(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 556 589 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
21.05.2025 Bulletin 2025/21

(21) Application number: **23839656.8**

(22) Date of filing: **12.07.2023**

(51) International Patent Classification (IPC):
C22C 38/00 *(2006.01)* ***C21D 8/00*** *(2006.01)*
C21D 9/00 *(2006.01)* ***C22C 30/00*** *(2006.01)*
C22C 38/60 *(2006.01)* ***C22F 1/00*** *(2006.01)*
C22F 1/16 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C21D 8/00; C21D 9/00; C22C 30/00; C22C 38/00; C22C 38/60; C22F 1/00; C22F 1/16

(86) International application number:
PCT/JP2023/025751

(87) International publication number:
WO 2024/014484 (18.01.2024 Gazette 2024/03)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **12.07.2022 JP 2022111934**

(71) Applicant: **Shinhokoku Material Corp.**
Saitama 350-1124 (JP)

(72) Inventors:
- **MATSUMURA, Shingo**
Kawagoe-shi, Saitama 350-1124 (JP)
- **OHNO, Haruyasu**
Kawagoe-shi, Saitama 350-1124 (JP)
- **ONA, Kotaro**
Kawagoe-shi, Saitama 350-1124 (JP)

(74) Representative: **Vossius & Partner Patentanwälte Rechtsanwälte mbB**
Siebertstrasse 3
81675 München (DE)

(54) LOW THERMAL EXPANSION ALLOY

(57) The object of the present invention is to obtain a low thermal expansion alloy with excellent machinability. The low thermal expansion alloy of the present invention comprises, by mass %, C:0.050% or less, Si:0.30 to 1.00%, Mn:0.50 to 2.00%, S:0.030 to 0.150%, Ni:27.00 to 38.00%, Co:0 to 12.00%, sol.Al:0.003 to 0.100%, O:0.010% or less, and the balance of Fe and impurities, wherein [Mn], [S], [Ni], [Co], and [Si], which represent the content of Mn, S, Ni, Co, and Si, by mass%, respectively, satisfy [Mn]/[S]≥10.0, 32.0%≤[Ni]+0.4[Co]≤38.0%, and [Si]+[Mn]≤2.50%; and the average coefficient of thermal expansion at 25 to 100°C of the low thermal expansion alloy is 3.0×10^{-6}/°C or less.

EP 4 556 589 A1

Description

FIELD

[0001] The present invention relates to a low thermal expansion alloy, and more particularly, to a low thermal expansion alloy having excellent machinability.

BACKGROUND

[0002] Invar alloys having high thermal stability are widely used as component materials for electronics, semiconductor-related equipment, laser working machines, and ultra-precision working equipment. However, conventional Invar alloy has low machinability, and therefore it is limited to a very narrow field of practical use.

[0003] Patent Literature 1 discloses a low thermal expansion alloy having excellent machinability in which S is used as a machinable element. The alloy comprises, by weight%, C:0.05% or less, Si:0.3%, Mn:0.45 to 1.2%, P:0.5% or less, S:0.015 to 0.035%, Ni:33.0 to 34.5%, Co:3.0 to 4.0%, and the balance of substantially Fe, [Mn]/[S] is 15 or more when [Mn] represents the weight% of Mn and [S] represents the weight% of S, and the alloy has an average coefficient of thermal expansion of 1.0×10^{-6}/°C or less.

[0004] Patent Literature 2 discloses a low thermal expansion cast iron in which C is used as a machinable element, and a graphite structure is comprised in the austenite base iron. The alloy comprises, by weight%, the solid solution C: 0.09% or more and 0.43% or less, Si: less than 1.0%, Ni: 29% or more and 34% or less, Co: 4% or more and 8% or less, and the balance of Fe, and the coefficient of thermal expansion in the temperature range of 0 to 200°C is 4×10^{-6}/°C or less.

[0005] Patent Literature 3 discloses a cast iron comprising C: 0.8 to 3.0%, Si: 1.0 to 3.0%, Mn: 0.4 to 2.0%, Ni: 30.0 to 33.0%, and Co: 4.0 to 6.0%, in which C is used as a machinable element.

[CITATIONS LIST]

[PATENT LITERATURE]

[0006]

[PLT 1] JP 2001-262277 A
[PLT 2] JP H6-172919 A
[PLT 3] JP S 58-210149 A

SUMMARY

[TECHNICAL PROBLEM]

[0007] An alloy used for a component of a precision equipment is required to have excellent machinability from the viewpoint of ease of working. There is room for further improvement in the machinability of alloys having a low coefficient of thermal expansion. In view of the above circumstances, the object of the present invention is to provide a low thermal expansion alloy excellent in machinability.

[SOLUTION TO PROBLEM]

[0008] The inventors have intensively studied a method of obtaining a low thermal expansion alloy with further improved machinability. As a result, it was found that a low thermal expansion alloy having a small coefficient of thermal expansion and excellent machinability can be obtained by appropriately controlling the contents of Si, Mn, S, Ni, and Co.

[0009] The present invention has been made based on the above knowledge, and the gist thereof is as follows.

[0010] A low thermal expansion alloy comprising, by mass%, C: 0.050% or less, Si: 0.30 to 1.00%, Mn: 0.50 to 2.00%, S : 0.030 to 0.150%, Ni: 27.00 to 38.00%, Co: 0 to 12.00%, Sol.Al: 0.003 to 0.100%, O: 0.010% or less, and balance of Fe and impurities, wherein [Mn], [S], [Ni], [Co], and [Si], which represent the content of Mn, S, Ni, Co, and Si, by mass%, respectively, satisfy $[Mn]/[S]\geq10.0$, $32.0\%\leq[Ni]+0.4[Co]\leq38.0\%$, and $[Si]+[Mn]\leq2.50\%$; and the average coefficient of thermal expansion at 25 to 100° of the low thermal expansion alloy is 3.0×10^{-6}/°C or less.

[ADVANTAGEOUS EFFECTS OF INVENTION]

[0011] According to the present invention, it is possible to obtain a low thermal expansion alloy excellent in machinability.

Therefore, for example, it is possible to easily work the component parts of the precision equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

[Fig. 1] Fig. 1 is a diagram for explaining an evaluation of a tool wear amount in examples.
[Fig. 2] Fig. 2 is a diagram for explaining an evaluation of crushability of chips in examples.

DESCRIPTION OF EMBODIMENTS

[0013] The present invention is described in detail below. Hereinafter, "%" regarding the chemical composition means "mass%" unless otherwise specified. First, the chemical composition of the low thermal expansion alloy of the present invention is described.

(C: 0.050% or less)

[0014] C is an element which crystallizes as graphite in castings and improves machinability. However, C is also an element which increases the coefficient of thermal expansion. In the low thermal expansion alloy of the present invention, in order to suppress an increase of the coefficient of thermal expansion, the C content is 0.050% or less. It is preferably 0.040% or less, more preferably 0.030% or less, and still more preferably 0.020% or less.

(Si:0.30 to 1.00%)

[0015] Si is an element which improves machinability by combining with S. Since the coefficient of thermal expansion increases as the content of Si increases, Si content is set to 0.30 to 1.00%, considering the balance between machinability and coefficient of thermal expansion. The lower limit of Si content may be 0.40% or 0.50%. The upper limit of Si content may be 0.90% or 0.80%.

(Mn: 0.50 to 2.00%)

[0016] Mn is an element which forms a compound with S and improves machinability. Mn is also an element for suppressing cracking during casting and forging. Since the coefficient of thermal expansion increases as the content of Mn increases, Mn content is set to 0.50 to 2.00%, considering the balance between machinability and coefficient of thermal expansion. The lower limit of Mn content may be 0.60%, 0.70%, or 0.80%. The upper limit of Mn content may be 1.90%, 1.80%, or 1.70%.

(S: 0.030 to 0.150%)

[0017] S is an element which forms a compound with Mn and improves machinability. When the amount of S is increased, the alloy is embrittled by segregation of S at the grain boundaries, and cracks tend to occur during casting and forging. Therefore, the S content is 0.030 set to 0.150%, considering the balance between machinability and embrittlement of the alloy. The lower limit of the S content may be 0.040%, 0.050%, or 0.060%. The upper limit of the S content may be 0.140%, 0.130%, or 0.120%.

(Ni: 27.00 to 38.00%)

[0018] Ni is an element which decreases the coefficient of thermal expansion. The low thermal expansion alloys of the present invention have an average coefficient of thermal expansion of 3.0×10^{-6}/°C or less at the range of 25 to 100°C. The coefficient of thermal expansion can be obtained mainly by setting the content of Ni and Co to an appropriate range. Even if the Ni content is too large or too small, the coefficient of thermal expansion is not sufficiently low. In order to sufficiently decrease the coefficient of thermal expansion, Ni content is set to 27.00 to 38.00%. The lower limit of the Ni content may be 28.00%, 29.00%, or 30.00%. The upper limit of the Ni content may be 37.00%, 36.00%, or 35.00%.

(Co:0 to 12.00%)

[0019] Co contributes to a decrease in the coefficient of thermal expansion by being combined with Ni. The Co content may be 0. In order to obtain the desired coefficient of thermal expansion, Co is set to 0 to 12.00%. The upper limit of Co content may be 11.00%, 10.00%, or 8.00%.

(sol.Al:0.003 to 0.100%)

[0020] Sol.Al is an element which improves machinability. Since sol.Al is also an element which increases the coefficient of thermal expansion, considering the balance between machinability and the coefficient of thermal expansion, sol.Al is set to 0.003 to 0.100%. Sol.Al means an acid-soluble Al which is not a part of an oxide such as Al_2O_3 and can be soluble in acid. The content of sol.Al is determined as an Al measured by subtracting the undissolved residue on the filter paper generated in the analytical process of Al. The lower limit of sol.Al content may be 0.010%, 0.020%, or 0.030%. The upper limit of sol.Al content may be 0.090%, 0.080%, or 0.070%.

(O:0.010% or less)

[0021] O is an element contained as an impurity, and is not an essential element. The lower limit of the O content is 0. O combines with Al to form alumina. Alumina is hard and thus promotes tool wear. In addition, the formation of alumina reduces sol.Al content and lowers the machinability. Therefore, the O content is set to 0.010% or less. The O content is preferably 0.008% or less, more preferably 0.007% or less, and still more preferably 0.006% or less.

[0022] The balance of chemical composition consists of Fe and impurities. Here, the impurities mean elements other than the elements described above which, if contained, do not deteriorate machinability and coefficient of thermal expansion of the low thermal expansion alloys of the present invention, and which are mainly unavoidably contained from raw materials, manufacturing environment, etc., during the industrial manufacture of cast steel with the chemical compositions specified in the present invention. For example, P of 0.050% or less is included.

[0023] Further, in the low thermal expansion alloy of the present invention, [Mn], [S], [Ni], [Co], and [Si], which represent the content of Mn, S, Ni, Co, and Si, by mass%, respectively, satisfy the following formula.

$$([Mn]/[S] \geq 10.0)$$

[0024] [Mn]/[S] is set to 10.0 or more in order for S to sufficiently form a compound with Mn to improve the machinability. [Mn]/[S] is preferably 15.0 or more, more preferably 20.0 or more, and still more preferably 30.0 or more. The small [Mn]/[S] means that the S content is relatively large with respect to Mn content, and since the amount of S segregating at the grain boundaries increases, cracking may occur easily during casting or forging.

$$(32.0\% \leq [Ni]+0.4[Co] \leq 38.0\%)$$

[0025] Both Ni and Co are elements which decrease the coefficient of thermal expansion. By optimizing the combination, the coefficient of thermal expansion can be further decreased, in particular, [Ni]+0.4[Co] is set to 32.0 to 38.0%. The lower limit of [Ni]+0.4[Co] is preferably 32.5%, more preferably 33.0%. The upper limit of [Ni]+0.4[Co] is preferably 37.0%, more preferably 36.0%, and even more preferably 35.0%.

$$([Si]+[Mn] \leq 2.50\%)$$

[0026] Both Si and Mn are elements which improve machinability but increase the coefficient of thermal expansion. Therefore, the sum of the contents is set to 2.50% or less. [Si]+[Mn] is preferably 2.30% or less, more preferably 2.00% or less.

(Average coefficient of thermal expansion at 25 to 100°C of 3.0×10^{-6}/°C or less)

[0027] The low thermal expansion alloy of the present invention has an average coefficient of thermal expansion at 25 to 100°C of 3.0×10^{-6}/°C or less. As described above, this coefficient of thermal expansion is obtained mainly by setting the content of Ni and Co to the appropriate range. The average coefficient of thermal expansion at 25 to 100°C may be 2.80×10^{-6}/°C or less, 2.60×10^{-6}/°C or less, 2.40×10^{-6}/°C or less, 2.20×10^{-6}/°C or less, 2.00×10^{-6}/°C or less, or 1.80×10^{-6}/°C or less.

[0028] The coefficient of thermal expansion is measured at the range of -1 to 130°C using a thermal expansion measuring device at a heating rate of 3°C/min. As the thermal expansion measuring device, TD5030S manufactured by BRUKER can be used.

[0029] Next, an example of a manufacturing method for obtaining the low thermal expansion alloy of the present invention is described.

[0030] The low thermal expansion alloy of the present invention is manufactured by a manufacturing method comprising the steps of:

(1) melting and solidifying raw materials prepared so as to have a desired chemical composition to produce a cast product,
(2) performing solution treatment to the cast product, and
(3) performing stress relief annealing to the cast product which is solution treated.

[0031] The cast product obtained by the above manufacturing method may be forged to form a forged product. The forging is performed after manufacturing the cast alloy and before performing solution treatment. In other words, the low thermal expansion alloy of the present invention comprises the steps of:

(1) melting and solidifying raw materials prepared so as to have a desired chemical composition to produce a cast product,
(2) forging the cast product,
(3) performing solution treatment to the obtained forged product, and
(4) performing stress relief annealing to the forged product which is solution treated.

[0032] A mold used for manufacturing the cast product, an injection device used for injecting a molten alloy into the mold, and an injection method are not particularly limited, and known devices and methods can be used.
[0033] In the solution treatment, the cast product is heated to 750 to 850°C, held for 0.5 to 3hr, and then quenched. The cooling rate is preferably 10°C/min or more, and more preferably 100°C/min or more. By the solution treatment, the coefficient of thermal expansion can be decreased.
[0034] In the stress-relief annealing, the cast product is maintained at 300 to 350°C for 1 to 5hr, and then, the cast product is air cooled.
[0035] The solution treatment and the stress relief annealing may be performed after the forging instead of after the casting.
[0036] When forging the cast product, the cast product is heated to 1050 to 1250°C in a heating furnace, and then hot forged. In this case, the forging ratio is preferably 3 or more. Even if hot forged, the low thermal expansion characteristic of the low thermal expansion alloy of the present invention is substantially maintained. Further, it is also possible to be worked to a thickness of 0.1 to 10mm by hot rolling or cold rolling. Even in this case, the low thermal expansion characteristic is substantially maintained.
[0037] The alloy has the chemical composition of the present invention has a low thermal expansion alloy excellent in machinability without using a special manufacturing method, as described above.
[0038] By working the low thermal expansion alloy (including cast product and forged product) of the present invention, it is possible to obtain, for example, alloy parts used in electronics, semiconductor-related equipment, laser working machines, and ultra-precision working equipment. The low thermal expansion alloy of the present invention is suitable as a material of an alloy component since it is thermally stable and excellent in machinability.

EXAMPLES

[0039] Using a high-frequency melting furnace, a cast product (Y-type test material, and ingot of 10kg) was fused so as to have the chemical composition shown in Table 1. For the examples described as "forged products" in Tables 1 and 2, the obtained ingot was heated to 1200°C in a heating furnace and then hot forged to obtain a forged product (40mm square bar). The forging ratio was 5 or more.
[0040] The obtained cast product and forged product were each subjected to solution annealing treatment by heating to 800°C and holding for 1.5hr, and after the solution treatment, were each subjected to a stress-annealing treatment by holding for 3hr at 300°C and air-cooling.
[0041] A test piece for measuring the coefficient of thermal expansion and a test piece for evaluating machinability were taken from each of the cast product and the forged product after the stress annealing treatment.

[Table 1]

No.		Chemical composition (wt%)										
		C	Si	Mn	S	Ni	Co	sol.Al	O	[Mn]/[S]	[Ni]+0.4[Co]	[Si]+[Mn]
1	forged product	0.006	0.35	0.72	0.043	36.32	0	0.035	0.007	16.7	36.3	1.07

(continued)

No.		Chemical composition (wt%)										
		C	Si	Mn	S	Ni	Co	sol.Al	O	[Mn]/[S]	[Ni]+0.4[Co]	[Si]+[Mn]
2	forged product	0.008	0.52	1.15	0.109	34.89	0.97	0.047	0.005	10.6	35.3	1.67
3	forged product	0.016	0.75	1.48	0.112	37.15	0.00	0.065	0.004	13.2	37.2	2.23
4	cast product	0.005	0.42	0.78	0.049	32.81	3.42	0.041	0.007	15.9	34.2	1.20
	forged product	"	"	"	"	"	"	"	"	"	"	"
5	forged product	0.007	0.71	1.35	0.084	33.41	2.86	0.040	0.005	16.1	34.6	2.06
6	cast product	0.010	0.59	1.71	0.095	33.68	3.22	0.069	0.004	18.0	35.0	2.30
	forged product	"	"	"	"	"	"	"	"	"	"	"
7	forged product	0.011	0.44	0.91	0.052	31.85	5.12	0.032	0.005	17.5	33.9	1.35
8	cast product	0.004	0.46	1.46	0.111	31.28	7.18	0.019	0.007	13.2	34.2	1.92
	forged product	"	"	"	"	"	"	"	"	"	"	"
9	forged product	0.007	0.73	1.68	0.082	31.53	5.72	0.034	0.005	20.5	33.8	2.41
10	forged product	0.008	0.61	1.78	0.114	30.08	8.52	0.039	0.005	15.6	33.5	2.39
11	cast product	0.009	0.39	0.67	0.039	28.91	9.76	0.032	0.005	17.2	32.8	1.06
	forged product	"	"	"	"	"	"	"	"	"	"	"
12	forged product	0.007	0.54	1.15	0.052	30.34	11.23	0.045	0.005	22.1	34.8	1.69
13	forged product	0.012	0.65	1.24	0.085	29.58	10.05	0.055	0.004	14.6	33.6	1.89
14	forged product	0.004	0.82	1.16	0.105	28.97	8.42	0.023	0.006	11.0	32.3	1.98
15	forged product	0.006	0.26	0.85	0.082	32.12	5.25	0.031	0.005	10.4	34.2	1.11
16	forged product	0.010	1.20	1.61	0.074	31.88	4.86	0.039	0.005	21.8	33.8	2.81
17	forged product	0.011	0.65	0.48	0.077	31.92	5.08	0.027	0.006	6.2	34.0	1.13
18	forged product	0.008	0.81	2.14	0.069	32.37	5.10	0.026	0.006	31.0	34.4	2.95
19	forged product	0.003	0.55	1.26	0.025	31.63	5.53	0.054	0.004	50.4	33.8	1.81

(continued)

No.		Chemical composition (wt%)										
		C	Si	Mn	S	Ni	Co	sol.Al	O	[Mn]/[S]	[Ni]+0.4[Co]	[Si]+[Mn]
20	forged product	0.002	0.88	0.73	0.162	30.99	5.04	0.039	0.005	4.5	33.0	1.61
21	forged product	0.002	0.92	1.24	0.049	26.41	5.25	0.041	0.005	25.3	28.5	2.16
22	forged product	0.002	0.54	0.98	0.082	38.50	5.16	0.026	0.006	12.0	40.6	1.52
23	forged product	0.002	0.35	1.82	0.102	28.21	12.50	0.033	0.005	17.8	33.2	2.17
24	forged product	0.006	0.42	0.72	0.065	32.05	5.01	0.001	0.014	11.1	34.1	1.14
25	forged product	0.004	0.59	0.67	0.124	32.64	4.69	0.047	0.005	5.4	34.5	1.26
26	forged product	0.006	0.39	1.25	0.071	28.32	4.97	0.054	0.004	17.6	30.3	1.64
27	forged product	0.005	0.86	1.78	0.051	35.27	7.56	0.058	0.004	34.9	38.3	2.64
28	forged product	0.004	0.92	1.89	0.109	31.42	7.16	0.021	0.006	17.3	34.3	2.81
29	cast product	0.008	0.12	0.24	0.008	35.94	0.00	0.033	0.005	30.0	35.9	0.36
	forged product	"	"	"	"	"	"	"	"	"	"	"
30	forged product	0.011	0.09	0.20	0.003	33.57	3.21	0.028	0.006	66.7	34.9	0.29
31	forged product	0.013	0.10	0.38	0.017	33.64	3.10	0.024	0.006	22.4	34.9	0.48
32	cast product	0.006	0.08	0.16	0.004	32.05	5.01	0.039	0.005	40.0	34.1	0.24
	forged product	"	"	"	"	"	"	"	"	"	"	"
33	cast product	0.010	0.13	0.42	0.019	31.95	4.98	0.029	0.006	22.1	33.9	0.55
	forged product	"	"	"	"	"	"	"	"	"	"	"
* Underline means outside the scope of the invention.												

[0042] The coefficient of thermal expansion was measured by using a thermal expansion measuring device (TD5030S manufactured by BRUKER Co., Ltd.) from -1 to 130°C at a temperature increase rate of 3°C/min to obtain the average coefficient of thermal expansion from 25°C to 100°C.

[0043] Machinability and crushability of chips were evaluated by 13mm depth hole drilling the test piece for evaluating machinability (non-step working) with a drill (TiN coated Co-HSS) having a diameter of 2.6 mm and a water-soluble cutting fluid at a cutting speed of 45 m/min and a feed rate of 0.052 mm/min.

[0044] The machinability was evaluated according to tool wear amount and crushability of chips. The tool wear amount is explained with reference to Fig. 1. The tool wear amount was defined as a distance in the drill after drilling 100 holes from from the place where the base metal of the drill is visible (1) to the cutting edge (2), as shown in in Fig. 1, and the tool wear amount of 0.05 mm or less was judged to be good. In Table 2, "not borable" indicates that breakage or defect of the drill was confirmed, or abnormal noise was generated during the drilling, and it was determined that the drill cannot bore the test piece. Further, in the example described as "forging crack", since cracks occurred during forging, coefficient of thermal expansion, tool wear amount, and crushability of chips was not evaluated.

[0045] The crushability of the chips is explained with reference to Fig. 2. Crushability of the chips was evaluated as good as "G", if 80% or more of the chips are divided in the length of 1cm or less when the chips were observed. Fig. 2A is an example in which the crushability of chips is good, and Fig. 2B is an example in which the crushability is poor. Note that "P-elongated" in Table 2 means that the length exceeded 1cm in the chips of more than 20%.

[0046] Table 2 shows the results. It was judged that machinability was good when both tool wear amount and crushability of the chips were evaluated as good.

[Table 2]

No.		Coefficient of thermal expansion (25 to 100°C) [$\times 10^{-6}$/°C]	Tool wear amount [mm]	crushability of chips	
1	forged product	1.86	0.043	G	Inv. Ex.
2	forged product	2.13	0.024	G	Inv. Ex.
3	forged product	2.70	0.021	G	Inv. Ex.
4	cast product	1.15	0.035	G	Inv. Ex.
	forged product	1.04	0.038	G	Inv. Ex.
5	forged product	1.62	0.015	G	Inv. Ex.
6	cast product	2.96	0.021	G	Inv. Ex.
	forged product	2.73	0.016	G	Inv. Ex.
7	forged product	1.65	0.034	G	Inv. Ex.
8	cast product	1.72	0.017	G	Inv. Ex.
	forged product	1.41	0.019	G	Inv. Ex.
9	forged product	2.54	0.019	G	Inv. Ex.
10	forged product	2.53	0.016	G	Inv. Ex.
11	cast product	2.07	0.040	G	Inv. Ex.
	forged product	1.95	0.045	G	Inv. Ex.
12	forged product	2.61	0.033	G	Inv. Ex.
13	forged product	2.83	0.022	G	Inv. Ex.
14	forged product	2.88	0.013	G	Inv. Ex.
15	forged product	1.20	0.057	G	Comp. Ex.
16	forged product	3.17	0.017	G	Comp. Ex.
17	forged product	-	forging crack	forging crack	Comp. Ex.
18	forged product	3.05	0.023	G	Comp. Ex.
19	forged product	1.60	not borable	P-elongated	Comp. Ex.
20	forged product	-	forging crack	forging crack	Comp. Ex.
21	forged product	4.78	0.025	G	Comp. Ex.
22	forged product	3.63	0.016	G	Comp. Ex.
23	forged product	3.37	0.018	G	Comp. Ex.
24	forged product	1.10	0.072	G	Comp. Ex.
25	forged product	-	forging crack	forging crack	Comp. Ex.
26	forged product	4.44	0.025	G	Comp. Ex.
27	forged product	3.56	0.024	G	Comp. Ex.

(continued)

No.		Coefficient of thermal expansion (25 to 100°C) [×10-6/°C]	Tool wear amount [mm]	crushability of chips	
28	forged product	3.15	0.012	G	Comp. Ex.
29	cast product	1.46	not borable	P-elongated	Comp. Ex.
	forged product	1.41	not borable	P-elongated	Comp. Ex.
30	forged product	0.63	not borable	P-elongated	Comp. Ex.
31	forged product	0.78	not borable	P-elongated	Comp. Ex.
32	cast product	0.31	not borable	P-elongated	Comp. Ex.
	forged product	0.26	not borable	P-elongated	Comp. Ex.
33	cast product	0.67	not borable	P-elongated	Comp. Ex.
	forged product	0.52	not borable	P-elongated	Comp. Ex.
* Underline means outside the scope of the invention, or the desired properties were not obtained.					

[0047] Nos. 1 to 14 are inventive examples, in which the coefficient of thermal expansion is small, the tool wear amount and the crushability of the chips is also good. Therefore, the low thermal expansion alloy of the present invention was confirmed to have good machinability in both cast product and forged product.

[0048] No. 15 had a small amount of Si, and as a result, had large tool wear amount.

[0049] No. 16 had a large amount of Si amount and a large [Si]+[Mn], and as a result, had a large coefficient of thermal expansion.

[0050] No. 17 had a small amount of Mn and a small [Mn]/[S], and as a result, forging cracks occurred.

[0051] No. 18 had a large amount of Mn and a large [Si]+[Mn], and as a result, had a large coefficient of thermal expansion.

[0052] No. 19 had a small amount of S, and as a result, had a large tool wear amount and poor crushability of chips.

[0053] No. 20 had a large amount of S and a small [Mn]/[S] was small, and as a result, forging cracks occurred.

[0054] No. 21 had a small amount of Ni, and as a result, had a large coefficient of thermal expansion.

[0055] No. 22 had a large amount of Ni, and as a result, had a large coefficient of thermal expansion.

[0056] No. 23 had a large amount of Co, and as a result, had a large coefficient of thermal expansion.

[0057] No. 24 had a small amount of sol.Al and a large amount of O, and as a result, had a larger tool wear amount.

[0058] No. 25 had a small [Mn]/[S], and as a result, forging cracks occurred.

[0059] No. 26 had a small [Ni]+0.4[Co], and as a result, had a large coefficient of thermal expansion.

[0060] No. 27 had a large [Ni]+0.4[Co] and a large [Si]+[Mn], and as a result, had a large coefficient of thermal expansion.

[0061] No. 28 had a large [Si]+[Mn], and as a result, had a large coefficient of thermal expansion.

[0062] Nos. 29 to 33 had a small amount of Si, Mn, and S, and as a result, had a large tool wear amount and poor crushability of the chips.

REFERENCE SIGNS LIST

[0063]

1 Places where base metal of drill is visible
2 Cutting edge

Claims

1. A low thermal expansion alloy comprising, by mass%,

C: 0.050% or less,
Si: 0.30 to 1.00%,
Mn: 0.50 to 2.00%,
S : 0.030 to 0.150%,
Ni: 27.00 to 38.00%,

Co: 0 to 12.00%,
Sol.Al: 0.003 to 0.100%,
O: 0.010% or less, and
balance of Fe and impurities,
wherein
[Mn], [S], [Ni], [Co], and [Si], which represent the content of Mn, S, Ni, Co, and Si, by mass%, respectively, satisfy

$$[Mn]/[S] \geq 10.0,$$

$$32.0\% \leq [Ni]+0.4[Co] \leq 38.0\%,$$

and

$$[Si]+[Mn] \leq 2.50\%;$$

and
the average coefficient of thermal expansion at 25 to 100° of the low thermal expansion alloy is 3.0×10^{-6}/°C or less.

Fig. 1

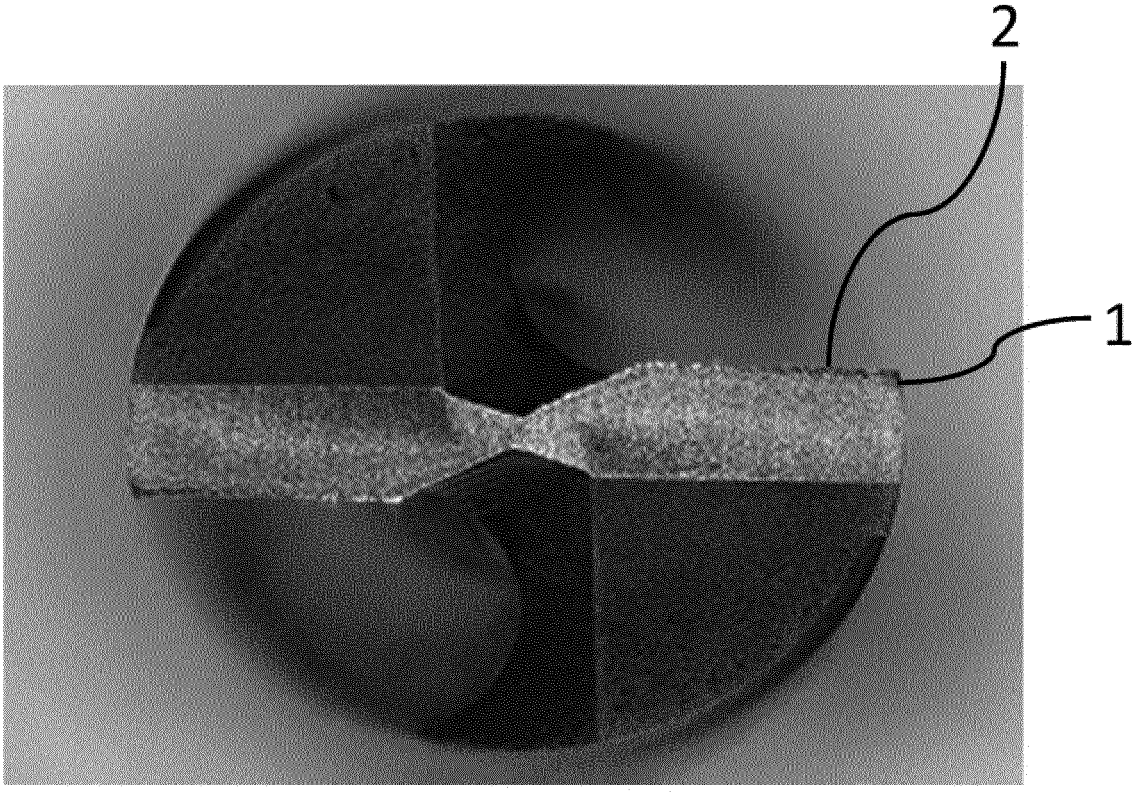


Fig. 2A

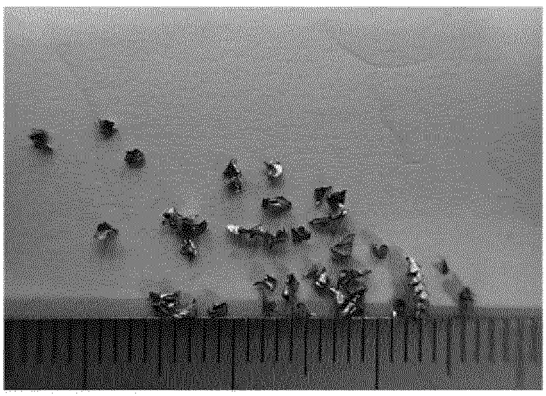
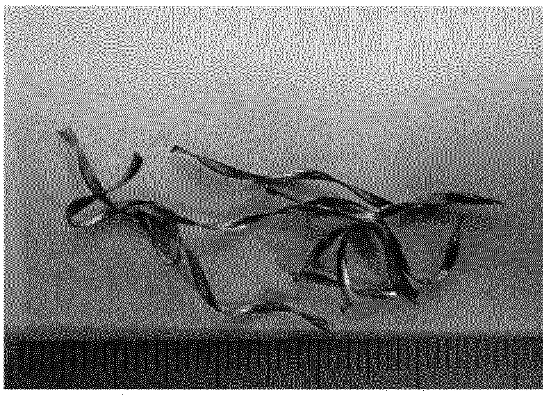


Fig. 2B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/025751

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 8/00***(2006.01)i; ***C21D 9/00***(2006.01)i; ***C22C 30/00***(2006.01)i; ***C22C 38/60***(2006.01)i; ***C22F 1/00***(2006.01)i; ***C22F 1/16***(2006.01)i
FI: C22C38/00 302R; C21D8/00 D; C21D9/00 A; C22C30/00; C22C38/60; C22F1/00 630J; C22F1/00 650E; C22F1/00 691B; C22F1/00 691C; C22F1/00 692A; C22F1/00 694A; C22F1/00 694B; C22F1/16 Z

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00; C21D8/00; C21D9/00; C22C30/00; C22C38/60; C22F1/00; C22F1/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2018-145491 A (SHINHOKOKU STEEL CORP.) 20 September 2018 (2018-09-20) entire text	1
A	JP 2018-165380 A (SHINHOKOKU STEEL CORP.) 25 October 2018 (2018-10-25) entire text	1
A	JP 2019-65344 A (SHINHOKOKU STEEL CORP.) 25 April 2019 (2019-04-25) entire text	1
A	JP 2003-286546 A (NIPPON CHUZO K.K.) 10 October 2003 (2003-10-10) entire text, all drawings	1
A	JP 2001-262277 A (NIPPON CHUZO K.K.) 26 September 2001 (2001-09-26) entire text, all drawings	1
A	JP 2012-530001 A (FORD MOTOR CO.) 29 November 2012 (2012-11-29) entire text, all drawings	1

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 2023	**19 September 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/025751

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2018-145491 A	20 September 2018	(Family: none)	
JP 2018-165380 A	25 October 2018	(Family: none)	
JP 2019-65344 A	25 April 2019	(Family: none)	
JP 2003-286546 A	10 October 2003	(Family: none)	
JP 2001-262277 A	26 September 2001	(Family: none)	
JP 2012-530001 A	29 November 2012	US 2012/0139160 A1 entire text, all drawings WO 2010/144786 A2 EP 2440681 B1 CN 102575332 A	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2001262277 A **[0006]**
- JP H6172919 A **[0006]**
- JP S58210149 A **[0006]**