

JSSE

Japan Society of Spring Engineers

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# Materials for Springs

 Springer

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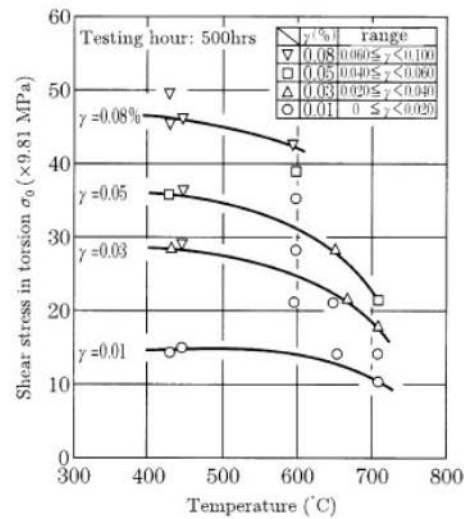
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**Fig. 2.214.** Shear stress-temperature diagram in torsion of Inconel X-750 ( $\gamma$ : residual shear strain)

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## 2.3 Constant Modulus and High Modulus Spring Material

### 2.3.1 Constant Modulus Spring Material

By the French physicist, Guillaume, Fe-36%Ni alloy of which thermal expansion is extremely small around room temperature, was invented in 1896. This alloy was named the Invar alloy based on the French word “invariable” that is also the same meaning in English. Although the temperature dependency of thermal expansion coefficient of this alloy was small, the temperature dependency of elastic coefficient was large. After that, the research by Guillaume was continued, then the alloy of which the temperature dependency of elastic coefficient was small, namely the Elinvar alloy was developed in 1919. This alloy was called the constant elastic alloy or the elastic constant steel, but

origin of the word came from a French word of “élasticité invariable” having the meaning of invariable elasticity.

As for the usual metal and alloy, when the temperature rises, the distance between atoms of metal crystal becomes large and the restoring force becomes weak, so the elastic coefficient decreases. The temperature coefficient is approximately  $10^{-4}/^{\circ}\text{C}$ . However, regarding the precise equipments which utilizes elastic characteristic, such as aircraft instrument parts, spiral springs for clock, springs for seismometers, precise dynamometers for calibration and weighing appliances, some problems may cause when the elastic coefficient changes with the surrounding temperature.

For example, a mechanical type watch using a spiral spring made of the conventional material has 16 seconds delay per day as temperature becomes high by  $1^{\circ}\text{C}$ . This means that time lag and advancing can change with the temperature change of seasons. As for the applications for precise equipments, the temperature coefficient to elastic modulus can be desirable to be  $10^{-5}$ – $10^{-7}/^{\circ}\text{C}$ . The elinvar alloy can be used for this kind of applications. Table 2.65 shows the comparison of temperature dependency to elastic coefficient between Ni-Span C which is a kind of Elinvar alloy, and various alloys [2,3].

The alloy which shows this kind of characteristics was developed in large numbers. They are called elinvar type alloy and can be classified into Fe–Ni type alloy and Fe–Co type alloy from the chemical compositions.

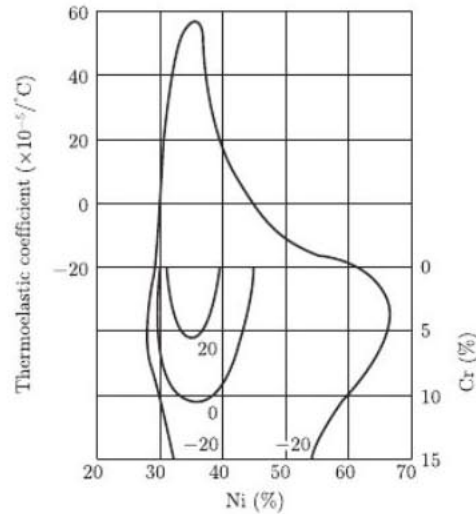
#### (1) Fe–Ni type elinvar alloy

Figure 2.215 shows the effect of Ni and Cr contents on the temperature coefficient of modulus of rigidity (or thermoelastic coefficient) for Fe–Ni–Cr

**Table 2.65.** Temperature coefficient of various alloys [2,3]

Material	Average temperature coefficient of rigidity modulus ( $-50$ – $50^{\circ}\text{C}$ ) $\times 10^{-5}/^{\circ}\text{C}$	Modulus of elasticity GPa	Change of temperature coefficient $-46$ – $66^{\circ}\text{C}$ %
Ni-Span C	0	186	0
0.9% Carbon steel	–25.2	206	2.9
17% Cr Stainless steel	–25.4	196	2.9
3.5% Nickel steel	–25.9	206	3.0
Monel	–28.4	172	3.3
Beryllium copper	–33.5	127	3.9
18% Nickel silver	–33.5	132	3.9
Phosphorus bronze	–36.4	108	4.2
18-8 Stainless steel	–39.1	181	4.5
70/30 Brass	–37.1	98	4.3
Duralmin	–56.0	69	6.5
36% Ni Invar	–48.2	144	5.4





**Fig. 2.215.** Temperature coefficient of Rigid ratio for Fe-Ni-Cr based alloy *g* [1]

and Fe-Ni alloys. When no Cr is contained in the alloys, the temperature coefficient has its maximum value and zero value at the Ni content of 34% and both at 30% and 43%, respectively. The temperature coefficient of Fe-Ni-Cr alloy is shown in the lower part of Fig. 2.215. The ternary alloy's chemical compositions that show the zero thermoelastic coefficient are numerous and are along the line zero in the Fig. 2.215. However, these ternary alloys with zero thermoelastic coefficient have rather low modulus of elasticity and tensile strength. To improve these drawbacks, C and W are alloyed further, which is called the Elinvar alloy. In Fe-Ni base alloys, Meterinvar is alloyed with Mo and W, Ni-SpanC and Durinvar are alloyed with precipitation hardening elements, Ti and Al, and Nivarox is alloyed with W, Cr, Mo and Be. Table 2.66 shows the chemical compositions of constant modulus alloys and their various characteristics [2,4,5,7].

Among these alloys, Fe-Ni-Cr-Ti-Al type alloy such as Ni-Span C, YniC and sumi Span-3 have been widely used. Nivarox shows weak magnetism and is influenced little with the magnetic field. Therefore, it has been used widely as a spiral spring of a watch. However, the quantity consumed has been decreasing from the time before due to the spread of the quartz (crystal oscillation) and the digital watch.

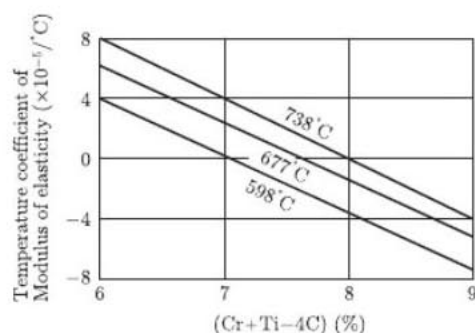
Fe-Ni-Cr-Ti-Al type alloy represented by Ni-Span C is precipitation hardening type alloy, that is applied cold working after 950–1,000°C solution heat treatment, and followed by precipitation hardening process. The aging for precipitation hardening can be conducted at such a condition as 600°C × 48 hrs. to 730°C × 3hrs. for post solution heat treatment or as 600°C × 4hrs. to 730°C × 1 hr. for post 50% cold working, depending upon the size of material to be heat treated [6]. During the aging for precipitation hardening processing, some part of Ti and Cr form carbides with the carbon which is included as the impurity, so the characteristics can change due to the reduction of effective

Table 2.66. Chemical compositions and characteristics of constant elastic materials

Classification		Commodity name	Chemical compositions (mass %)												Cited reference	Coefficient of thermal expansion ( $\times 10^{-6}$ )	Temperature coefficient of elastic ratio ( $\times 10^{-5}/^{\circ}\text{C}$ )	Tensile strength MPa	
			C	Si	Mn	Ni	Co	Cr	W	Mo	Cu	V	Al	Ti					Be
Fe-Ni base	Fe-Ni-Cr	Elinvar	0.8	1~2	1~2	36	—	12	1~3	—	—	—	—	—	1), 2)	0.8	$\pm 0.37$	735	
	Fe-Ni-Cr-Co	Super Elinvar	—	—	0.7	36~39	5~10	5~10	—	—	—	—	—	—	1), 2)	—	—	—	
	Fe-Ni-Cr-Mo	iso-elastic	—	—	—	36	—	7~8	—	0.5	—	—	—	—	1), 2)	2.2	$-1.1 \sim +0.8$	1177	
	Fe-Ni-Cr-Mo		0.1	0.5	0.6	36	—	7.2	—	0.5	0.2	—	—	—	3)	7.2	$-3.6 \sim +2.7$	—	
	Fe-Ni-Cr-W	Metelinvar	0.6	—	2	40	—	6	3	1.5	—	—	—	—	1), 2)	—	—	1432	
	Fe-Ni-Cr-Ti	Elinvar Extra	—	—	—	43	—	5	—	—	—	—	2.8	—	2)	—	—	—	
			0.6	0.5	0.5	42	—	5.5	—	—	—	0.6	2.5	—	3)	7.5	0	—	
			0.04	0.5	0.6	43	0.35	5	—	—	—	0.3	2.75	—	1)	—	—	—	
			1	—	1	36	—	5	2	—	—	—	—	—	1)	8	—	—	
	semi spun-3		—	—	—	42	—	5.5	—	—	—	—	2~3	—	4)	—	$\pm 1.0$	—	
	Fe-Ni-Cr-Ti-Al	Ni-Span C	—	—	—	41~43	—	4.9~5.5	—	—	—	—	$\leq 0.1$	2.1~2.5	—	2)	2.5	$\pm 0.6$	612~1373
			$\leq 0.05$	$\leq 0.1$	$\leq 0.8$	42	—	5.2	—	—	—	—	2.3	—	3)	—	—	—	—
			0.02	0.33	0.52	42.27	—	5.32	—	—	0.05	—	0.46	2.46	—	1)	8.1	$\pm 1.8$	—
		YnC	0.03	—	—	41~43	—	5.1~5.5	—	—	—	—	0.5~0.6	2.2~3.0	—	1)	—	—	—
	Fe-Ni-Mo	Vitalloy	$\leq 0.02$	—	0.1~0.65	38~43	$\leq 0.5$	—	—	15.7	—	—	—	—	—	2)	—	—	—
			0.3	—	2.2	34.8	1.2	—	—	—	—	—	—	—	—	2)	—	—	—
			—	—	—	40	—	—	—	10	—	—	—	—	—	3)	—	—	—
		—	—	—	39	—	—	—	9	—	—	—	—	—	1)	—	0.8	—	
Fe-Ni-Al-Ti	Durinvor	0.1	—	2	40~42	—	—	—	6	—	—	1.9~2.0	2.1	—	2)	—	$\pm 1.0$	—	
Fe-Ni-Be-W	Nivarox	—	0.1	0.8	36	—	—	8	—	—	—	—	—	1)	—	—	—	—	
Fe-Ni-Be-Mo		—	0.1	0.8	36	—	—	—	7	—	—	—	—	1)	—	—	—	—	
		—	—	—	30	—	—	—	9	—	—	—	—	1)	—	—	—	—	
		—	—	—	40	—	—	—	9	—	—	—	—	1)	—	—	—	—	
	Fe-Ni-Be-Cr-Ti		—	—	—	36	—	8	—	—	—	—	—	1)	1)	—	—	—	
		0.2	1	1	38	—	8	—	—	—	—	—	1	1	1)	7.5	$\pm 2.5$	—	
Fe-Ni-Be-Ti		—	—	—	36	—	—	—	—	—	—	1	1	1)	—	—	—	—	
Fe-Co base	Fe-Co-Cr	Co-elinvar	—	—	—	—	60	15	—	—	—	—	—	—	2)	14	-0.9	—	
			—	—	—	16.7	34.6	10.8	—	—	—	—	—	—	2)	7.7	0.8	—	
			—	—	—	15~20	25~30	8~12	—	—	—	—	—	—	3)	—	$\pm 2.0$	—	
			—	—	—	—	60	10	—	—	—	—	—	—	1)	5.1	-0.2	—	
			—	—	—	9.1	43.6	12.7	—	—	—	—	—	—	1)	7.4	0	—	
			—	—	—	23.1	27.7	10	—	—	—	—	—	—	1)	8.1	0.3	—	
	Fe-Co-V	Velinvar	—	—	—	—	60	—	—	—	—	10	—	—	1), 2)	7.4	0.7	—	
			—	—	—	20	37.6	—	21.5	—	—	10	—	—	2)	7.8	-0.5	—	
			—	—	—	30	20	—	—	—	—	10	—	—	1)	11.6	-0.7	—	
	Fe-Co-W	Tungelinvor	—	—	—	—	50	—	19	—	—	—	—	—	2)	7.4	-0.7	—	
			—	—	—	—	50	—	21.5	—	—	—	—	—	1)	7.4	0.7	—	
			—	—	—	10	39	—	19	—	—	—	—	—	1)	7.8	4.3	—	
	Fe-Co-Mo	Moelinvar	—	—	—	—	50	—	—	17.6	—	—	—	—	2)	9.6	-0.2	—	
			—	—	—	30	10	—	—	15	—	—	—	—	2)	9.8	-0.4	—	
	Fe-Co-Ni-Mo-Cr	Elcovor	—	—	—	15~18	35~40	5	4~5	5	—	—	—	—	3)	—	—	—	—
			—	—	—	16	36	—	4	4	—	—	—	—	1)	9.0	0.5	—	
			—	—	—	15	35	5	—	5	—	—	—	—	1)	5.0	0.2	—	

1) Metal manual Revision 3edition 2) Steel material manual 1967 3) Metal 1971 November 1st number 4) Metal 1970 July 15th number





**Fig. 2.216.** The influence of C, Ti, Cr amount of Ni-spanC and Precipitation hardening processing temperature for Thermoelasticity factor [2]

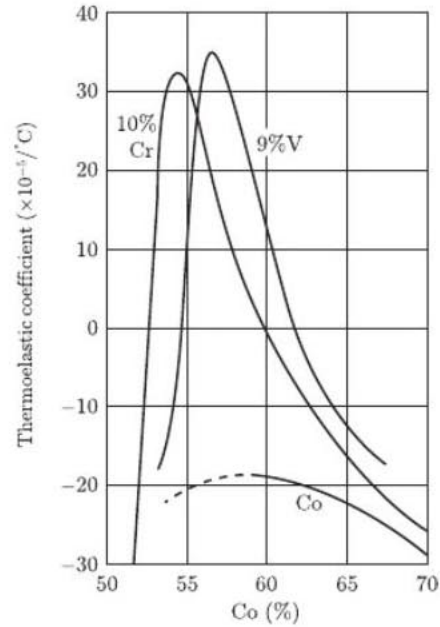
content of Ti and Cr, depending upon the precipitation hardening condition. Therefore, in order to obtain the intended constant modulus characteristics, the precipitation hardening condition should be determined taking carbon contents (or effective content of Ti and Cr) into consideration. Figure 2.216 shows the influence of precipitation hardening temperature and C, Ti, and Cr contents on Ni-SpanC alloy's thermoelastic coefficient (temperature coefficient of modulus of elasticity) [2].

## (2) Fe-Co base elinvar type alloy

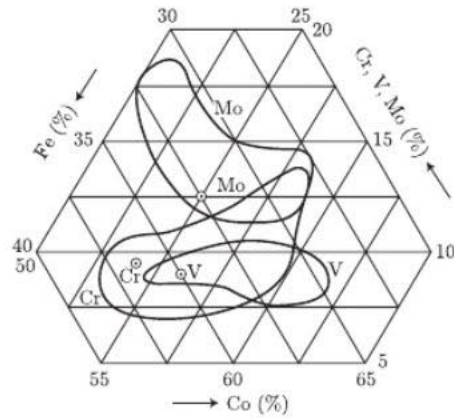
Although Fe-Ni based alloy has been in the center of research works, in Japan, Fe-Co based alloy has become popular after the constant elastic alloy (Co-elinvar) had been found by Masumoto and Saito of Institute of Materials Research, Tohoku University. Figure 2.217 shows the effect of Co content on thermoelastic coefficient for Fe-Co, Fe-9%V-Co, and Fe-10%Cr-Co alloy [1]. As for the Fe-Co base alloy without Cr and V, there is a gradual negative dependency, however, with adding Cr or V, a typical characteristic of Elinvar type alloy can appear. The similar phenomenon occurs not only with Cr and V but also with Mo and W. Figure 2.218 shows the chemical compositional curves on which the thermoelastic coefficient becomes zero for Fe-Co-Cr, Fe-Co-Mo and Fe-Co-V alloy. In case of Fe-Co-W alloy, the thermoelastic coefficient does not reach to the plus range. However, when Ni is added, it becomes possible to improve the characteristic and to save the Co content. Co-elinvar is named for Fe-Co-Cr alloy, Moelinvar is for Fe-Co-Mo, Velinvar is for Fe-Co-V, and Tugelinvar is for Fe-Co-W. Since Nivarox of Fe-Ni alloy is added Be, it is said that wide scatterings of the product quality may occur due to the oxidization of Be [7]. Since Co-elinvar is stable in the sense of productivity, and shows small scatterings between the production lots, it had been used for more than 90% of spiral spring (hair spring) material of watches in Japan [7].

The Elinvar type alloy is designed in metal physics standpoint to make magnetostriction<sup>1</sup> large enough to compensate the normal temperature coefficient at room temperature. One characteristic of this kind of alloy is easy

<sup>1</sup> Magnetostriction: Strain when it is subjected to a magnetic field.



**Fig. 2.217.** Effect of Co content on thermoelastic coefficient for Fe-Co, Fe-Co-10%Cr, Fe-Co-9%V [1]



**Fig. 2.218.** Chemical compositional curves for Fe-Co-Cr, Fe-Co-V, Fe-Co-Mo alloys with thermoelastic coefficient  $g = 0$ , Outside is  $g < 0$ , ● mark shows positive max.value [1].

to be influenced by external magnetic condition. When the external magnetic field becomes large, thermoelastic coefficient gradually increases. At the magnetic saturation condition, it shows the same temperature dependency as the paramagnetic material that is magnetized slightly in magnetic field direction, and no longer shows the original characteristic of Elinvar type alloy. In addition, the Elinvar type alloy magnetized once shows the temperature dependency of the elastic coefficient which is similar to the general metal, if having residual magnetization state after removing the magnetic field. There-



fore, it is necessary to sufficiently pay attention to the external magnetic field for using the Elinvar type alloy.

### 2.3.2 High Modulus Spring Material

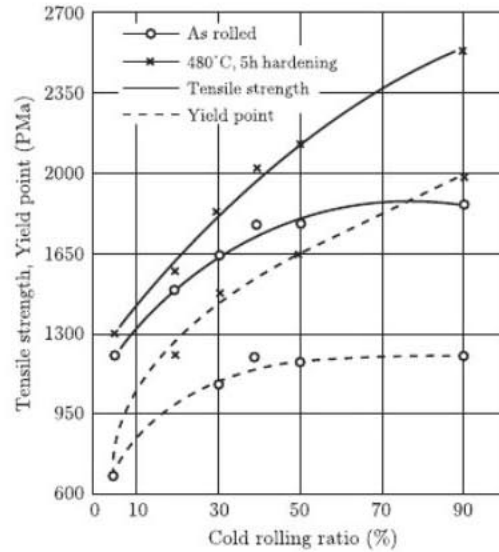
High modulus spring material is Co base alloy containing 35% to 45% Co or Co–Ni base alloy. It is somewhat confusing with constant modulus spring material because containing much Co. However, the applications are quite different each other. A typical example of high modulus spring material is a power spiral spring (main spring) for a mechanical type watch that has been recently replaced at large by the electronic digital type watch and the quartz watch. The carbon steel was mainly used as material of this power spiral spring before the World War II. Since the carbon steel with quenching and tempering, could show higher elastic limit in comparison with the other metals, it was suitable for the raw material of the spiral spring, therefore, still used for the power spiral spring at present.

The spiral spring has a characteristic of increasing the duration of generating force, as its length becomes long, and in case of a clock, it is necessary to be operated for a long time with the torque as weak as possible, so the shape of a clock spring should be thin and long. In addition, when using a spring for a long time, it occasionally cause the breakage. Generally, a thicker spiral spring may have a possibility of early fracture. As a characteristic of the power spring material of clocks, high elastic modulus, large  $\sigma/E$  ( $\sigma$ : Elastic limit,  $E$ : Young's modulus), high fatigue characteristic, good corrosion resistance, low notch sensitivity, and good forming ability can be required [5].

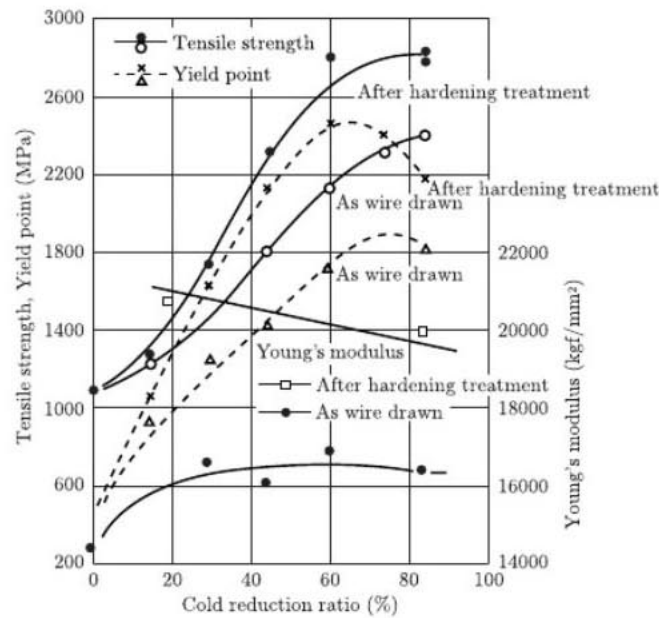
After the World War II, many new alloys were developed for the watch spring, and one of them was Elgiloy of Co base alloy. Elgin National Watch Co. in Illinois, U.S.A., received the information concerning the complaint that watch springs broke during the maneuvers by the return soldiers of the World War II, then requested to Battelle Institute to develop ultimate spring material. Then, in 1949, Elgiloy of Co–Cr–Ni–Fe–Mo base alloy was born. Besides Elgiloy, alloys such as Dynavar, Diaflex, Citizen alloy, SPRON100, SPRON510, Nivaflex, Phynox, Vimetal, and NASV604PH were developed. The chemical compositions of these high elastic spring materials and characteristics are shown in Table 2.67 [2, 3, 8, 9]. The Modulus of elasticity of these materials is 206 to 226 GPa, which is equivalent to or more than the quenched and tempered steel, and show good corrosion resistance with low notch sensitivity and nonmagnetism. A heavy working in cold condition and precipitation hardening heat treatment can be used for these alloys in order to obtain high spring characteristic. But in case of strip shaped material, it is necessary to pay attention to the strong anisotropy in bending. Although the precipitation hardening condition can be different for each alloy, it can be chosen at 450 to 600°C for 2 to 5 hours. The degree of cold working and mechanical properties of Elgiloy sheet and wire are shown in Fig. 2.219 and Fig. 2.220 [10], and the rotating bending fatigue test results for SPRON100

**Table 2.67.** Chemical compositions and characteristics of high modulus spring material

Material name	C	Si	Mn	Co	Cr	Ni	W	Mo	Ti	Al	Be	Fe	Linear expansion coefficient ( $\times 10^{-6}$ )	Modulus of elasticity (GPa)	Thermoelastic coefficient ( $\times 10^{-5}/^{\circ}\text{C}$ )	Hardness (HV)	Tensile strength (MPa)	Elastic limit (MPa)	$\sigma^2/E$
Elgiloy	0.15	—	2	40	20	15	—	7	—	—	0.04	Bal.	12.7	211	−39.6	700	2450	1667	1.35
Phynox	0.15	—	2	38	20	17	—	7	—	—	—	Bal.	12.7	206	−40.0	650	2400	1667	1.38
Nivaflex	0.02	0.5	1	45	12	26	4	4	1	—	0.3	Bal.	—	221	—	710	2250	1736	1.40
Dynavar	0.2	—	1.6	42.5	20	13	2.8	2	—	—	0.04	Bal.	—	—	—	—	—	—	—
NAS V 604 PH	0.10–0.15	$\leq 0.5$	$\leq 1.5$	$40 \leq$	$20.5\text{--}22.5$	$15.5\text{--}17.5$	—	$5.8\text{--}6.8$	—	$\leq 0.35$	—	Bal.	—	—	—	—	—	—	—
Vimetal	—	—	0.5	34	14	—	—	6	Cb:2.5, Ta: 0.5		Bal.	—	—	—	—	—	—	—	—
SPRON 100	$\leq 0.03$	0.9	0.8	39	12	16.5	4	3.9	0.6	0.08	—	Bal.	13	216	—	560	1960	—	—
SPRON 510	$\leq 0.04$	$\leq 0.1$	$\leq 0.5$	Bal.	20	32.5	—	10	0.5	—	—	1.6	13	226	—	670	2450	—	—
Diaflex	—	—	1	40	15	20	4	4	1	—	—	Bal.	12.6	226	—	670	2450	1765	1.41
Citizen alloy	0.1	—	1.5	41	21	16	—	6.5	—	—	—	Bal.	—	203	—	720	2350	—	—



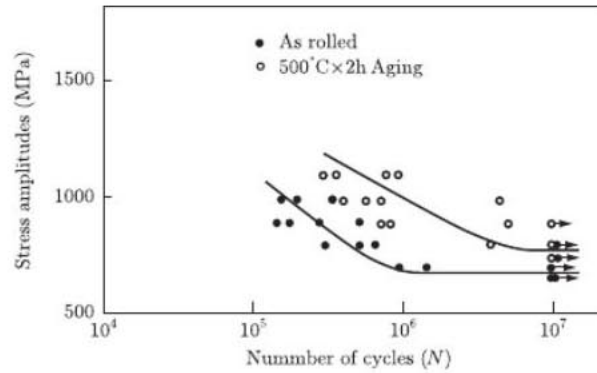
**Fig. 2.219.** Characteristics of Elgiloy sheet as-rolled and as-age-hardened [10]



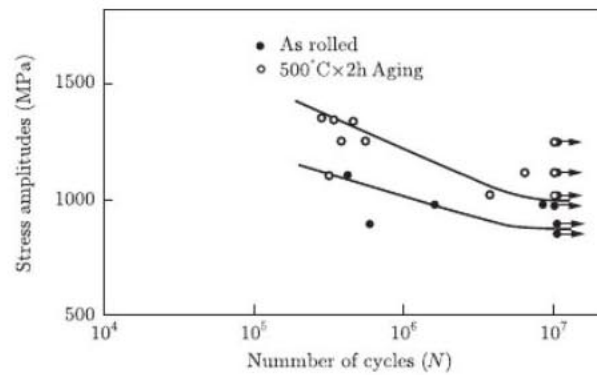
**Fig. 2.220.** Characteristics of Elgiloy wire as-drawn and as-age-hardened [10]

and SPRON510 wire are shown in Fig. 2.221 and Fig. 2.222 [9]. Because of good characteristics as spring material, Elgiloy was used for power springs of clocks and belt for printers in the early time [11]. Additionally, this material has been also used for aerospace, medical, and petrochemical fields. As for examples, the applications are extended to springs for various meters, metal diaphragms of valves, medical tweezers, and brace wire for orthodontics and so on [12,13].





**Fig. 2.221.** S-N Curve of SPRON 100, 60% cold worked material [9]



**Fig. 2.222.** S-N Curve of SPRON 510, 60% cold worked material (wire diameter 0.40 mm) [9]

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## 2.4 Copper Base Alloy Spring Material

### 2.4.1 General Remarks

#### (1) Features

Copper has features of good corrosion resistance, good formability, good electrical and thermal conductivity, and non-magnetism. Copper has been used for ornaments and machine parts by bronze (with Sn), brass (with Zn), nickel silver (with Ni and Zn) since ancient times. However, in modern times after electricity being invented, it has been used as material of wiring and switching parts of electric circuit.

Although copper alloy is more expensive than steel, it is mostly used for the purpose of reducing the resistance or heat generation along the electrical circuit.

On the other hand, since Young's modulus of copper is as low as approximately 60% of steel, it is possible to make a pliable spring that has more displacement compared with steel at the same shape and strength.

#### (2) Various standards

In Japan, copper alloy is standardized in JIS, as shown in Table 2.68. JIS H3130 (sheet and strip of phosphor bronze for spring, nickel silver and copper beryllium) includes the standardized copper alloy for springs. However, other alloys have been used extensively as spring material. The expression of alloy number can be shown in Table 2.69 [1].

In the U.S., five digits number can be registered by applying to CDA (Copper Development Association). Only chemical compositions and physical properties are standardized, without specifying the properties for the grade [2]. ASTM (American Society for Testing and Materials) defines the mechanical properties such as the grade of tensile strength and hardness to CDA Number [3]. DIN (Deutsche Industriale Normen) is relatively popular in Europe. As world standard, ISO has been proposed and has been included in JIS.

**Table 2.68.** JIS standard of Copper alloy

JIS No.	Contents
H3100	Copper and Copper alloy, sheets, plates and strips
H3110	Phosphor bronze, Nickel silver, sheets, plates and strips
H3130	Copper beryllium alloy, Copper-titanium alloy, Phosphor bronze, Copper-nickel-tin alloy and Nickel-silver sheets, plates and strips for springs
H3250	Copper and Copper alloy rods and bars
H3260	Copper and Copper alloy wire
H3270	Phosphor bronze, Nickel silver, Copper beryllium, bars, strips, and wire

**Table 2.69.** Expression of JIS Alloy's Number [1]

Alloy No.	Principal component
C1xxx	Cu-high Cu base alloy
C2xxx	Cu-Zn base alloy
C3xxx	Cu-Zn-Pb base alloy
C4xxx	Cu-Zn-Sn base alloy
C5xxx	Cu-Sn base alloy·Cu-Sn-P base alloy
C6xxx	Cu-Al base alloy·Cu-Si base alloy·Special Cu-Zn base alloy
C7xxx	Cu-Ni base alloy·Cu-Ni-Zn base alloy

### (3) Classifications of Copper alloy for springs

Although there are various classifications for copper alloy [4], standing on spring manufacturer and user side in this book, they are classified as shown in Table 2.70.

Strength of each alloy can be determined by the combination of the following conditions.

- 1) solid solution strengthening with alloy elements
- 2) annealing condition
- 3) cold working ratio by rolling, drawing and so on.
- 4) low temperature stress relief (annealing)
- 5) age hardening

Chemical compositions of typical copper alloys for springs are shown in Table 2.71.

#### (i) Brass (Low cost spring material)

Brass is used for the spring with low cost, because its cost becomes lower as the Zn (zinc) element increases. The strength level is low like 400 MPa to 600 MPa. However, the electrical conductivity is 28%<sup>2</sup>, therefore, Brass is popular in various applications where some amount of current flows, such as plugs, switches, and terminals of lighting equipments, and also battery terminals of toy and connector for the circuit of lighting equipments of automobiles. Usually, spring manufacturers form the rolled and drawn material to springs. However, since Brass has the issue of stress corrosion cracking and large permanent set at high temperature, many improved copper alloys have been proposed by Copper alloy manufacturers.

#### (ii) Phosphor bronze and nickel silver (general-purpose spring material)

Although the strength and price of phosphor bronze increase with adding Sn (tin), it has been widely used as electric conductive spring material such as various switches and relays for industry and home electronic equipments

<sup>2</sup> Electrical conductivity: The capacity of material to conduct electric current expressed as a percentage of that of the International Annealed Copper Standard measured at 20°C (1.7241  $\mu\Omega$ ). The unit is IACS.



**Table 2.70.** Classification of copper alloy for springs

JIS standard	Classification	Strengthening method	Selection criterion	Main applications
Available	① Brass	Work hardening Stress relieving (low temperature annealing)	Cost-conscious	Electrical outlet Terminal for lightings Harness terminal for automotive equipments Contact point Spring for toys
	② Phosphor bronze · Nickel silver	Work hardening Stress relieving (low temperature annealing)	Versatility	Connector, Switch, Relay for electric and electronic parts
	③ Copper beryllium	Work hardening Precipitation hardening	Lighter, more compact High reliability	Connector, Switch for electronic parts Connector, Socket for industry Contact point Spring, Relay for communication equipment
Not available	④ Other copper alloys	Work hardening Low temperature stress relieving (low temperature annealing) Precipitation hardening Fine particle dispersion Spinodal decomposition	Dedicated design Improved characteristic Cost reduction	Lead frame Harness connector for automobile Connector, switch, and relay for electric and electronic parts

**Table 2.71.** Chemical compositions of typical copper alloy for springs [5]

Alloy name	Code	Principal component (%)	Shape
Brass	C2600	Cu–Zn(30)	Sheet, Strip, Bar, Wire
	C2680	Cu–Zn(35)	Sheet, Strip
	C2700	Cu–Zn(35)	Bar, Wire
	C2720	Cu–Zn(37)	Sheet, Strip, Wire
	C2800	Cu–Zn(40)	Bar, Wire
	C2801	Cu–Zn(40)	Sheet, Strip
Phosphor bronze	C5111	Cu–Sn(4)–P(0.1)	Sheet, Strip, Bar, Wire
Nickel silver	C5102	Cu–Sn(5)–P(0.1)	Sheet, Strip, Bar, Wire
	C5191	Cu–Sn(6)–P(0.1)	Sheet, Strip, Bar, Wire
	C5212	Cu–Sn(8)–P(0.1)	Sheet, Strip, Bar, Wire
	C7351	Cu–Ni(18)–Zn(10)	Sheet, Strip, Bar, Wire
	C7451	Cu–Zn(25)–Ni(10)	Sheet, Strip, Wire
	C7521	Cu–Zn(18)–Ni(18)	Sheet, Strip, Bar, Wire
	C7541	Cu–Zn(24)–Ni(14)	Sheet, Strip, Bar, Wire
Phosphor bronze for spring	C1700	Cu–Be(1.7)–Co(0.25)	Sheet, Strip
	C1720	Cu–Be(1.9)–Co(0.25)	Sheet, Strip, Bar, Wire
Nickel silver	C5210	Cu–Sn(8)–P(0.2)	Sheet, Strip
Copper beryllium	C7701	Cu–Zn(26)–Ni(18)	Sheet, Strip, Bar, Wire

because of a good balance of various characteristics. Regarding spring use, the alloy containing 8% tin is standardized in JIS. The material to which low temperature annealing (stress relief) is applied after rolling is supplied to spring manufacturers.

Nickel silver, containing Zn and Ni, shows silver white color and good corrosion resistance. Although its electric conductivity is as low as 5%, the strength is 450MPa to 850MPa. It has been used as the standard material for wire spring of the crossbar switch for a long time. At present, it is used for the parts that need corrosion resistance, such as transistor cases and moving contact of rheostats.

As for the spring uses, the alloy containing 26% Zn and 18% Ni is standardized in JIS. The material can be used after low temperature stress relief like Phosphor Bronze.

### (iii) Copper beryllium (high grade spring material)

Copper beryllium is the conductive spring material having good high temperature characteristics. When the 2% maximum of beryllium is added, it shows the tensile strength of 1,500MPa and electric conductivity of 22% minimum. However, because of high cost, it is applied to small-sized parts and the parts in the system where a longtime reliability is required, which cannot be designed with phosphorus bronze.

In the U.S., copper beryllium has been used for the connector of military use, and has spread to switches, relays, and connectors for industries and consumer applications. In Japan, it has become the indispensable material to

meet with the requirement of lighter and more compact electronic equipments in consumer uses. Generally, the rolled material is formed and heat treated by spring manufacturers. However, the consumption of mill hardened material which does not need any heat-treatment, has been increasing.

**(iv) Other copper alloys (exclusive or developed alloy)**

Although the above-mentioned typical spring material can meet with most applications for electric conductive springs, as for lead frames of semiconductor packages and harness connectors of automobiles, dedicated developments to meet required characteristics have been made aggressively, because of extremely large quantity requirements for both parts. It can be also seen that materials with characteristics between phosphor bronze and copper beryllium have been developed.

There are various kinds of alloys such as Cu-Fe base, Cu-Sn base, Cu-Ni-Si base, Cu-Ni-Sn base, Cu-Ti base and so on. Their tensile strength is 400 to 800 MPa, and electrical conductivity is 30 to 80% IACS. As for Cu-Ti, its tensile strength is 700 to 1,100 MPa, and electrical conductivity is 10 to 16% IACS. These materials can be formed by spring manufacturers after low temperature stress relief of cold rolled material or after precipitation hardening treatment. There is a case where precipitation hardening treatment is carried out after spring forming for Cu-Ti alloy strip.

**(4) Selection method for copper alloy spring material**

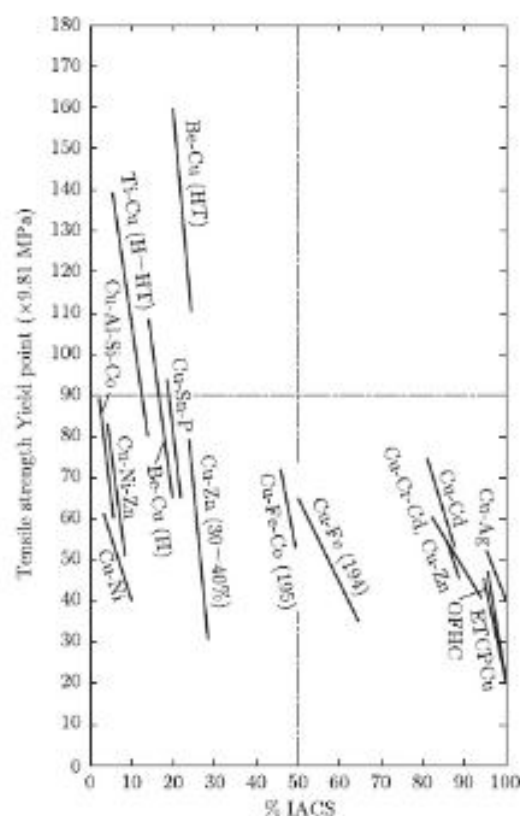
**(i) Tensile strength and electrical conductivity**

Generally, tensile strength and electrical conductivity are incompatible characteristics. When the tensile strength is increased with adding elements to Cu, the electrical conductivity becomes low. If the tensile strength is increased with heavy cold forming like rolling, electrical conductivity slightly falls. In case of strengthening with the precipitation hardening, the tensile strength and electrical conductivity rises simultaneously. If tensile strength and price is the same, the degree of freedom for designing becomes high for alloy which has higher electrical conductivity. Therefore, developments of new material have been continued by material manufacturers. The relation between tensile strength and electrical conductivity of typical copper alloy is shown in Fig. 2.223 [6].

**(ii) Method of choosing temper designation (tensile strength and forming ability)**

The temper designations are specified on the grade of strength or hardness, which can be determined by the combination of plastic working degree and heat treatment. This is summarized in JIS, shown in Table 2.72 [7]. The temper designation, H can be obtained by cold working with approximately 37% reduction in area for sheet, strip and approximately 60% for wire. In the U.S., A is sometimes used. A is equivalent to O (zero) in JIS which is the softest condition after annealing or solution heat treatment. M means that material is shipped after mill hardening at plant. T shows the characteristic after heat treatment at spring manufacturers after shipping.





**Fig. 2.223.** Tensile strength and electric conductivity of various copper alloys [6]

**Table 2.72.** Strength grade specified by JIS

Strength grade	Definition
F	As fabricated. No description of mechanical properties. F: Fabrication
O	Fully recrystallized or annealed. Tensile strength (TS) is the lowest.
OL	Annealed or lightly worked. TS is the same as O.
1/8H	Work hardened to the TS between O and 1/4H.
1/4H	Work hardened to the TS between 1/8H and 1/2H.
1/2H	Work hardened to the TS between 1/4H and 3/4H.
3/4H	Work hardened to the TS between 1/2H and H.
H	Work hardened to the TS between 3/4H and EH.
EH	Work hardened to the TS between H and SH. EH: Extra hard
SH	Heat-treated to the highest TS. SH: Spring hard
SR	Stress relieved. SR: Stress relief

The materials classified by high temper designation like EH and SH have high tensile strength. However, the forming ability of bending and drawing of sheet and strip is poor due to low elongation. Therefore, it is necessary to decide whether the first priority is taken to finished spring characteristics or spring formability. When both characteristics are needed, the practice of

using the one class higher alloy can be recommended. In addition, anisotropy of high temper designation material is large because of heavy plastic working. Especially when bending along the rolling direction, special attention for crack prevention is required. The bending test method is specified in JIS Z 2248 such as the right angle bend, 60 degree W bend, and 180 degree bend.

**(iii) Availability and international commonality**

The copper alloy with the standard thickness size specified in JIS can be comparatively easily obtained. While electronic parts manufacturers have transferred their productions to overseas, the need of local procurements of material has been increased.

A crosscheck between CDA, ASTM and ISO can be required.

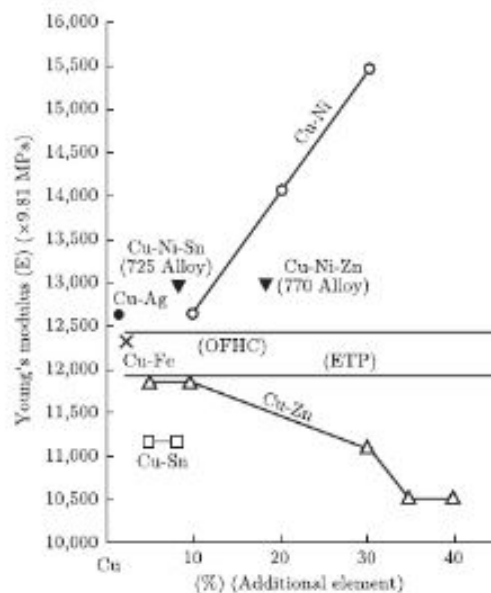
**(5) Remarks for spring design**

**(i) Young's modulus**

Young's modulus is the index which influences directly on the spring load. The value obtained by tensile tests, have been usually used. Young's modulus of copper alloy varies a little by additional element shown in Fig. 2.224 [8]. There is a tendency that calculation results correspond to experimental results when a deflection factor is used for a spring. The deflection factor can be obtained with the displacement at the loading point, by using the spring deflection limit tester specified in the 6.4 section of JIS H3130.

**(ii) 0.2% proof stress and spring deflection limit value**

0.2% proof stress, the stress when the 0.2% permanent strain occurs in the tensile test, is generally used as an index of the spring design. On the other hand, the spring deflection limit (Kb value), which is a surface bending stress



**Fig. 2.224.** Additional element and change of Young's modulus for Copper [8]

when a constant permanent deformation occurs at the loading point in deflecting and unloading a plate, is standardized in JIS H3130 (Japan) and DIN 1777 (Germany). The measuring method of  $K_b$  value, which falls into repeatedly deflecting method and moment method, is designated in JIS H3130. The moment method can be suitable for measuring material with high strength and large deflection material such as copper beryllium. Figure 2.225 [9] shows how to apply the load in the moment method.

It depends upon the applications that either 0.2% proof stress or  $K_b$  value should be used. For example, it should be safe to use 0.2% proof stress for the parts with complicated bending like connectors or when stress can be applied on the sheared surface with stamping. In the U.S., the research and development of connectors has been popular, so in ASTM, only 2% proof stress is standardized. In case of no bending and no plating process like some switches or relays, it becomes possible to draw out the capability of material by using  $K_b$  value. Especially, this tendency is more prominent in heavily worked material with high quality classification. Since the  $K_b$  value is a bending characteristic, the conditions around surface layer become important. The  $K_b$  value of material with heavy plating sometimes shows an extremely low value. JIS designates the applicable thickness range for  $K_b$  value to be between 0.2 mm and 1.6 mm. When stress relief (low temperature annealing) is applied to work-hardened material, the  $K_b$  value can be improved without decreasing elongation, to be able to produce springs with more complicate shape and high strength, refer to Fig. 2.226 [10]. The actual movement of complicatedly shaped springs has become possible to be analyzed by FEM recently. Therefore, it may be difficult to design with the point datum like 0.2% proof stress and  $K_b$  value. In this case, stress-strain curve and Poisson's ratio can be required.

### (iii) Fatigue characteristics

The thickness range of electrical conductive spring material is from 0.1 mm to 0.4 mm in general. The testing method of this kind of thin sheet has not

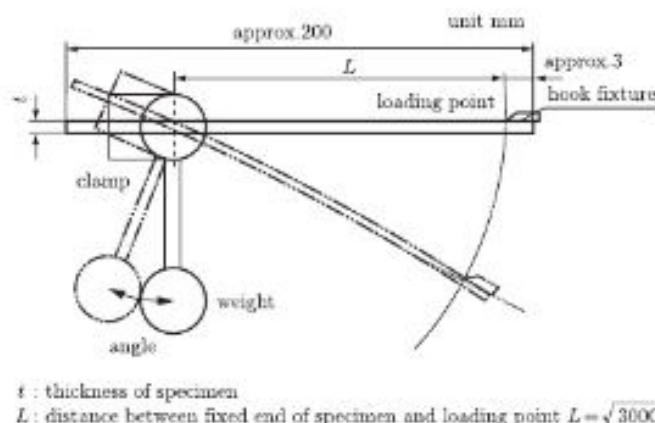


Fig. 2.225. Installation of specimen and loading method [9]



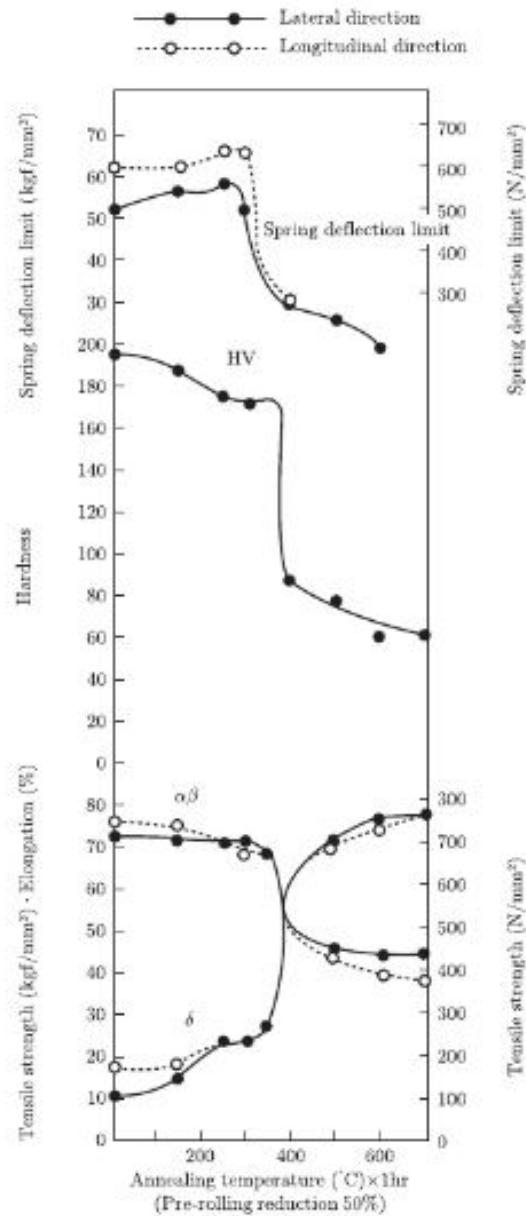
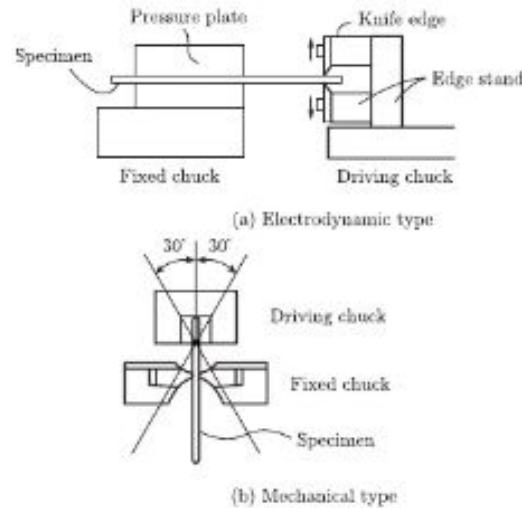


Fig. 2.226. Spring deflection limit of phosphor bronze (C5212) [10]

been standardized. However, Nishihata et al. have pointed out the difference of fatigue characteristics between testing methods and have also proposed a bending type testing method with pulley [12], which was standardized by JSMA. Two kinds of method among those can be shown in Fig. 2.227 [11].

#### (iv) Stress relaxation

The stress relaxation is such a phenomenon that the spring load decreases with time, even if the displacement is kept constant like a connector. Before carrying out evaluation tests of the product, design engineers can predict



**Fig. 2.227.** Fatigue testing methods [11]

the results with this characteristic while sorting the material. The testing method is standardized in ASTM E328 and EMAS 3003. There are two kinds of testing method, one is measuring load directly, and the other is to measure permanent deflection to be converted to stress. The method of measuring permanent deflection is more popular and practical because of its simplicity. In the latter method, there are still a few methods, having the surface stress constant (same curvature), or having the stress varied (cantilever). One of each example in ASTM and EMAS can be shown respectively in Fig. 2.228 [13,14].

There is a report which describes that even if the initial stress in the surface varies from the 30% to 80% of proof stress, the stress relaxation ratio shows the same value [15]. However, the 75% or 80% of proof stress can be normally used as the initial stress. This relation is shown in Fig. 2.229 [15]. Besides this, there are some research works concerning with the stress relaxation characteristic at the plastic deformation region and the bent portion [16].

#### (6) Remarks for applications

The length of electric conductive springs used in recent electronic equipments is sometimes less than 1mm. This kind of minute spring is easy to be affected by forming, to show different spring load from the calculated load. For example, after slightly bending the beam, then bending to the opposite direction, there is a case that the load is lower than the calculated value. This can be due to Bauschinger effect. This issue can be resolved with eliminating forming strains by heating or bending to extra amount, to obtain the specified dimension by bending back from the opposite side [17].

When bending stress is loaded in the sheared surface of blanking materials, and a different process between prototype and serial production is applied, there can be a case that the results become different. When choosing wire cutting or etching in prototype productions and stamping in serial productions,

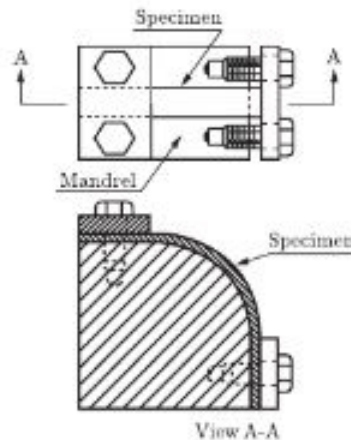


Fig. 2.228. (a) Stress relaxation testing method [13,14]

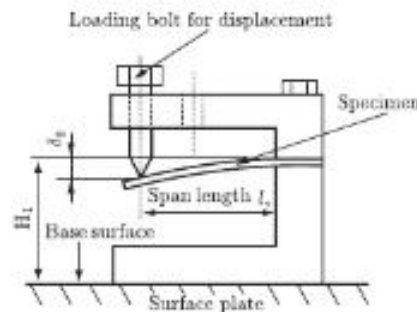


Fig. 2.228. (b) Cantilever method

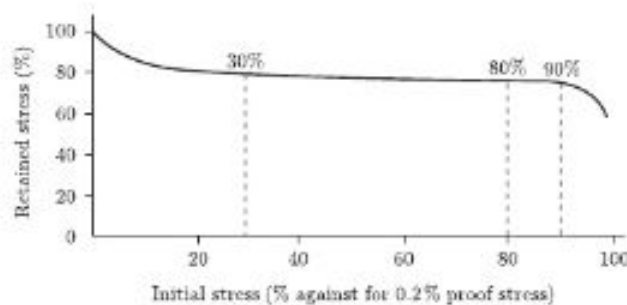


Fig. 2.229. Influence of initial stress for stress relaxation [15]

a special attention is required. In case of plating and soldering, it is necessary to make sure that no peeling from base material occurs due to the reaction with base material after long time passing.

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## 2.4.2 Brass

### (1) Features

Brass is the alloy of Cu and Zn, and has unique yellow gloss. Being less expensive among copper alloys, it is widely used for precision instruments and parts for ships which cannot be coped with steel due to machinability and corrosion resistance to sea water. Brass has been used for radiators of automobiles, daily necessities such as buttons and name plates, and interior decoration goods, due to its good formability.

### (2) Applications

Brass springs are used for lighting connectors and terminals of automobiles, lighting equipments and toys. In addition, although it is not a spring, brass wire with square or similar section is used for header pins of the base-plate of electronic parts.

### (3) Chemical compositions

JIS standard of brass is designated in JIS H 3100 (Copper and copper alloy sheets, plates and strips), JIS H 3250 (Copper and copper alloy rods and bars), and JIS H 3260 (Copper and copper alloy wires). The chemical compositions are shown in Table 2.73 [1]. Among these materials, C2680 and

angle or more than two complicated bent portions, it is recommendable to keep the stress within one-third of the spring deflection limit.

**(ii) Change in color**

Phosphor bronze does not easily change in color at normal ambient temperature and humidity. However, it should be cautious that touching with bare hands makes color change. In addition, when packed under insufficient drying after degreasing and washing with organic solvent, its color can be changed to bluish purple caused by the vaporised gas coming out of little solvent remained on the surface. Therefore, after degreasing and washing with organic solvent, it is necessary to pack the products after sufficient drying with ventilation.

**(iii) Design of bending radius**

Since there is a difference of workability between the bending in rolling direction (good way) and that in transverse direction (bad way), it is necessary to design a bending radius larger than the limit of respective bending ability.

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### 2.4.4 Copper Beryllium

Copper beryllium is precipitation hardening type alloy adding 1.6% to 2.0% beryllium into Cu. While maintaining electric characteristic and corrosion resistance which Cu possesses, it shows mechanical properties, fatigue characteristics, and wear resistance comparable to steel.

Developments of copper beryllium started in the early stage of the 20th century. It was known that copper beryllium had been adopted for the German fighter plane during World War I and the full-scale practical use had been done in the U.S.. Many research works had been carried out by major computer manufacturers and connector manufacturers, in regard to the applications of connector sockets which is attached to the motherboard of super

computers especially for military demands [1]. After that, copper beryllium has been used for the essential parts of communication equipments, industrial equipments, aircrafts, automobiles, personal computers and cellular phones. In Japan, the adoption of copper beryllium to the field of automotive electrical components and electronic parts started from the latter half of 1970's. In consumer applications, size of all parts was going to become smaller giving word of "Lighter and more compact". Since in many cases it has been difficult to design springs with phosphor bronze for springs because of insufficient strength, copper beryllium has been applied to switches and connectors for light-weight electronic equipments.

As for the conventional copper beryllium, although the price was relatively high due to many kinds of small quantity production, some cost down has been achieved by improving productivity with reducing kinds of material, and developing low copper beryllium based alloy, to become more familiar alloy.

#### (1) Features

Copper beryllium has the following features.

- 1) Tensile strength of 1500 MPa at the highest.
- 2) 20% to 60% electrical conductivity of Cu.
- 3) Good fatigue life
- 4) Good high temperature properties
- 5) Good forming ability for bending and deep drawing
- 6) Good corrosion resistance

These properties can be obtained with the solution heat treatment, cold working, and age hardening. The material without the cold working shows good forming performance and no anisotropy.

#### (2) Applications

- (a) Electronic parts  
Connectors, IC sockets, switches, relays, micro switches, mobile pieces of battery terminal
- (b) Automobiles  
Switches, relays, sensors, motor brushes, movable pieces of connector
- (c) Others  
Diaphragm, bellows, scale
- (d) Not for spring use  
Electrode, submarine cable repeater, bearing, metallic mold

#### (3) Chemical compositions

The chemical composition of typical copper beryllium is shown in Table 2.77 [2].

#### (4) Phase diagrams

The phase diagram of Cu-Be alloy is shown in Fig. 2.240.



**Table 2.77.** Chemical compositions · Features · Applications of copper beryllium [2]

Alloy No.	Shape	Chemical compositions %				Features	Applications
		Be	Ni+Co	Ni+Co+Fe	Cu+Be+Ni+Co+Fe		
C1700	Sheet Strip	1.60–1.79	0.20 min	0.6 max.	99.5 min	Corrosion resistance Ductility	High performance spring Connector, Socket Micro
C 1720	Sheet, Strip Bar, Wire	1.80–2.00	0.20 min	0.6 max.	99.5 min	Durability Conductivity	switch Relay

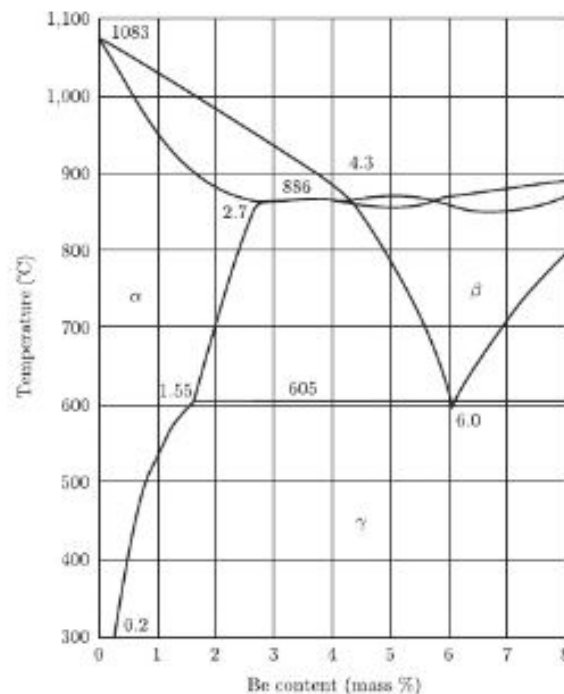
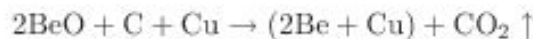


Fig. 2.240. Equilibrium phase diagram of copper beryllium

Copper beryllium in commercial use is 1) cooled rapidly to room temperature to make the supersaturated  $\alpha$  solid solution (solution heat treatment). In this state, it becomes possible to form the alloy to bellows or diaphragms as being soft and rich in malleability and ductility. 2) Then, after precipitation hardening at around  $315^{\circ}\text{C}$ , the strength improves considerably with the precipitation of supersaturated beryllium. The 0.2%Co can be added to the copper beryllium in practical use, in order to refine crystal grain and give aging stability.

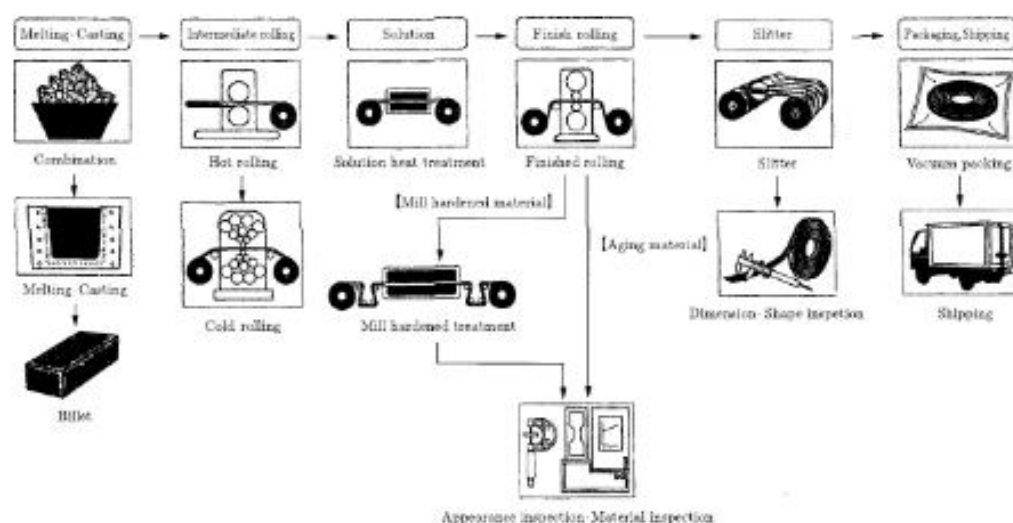
#### (5) Manufacturing processes

The base alloy containing approximately 4% beryllium is used as the raw material of copper beryllium. The base alloy is made by deoxidizing beryllium oxide with carbon in arc furnace around  $2,000^{\circ}\text{C}$ , and to melt the deoxidized beryllium into copper, as shown in the following equation.



Manufacturing processes of copper beryllium sheet and strip are shown in Fig. 2.241. The melting of copper beryllium is performed to add the same amount of copper and the base alloy, and some elements together to make a billet through the vertical type semi-continuous casting process.

In the next process, the billet hot worked, after removing surface oxide layer generated at the hot-working process mechanically, is cold-worked repeatedly to pre-determined thickness coils. Annealing or solution heat treat-



**Fig. 2.241.** Manufacturing process of copper beryllium sheet and strip

ment can be applied to the cold work-hardened material to get sufficient formability for making the next cold working process. This is the important process where annealing temperature and cooling conditions for controlling the grain size during the recrystallization, can give great influences on the characteristic of final products. After annealing or solution treatment, the surface oxide layer can be removed by sulfuric acid solution, etc. Then, the cold rolling process by multi-stage rolling mill is carried out to the specified thickness for users. The precipitation hardening treatment can be carried out by the spring manufacturer after forming springs. As for mill hardened material, since the appropriate precipitation hardening is processed by the manufacturer, the spring manufacturer carries out stress relief (low temperature annealing) after forming springs.

In case of wire, although cold drawing is conducted instead of rolling, the process is basically the same as that for sheet and strip.

## (6) Physical properties

Physical properties of copper beryllium are shown in Table 2.78.

## (7) Mechanical properties

### (i) Tensile characteristics

Figure 2.242 [3] shows tensile strength, 0.2% proof stress, 0.01% proportional limit, and elongation after aging, for the strength grade of C1720. As the working ratio become high, the tensile strength increases and the elongation decreases. The anisotropy also becomes large.

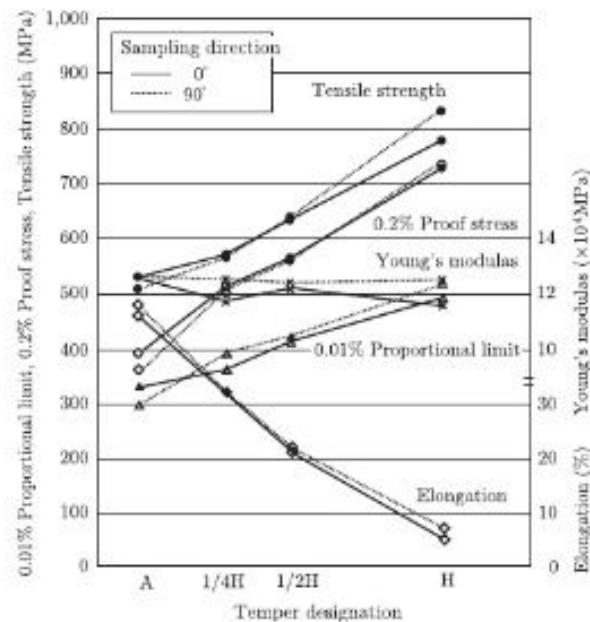
### (ii) Bendability

The bendability of typical copper beryllium is shown in Table 2.79 [4]. The GW (Good way) means the specimen with the rolling direction (0 degree direction) and BW (Bad way) does that at the right angle from the rolling direction.



**Table 2.78.** Physical characteristics of Beryllium copper

Items		C1700-C1720
Melting start temperature	°C	865
Solidification start temperature	°C	980
Density	g/cm <sup>3</sup> 20°C	8.26
Specific heat	J/(kg/K)	419
Coefficient of thermal expansion	/°C 20–300°C	$17.8 \times 10^{-6}$
Thermal conductivity	W/m 293 K	130
Electrical conductivity	%IACS	25
Modulus of elasticity	GPa	127
Modulus of rigidity	GPa	49
Poisson's ratio		0.3
Magnetic permeability		1.00004

**Fig. 2.242.** Tensile characteristic of copper beryllium (C1720) [3]**(iii) Spring deflection limit**

The spring deflection limit of copper beryllium can be improved greatly with the age hardening processing. The relation between the spring deflection limit and anisotropy, and cold working ratio is shown in Fig. 2.243 [5].

**(iv) Fatigue characteristics**

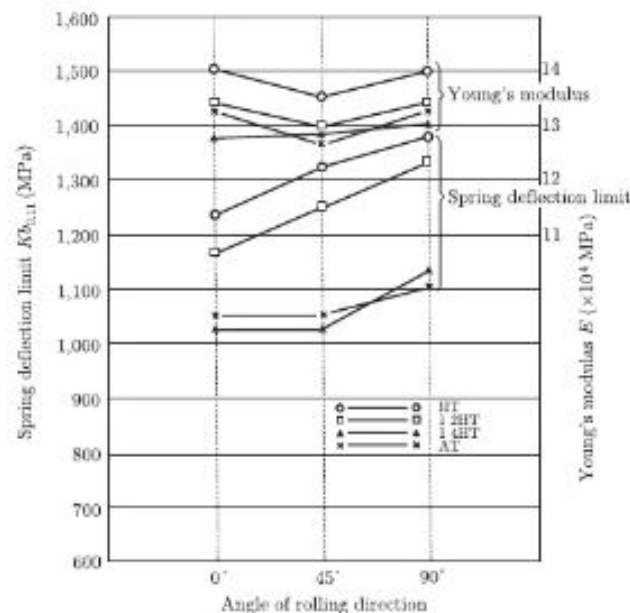
The fatigue characteristic of typical copper beryllium is shown in Fig. 2.244 [6].

In order to meet with the actual use, the fatigue tests were conducted for not only the completely reversed stresses but also the pulsating stresses, and also conducted beyond yield stress. The fatigue strength diagram where both

**Table 2.79.** Bendability of copper beryllium ( $R/t$ ) [4]

Alloy No.	Strength grade	$R/t$ of bending direction	
		Rolling direction	Perpendicular to rolling direction
C 1720	A	0	0
	1/4H	1.0	2.0
	1/2 H	2.0	3.0
	H	2.0	6.0
	AM	0.8	2.0
	1/4HM	1.0	3.0
	1/2HM	2.0	4.0
	HM	3.0	6.0
	XHM	4.0	—
	XHMS	6.0	—

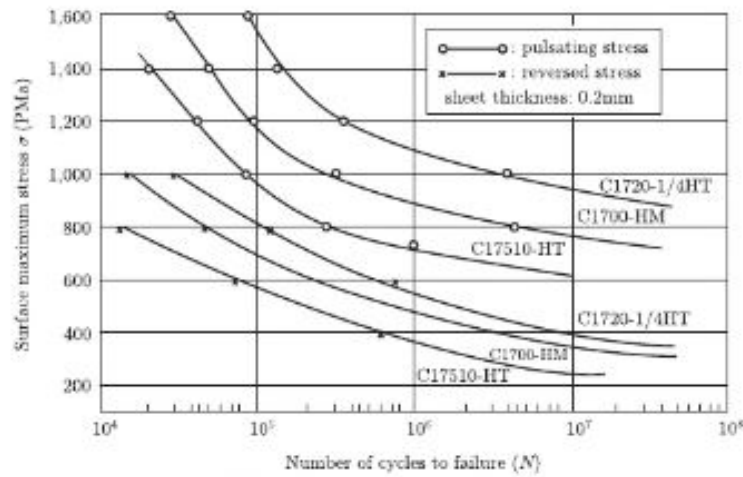
$R$ : Bending radius,  $t$ : Thickness, A: Equivalent with O (no hardening)  
 HM: mill harden, Hardness Level: HM < XHM < XHMS

**Fig. 2.243.** Spring deflection limit and anisotropy of copper beryllium (C1720) [5]

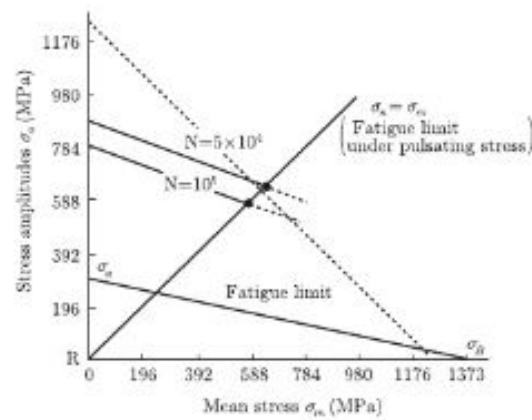
mean stresses and stress amplitudes vary, is shown in Fig. 2.245 [7]. The tests were conducted with an electro-dynamic type fatigue testing machine.

#### (v) Stress relaxation

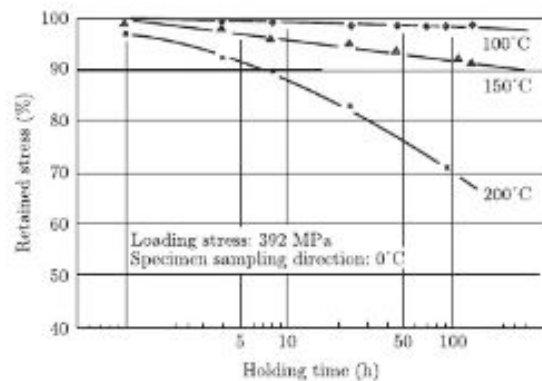
The stress relaxation characteristics of typical copper beryllium are shown in Fig. 2.246 [8]. The tests were carried out by the cantilever method standardized in EMAS3003.



**Fig. 2.244.** Fatigue characteristics under pulsating and reversed stress test for Beryllium copper alloys [6]

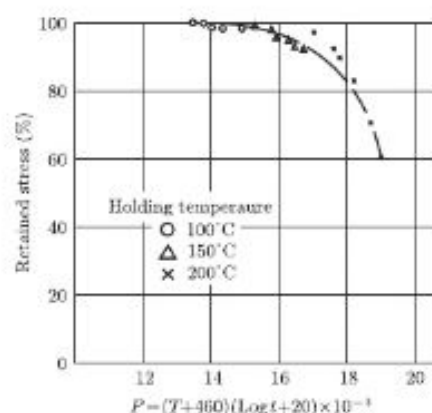


**Fig. 2.245.** Fatigue strength diagram of copper beryllium (C1720P-1/2HT) [7]



**Fig. 2.246.** Stress relaxation characteristics of copper beryllium (C1720P-1/4HT) [8]





**Fig. 2.247.** Larson Miller parameter of copper beryllium (C1720P-1/4HT) [9]

It is possible to predict long-term reliability from short-term test results at high temperature. For examples, when predicting a spring load after 10 years usage under ambient temperature of 120°C, the Larson Miller's Parameter,  $P$  is calculated as 14.47 by substituting  $T = 120^\circ\text{C}$  and  $t = 87600$  hours (10 years) to the Larson Miller's Formula, see Fig. 2.247 [9]. It can be read from the Fig. 2.247 that there would be no load loss under these conditions. When 200°C and 10 years, the  $P$  is calculated as 16.46. It can be also read from the Fig. 2.247 that there would be about 10% load loss under these conditions.

$$P = (T + 460)(\log t + 20)10^{-3}$$

$P$ : Larson Miller's parameter

$T$ : Temperature, °C

$t$ : Time (Hr)

#### (8) Remarks in use

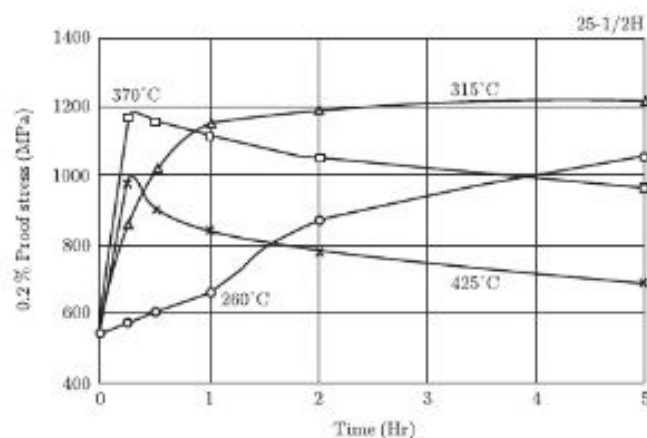
The potential ability of copper beryllium can be obtained with a suitable precipitation hardening processing. When applying this heat-treatment, it is essential to control the appropriate temperature and atmosphere.

##### (i) Temperature condition of heat treatment

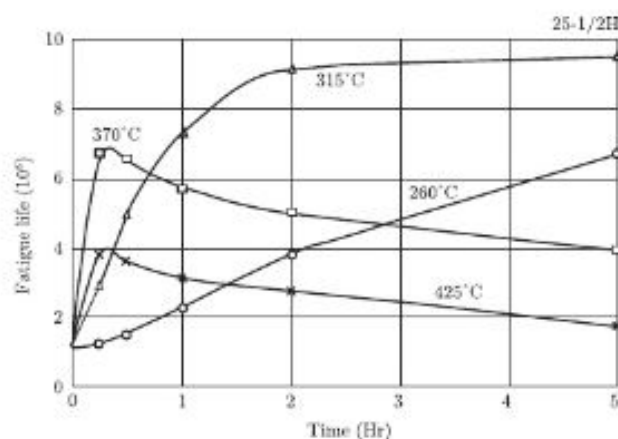
The heat-treatment of copper beryllium is normally carried out at 315°C for 2 to 3 hours. It can be recommendable that the temperature should be controlled within  $\pm 5^\circ\text{C}$ . Applying gaseous atmosphere such as nitrogen rather than vacuum, and inside forced agitation, the product with less hardness scatter can be obtained. The aging curves of this alloy in term of 0.2% proof stress and fatigue life are shown in Fig. 2.248 [10] and Fig. 2.249 [11], respectively. The temperatures in these figures indicate aging temperature.

##### (ii) Surface oxide layer

When carrying out age hardening of copper beryllium, it is necessary to avoid the occurrence of oxide film by adding a little hydrogen into nitrogen gas as required. Several hundred angstrom of oxide film is normally formed



**Fig. 2.248.** Aging curve of 0.2% proof stress measured at room temperature (C1720-1/2H) [10]



**Fig. 2.249.** Aging curve of fatigue life measured at room temperature (C1720-1/2H) [11]

on the heat-treated surface in atmosphere [12]. When plating, it is possible to remove the oxide layer only with approximately 20% warm sulfuric acid.

### (iii) Safety and health concerns

As for beryllium, no cases of oral obstacle have been reported different from other harmful substances. However, when continuing to inhale the dust over a certain level, in such cases as handling intermediate products or melting a large quantity of alloy at the production mill, there would be some possibility of causing lungs functional disorder. It is required to install powerful dust collectors when re-melting, welding or dry grinding copper beryllium alloy. In other cases, it can be handled in the same manner as normal copper alloy.

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### 2.4.5 Other Copper Alloy

The copper alloys not yet standardized in JIS and not introduced in this book are discussed here. There are approximately 133 types of alloys in this classification [1].

The strength level of these alloys are at large between brass and phosphor bronze and electrical conductivity is mostly higher than brass and phosphor bronze. Copper titanium has become popular to cover the properties between phosphor copper and copper beryllium. Concerning with the strengthening methods, work hardening, dispersion strengthening, precipitation hardening and spinodal decomposition have been adopted.

#### (1) Applications

The products at a special field with a large amount of productions are lead frames and harness connectors for automobiles. Most alloys in this category have been applied to either of these two areas. As far as the strength level is permitted, these alloys can be applicable for other parts such as connectors, switches and relays.

#### (2) Chemical compositions

The chemical compositions of the developed copper based alloys registered by CDA are shown in Table 2.80 [2].

#### (3) Characteristics

As for this alloy category, the optimum alloy designs and evaluations have been carried out for the respective applications. Although some of those items are introduced, all the characteristics of each alloy can not be described. For more details, see the catalogs of manufacturers or refer to copper alloy data book [3].

##### (i) Lead frame material

In order to meet the bending test requirement of lead frames, it is not possible to make the material strength excessively high. As a result, its strength level is mostly lower than that of brass and phosphorus bronze. Normally, lead