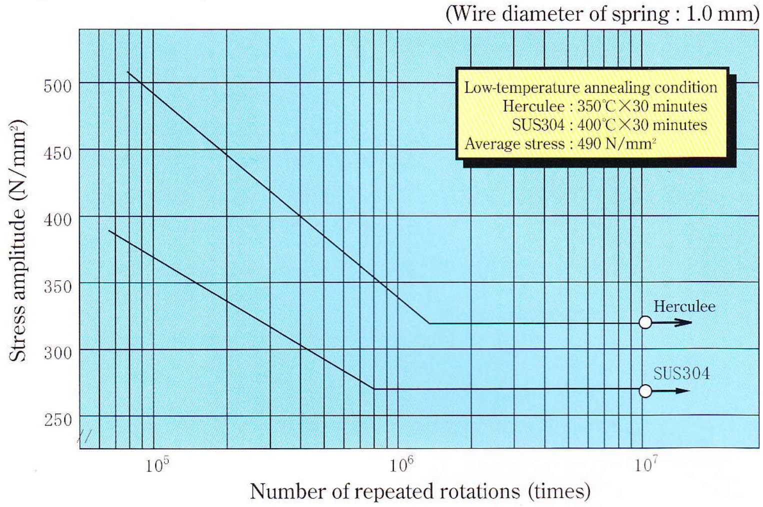

Fig. 8 Spring fatigue characteristic wear result

Table 8 Specs for compression coiled spring for fatigue test

Wire diameter (mm)	1.0
Average diameter of coil (mm)	10.0±0.1
Total number of wire turns (turns)	6.0
Effective wire turns (turns)	4.0
Free length (mm)	26.0±0.2
Squareness	2° or less

Figure 9 shows the result of spring fatigue test conducted on compression coiled spring (wire diameter 0.5 mm) of Herculee, and Figure 10 and Table 9 show the result of spring fatigue test, where shot peening is performed.
Table 10 shows specs for springs used in the test.

As to fatigue limit with average stress of 600 N/mm² kept constant, and 10^7 times of repetitions, it is found that fatigue limit can be substantially improved by performing shot peening. To be more specific, fatigue limit of 300 N/mm² without shot peening can be improved to 500 N/mm² by shot peening.

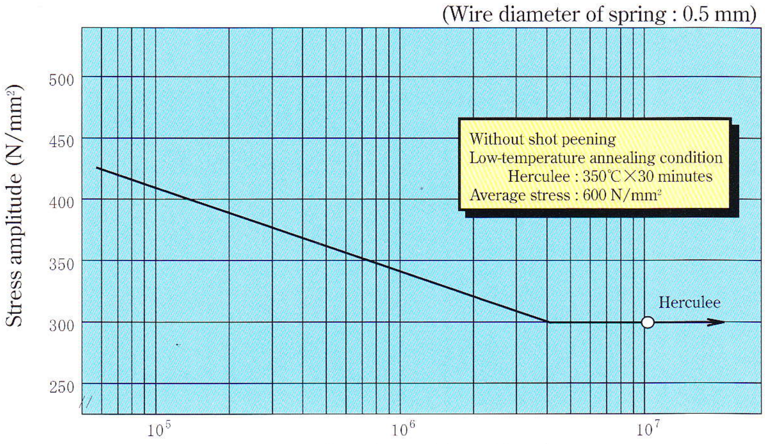

Fig. 9 Spring fatigue characteristic wear result (Without shot peening)

Table 9 Result of spring fatigue test

	Fatigue limit (N/mm²)
With shot peening	600±500
Without shot peening	600±300
Effect of shot peening	±200

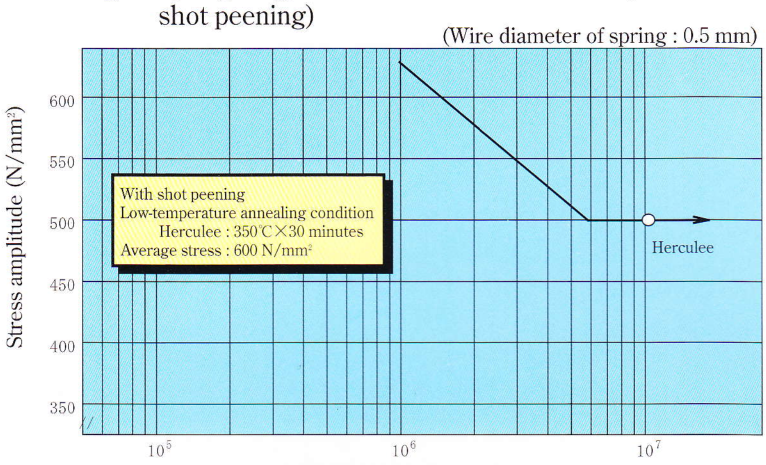

Fig. 10 Spring fatigue characteristic wear result (With shot peening)

Table 10 Specs for compression coiled spring for fatigue test

Wire diameter (mm)	0.5
Average diameter of coil (mm)	4.0
Total number of wire turns (turns)	10.5
Effective wire turns (turns)	8.5
Free length (mm)	14.0
Squareness	2° or less

4-7. Permanent set characteristic of spring

Figure 11 shows the result of residual shearing distortion measurement after spring fatigue test with 107 times of repetitions (wire diameter 1.0 mm), to evaluate permanent set resistance.

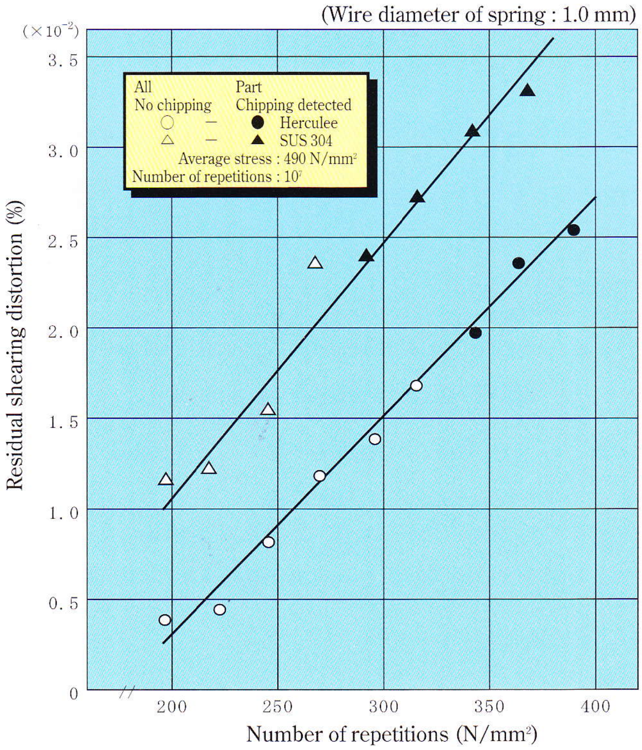

Fig. 11 Relation between stress amplitude and residual shearing distortion

Compared with SUS304, Herculee is extremely outstanding in its dynamic permanent set characteristic in spring, as residual shearing distortion (amount of distortion) within fatigue limit is as small as about 50 % or less.

4-8. Load characteristic of spring

A diagram showing load-to-distortion of tension springs of Herculee and SUS304 with fine wire diameter is shown in Figure 12, and Figure 13 shows a diagram as to Herculee and piano wire Class B (SWP-B).
Specification for the springs used in each test are as shown in Table 11 and Table 12.

Compared with SUS304, Herculee provides higher initial tension and higher load, and has the same load characteristic as that of piano wire Class B (SWP-B).

Table 11 Specs for tension spring for load-to-distortion test
(For comparison between Herculee and SUS304)

Wire diameter (mm)	0.4
Average diameter of coil (mm)	2.9
Number of wire turns (turns)	50・1/4
Free length (mm)	43
Low-temperature annealing processing	280 +20 −0 (°C)

Table 12 Specs for tension spring for load-to-distortion test
(For comparison between Herculee and SWP-B)

Wire diameter (mm)	0.4
Average diameter of coil (mm)	3.0
Number of wire turns (turns)	52・1/4
Free length (mm)	46
Low-temperature annealing processing	None

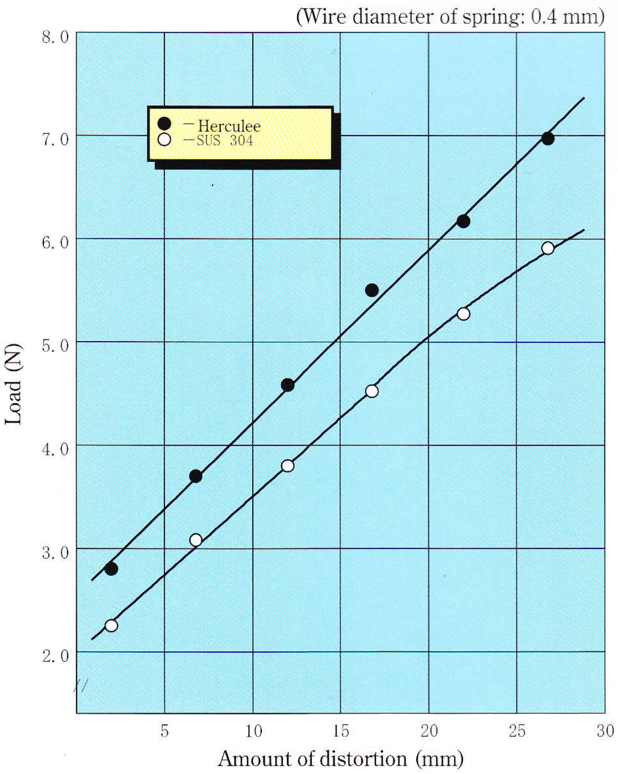

Fig. 12 Load-to-distortion diagram in tension spring

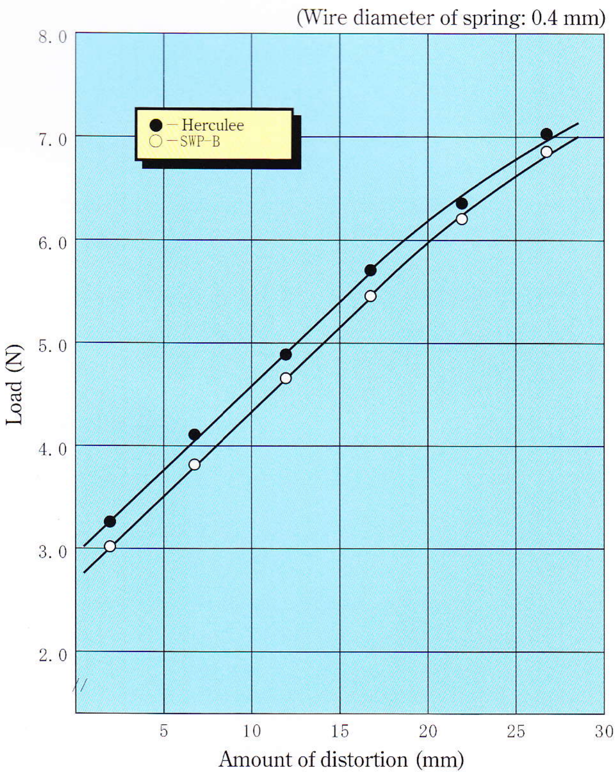

Fig. 13 Load-to-distortion diagram in tension spring

4-9. Permanent set characteristic of spring at high-temperature

Figure 14 shows the result of high-temperature tightening test of compression coiled springs (wire diameter 2.0 mm) of Herculee and SUS304.
Specs for the springs used in the test are as shown in Table 13.

High-temperature permanent set characteristic of Herculee spring is excellent because of its higher allowable stress compared with SUS304.

(Wire diameter of spring: 2.0 mm)

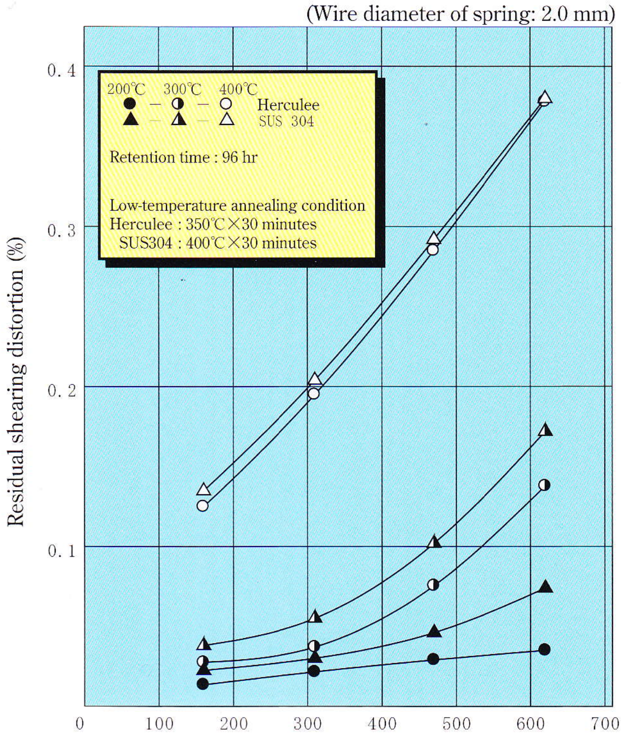

Fig. 14 Diagram showing deformation caused by spring fatigue at high temperature

Table 13 Specs for compression coiled spring for fatigue test

Wire diameter (mm)	2.0
Average diameter of coil (mm)	18.5±0.2
Total number of wire turns (turns)	6.5
Effective wire turns (turns)	4.5
Free length (mm)	47.0±0.3
Squareness	2° or less
Low-temperature annealing processing	Herculee:350℃×30 minutes SUS304:400℃×30 minutes

5. Examples of use

Since Herculee has excellent characteristics in terms of high strength, fatigue strength or permanent set resistance, Herculee is believed to be able to address the following cases;

- where it is impossible for SUS304 to deal with design stress,
- where permanent set resistance is regarded as important
- where replacing from piano wire, or hard steel wire due to corrosion resistance; and
- where replacing from piano wire due to cost aspects of spring with fine wire diameter.

Table 14 Examples of use

Automobile	Electrical machines/ home electronics	OA devices/ IT-related	Daily necessities/ others
●Radiator valve spring ●Carburetor spring ●Key ring	●Breaker spring ●Dishwasher spring	●Copying machine spring ●Connector spring ●Back-up tape-related spring ●Printer spring	●Hand soap spring ●Speed changer spring ●Whip