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# MONEL METAL CASTINGS

This preliminary bulletin has been prepared in response to persistent demands for information on the properties of Monel Metal castings, particularly the special 2-1/2% Silicon Monel Metal and the "S" Monel Metal castings which offer certain advantages in strength, hardness and non-galling properties over other corrosion resisting materials. Being a preliminary bulletin, it is subject to correction and revision. The finished bulletin, in printed form, is expected to be available for distribution early in 1936.

344/35

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street

New York, N.Y.

Report No. 344/35 Watertown Arsenal

July 17, 1935

## MONEL METAL CASTINGS

In addition to the advancements made in Monel Metal castings, progress has been made during the past two or three years in developing different properties in castings by the use of an increased amount of silicon. By varying the amount of silicon, the hardness can be altered over a wide range and above a definite level of silicon, Monel Metal castings respond to heat treatment.

The principal advantage gained through the use of increased silicon (3% or more), is hardness of a type that lends a non-seizing or non-galling characteristic to the alloy.

### COMPOSITION

Practical experience has lead to dividing these castings into a series of types according to silicon content, as follows:

Table I

Composition

| Type | Name | Silicon Percent | Copper Percent | Iron Percent | Carbon Percent |
|---|---|---|---|---|---|
| 1 | Regular M. M. | 1.25-1.75 | 27.5-29.5 | 1.0-2.0 | .10-.25 |
| 2 | High Silicon M.M. | 2.5-3.0 | 27.5-29.5 | 1.0-2.0 | .10-.25 |
| 3 | High Silicon M.M. | 2.5-3.5 | 32. -34. | 1.0-2.0 | .04-.25 |
| 4 | 'S' M. M. | 3.5-4.0 | 32. -34. | 1.0-2.0 | .04-.25 |
| 5 | 'S' M. M. | 3.75-4.5 | 32. -34. | 1.5-2.5 | .04-.25 |

The regular Monel Metal castings, as supplied under U. S. Navy Specification 46Mld, correspond to the Type 1 composition. Type 2 is known by the name of "High Silicon" Monel Metal or 2-1/2% Silicon Monel Metal. Type 3 is a modification of Type 2. Type 5 is known as S Monel Metal. Type 4 is a variation of S Monel Metal. Each type is supplied to meet special requirements -- usually after discussion of the particular requirements of the case with the user.

All five types are made at the Bayonne Works of The International Nickel Company.

All these types are made by melting Monel Metal and adding silicon in the form of 95% metallic silicon. The amount of copper is adjusted by additions of ingot copper to the melt. The effect of copper is important. In alloys of equal silicon content (in particular, compositions with 3% silicon or more), those higher in copper will be harder and a close adjustment of mechanical properties can be accomplished if the silicon and copper content are controlled within close limits.

Iron, within the limits given, seems to be beneficial in its effect on strength and hardness, and it has, apparently, no serious ill effects, either mechanical or chemical. Since it accumulates in scrap, the indicated amount of iron can be tolerated for all but exceptional cases where it might be objectionable from a chemical viewpoint.

## MECHANICAL PROPERTIES

The following table shows the range of mechanical properties typical of each of the type compositions listed in Table I:

Table II

Mechanical Properties

| Type | Proportional Limit psi | Yield Strength 0.5% set psi | Ultimate Tensile Strength psi | Elongation % in 2" | Reduction in Area % | Brinell Hardness |
|---|---|---|---|---|---|---|
| 1 | 25,000 | 32,000 | 65,000 | 25 | 30 | 140 |
| 2 | 30,000 | 53,000 | 85,000 | 15 | 18 | 190 |
| 3 | 35,000 | 65,000 | 95,000 | 10 | 12 | 205 |
| 4 | 60,000 | 75,000 | 105,000 | 1 | 2 | 300 |
| 5 | 110,000 | 110,000 | 110,000 | nil | nil | 385 |

This table gives in round figures the properties that will be found in the alloys as cast. A more detailed discussion of the mechanical properties of each type follows:

Type 1 - Regular Monel Metal Castings. (Silicon 1.75% max.)

Regular Monel Metal castings are of the composition Type 1, Table I. This alloy has a moderate proportional limit, is soft and ductile, and possesses a resistance to impact superior to that of many engineering steels. Its gall resisting properties are not good. It is magnetic at a temperature slightly below room temperature and does not respond to heat treatment. This is the standard and most generally used composition. The mechanical properties as specified by U. S. Navy Specification 46M1d are as follows:

Table III

Mechanical Properties of Type 1 - Regular Monel Metal Castings
(U. S. Navy Specification 46M1d)

| | |
|---|---|
| Yield Point, p.s.i. | 32,500 min. |
| Breaking Strength, p.s.i. | 65,000 min. |
| Elongation, % in 2" | 25 min. |

Type 2 - High Silicon Monel Metal Castings. (Silicon 2.5 to 3.0%)

The Bayonne Works of the International Nickel Company, Inc., regularly supply castings of the composition indicated in Type 2, Table I, under the name of "High Silicon Monel Metal".

In this alloy the silicon is held at a level not in excess of 3.0%. At very close to 3% silicon, microscopic silicides appear in the alloy. This critical silicon content is lower when the iron or copper content, or both, is increased. This point is important, because many applications require good ductility with increased but not maximum hardness. It is generally advisable to keep the silicon content between 2.50 and 2.75% to avoid the loss of ductility, which will result if the charge should happen to be abnormally high in copper or iron.

This alloy does not show remarkable resistance to galling, although its increased hardness renders it suitable for certain purposes, such as steam nozzles, which must resist mild erosion.

Alloys of the "High Silicon Monel Metal" composition respond slightly to heat treatment and will usually show mechanical properties falling within the ranges defined as follows:

Table IV

Mechanical Properties of Type 2 - High Silicon Monel Metal as Cast.

| | |
|---|---|
| Proportional Limit, p.s.i. | 27 - 32,000 |
| Yield Strength (0.5% Ext.) p.s.i. | 45 - 55,000 |
| Ultimate Tensile Strength, p.s.i. | 82 - 87,000 |
| Elongation, % in 2" | 15 - 10 |
| Reduction in Area, per cent | 20 - 15 |
| Brinell Hardness | 180 - 210 |

The outstanding characteristics of this composition, as compared to regular Monel Metal, are higher proportional limit, yield point, tensile strength, and Brinell hardness. The ductility is lower but adequate for many purposes. The melting point is lowered slightly by the increased silicon. Practically the full properties are developed in the sand castings, and heat treatment is not particularly advantageous. Castings in this alloy can be machined without difficulty, as cast.

Type 3 - High Silicon Monel Metal with Increased Copper. (Silicon 2.5 - 3.5%)

By using practically the same range of silicon content, but slightly increasing the copper, castings of composition Type 3, Table I, are produced. These differ only slightly from Type 2 in properties but are just on the borderline where the influence of silicon on hardness and ductility makes itself felt. By the addition of copper the solubility of the silicides is decreased and precipitation of a hard compound results in a sharp increase in hardness and rapid loss of ductility.

By suitable balance of silicon and copper, aiming to stay close as possible to the borderline where precipitation of silicides begins, it is possible to produce castings of the properties shown in Table V. These castings show some response to heat treatment (precipitation hardening) and a consequent improvement in resistance to galling.

Table V

Mechanical Properties of Type 3 - High Silicon-High Copper Monel Metal

| | As Cast |
|---|---|
| Proportional Limit (Berry strain gauge) psi | 30 - 40,000 |
| Yield Strength (0.5% ext) psi. | 60 - 70,000 |
| Tensile Strength, psi | 95 - 105,000 |
| Elongation, % in 2" | 12 - 8 |
| Reduction in Area, per cent | 15 - 10 |
| Brinell Hardness | 180 - 220 |

Type 4 - Grade "S" Monel Metal, Lower Hardness Range

A composition corresponding to Type 4, Table I, shows greater hardness than the preceding types, and definitely improved resistance to galling. The mechanical properties will be found to fall in the ranges indicated in Table VI.

Table VI

Mechanical Properties of Type 4 - Grade "S" Monel - Lower Hardness Range

| | As Cast | Softened | Rehardened |
|---|---|---|---|
| Brinell Hardness | 235-255 | 150-170 | 245-265 |
| Proportional Limit (Berry strain gauge) psi. | 50-60,000 | 25 -30,000 | 50-60,000 |
| Yield Strength (0.5% ext.) psi. | 70-80,000 | 40 -50,000 | 70-80,000 |
| Tensile Strength, psi | 90-110,000 | 60 -80,000 | 90-110,000 |
| Elongation, % in 2" | 6-2 | 20 -12 | 4-2 |
| Reduction in Area, per cent | 12-5 | 28 -20 | 10-5 |

This composition, even in the softened condition, carries microscopically visible silicides, which are believed to be the basis for the improved bearing properties observed. This alloy has a high proportional limit, with reference to tensile strength. Although the ductility is low, it is usually sufficient in services primarily involving gall resistance, as for example, in valve seats.

The castings can be oil or water quenched. Oil quenching gives somewhat less softening but minimizes a tendency to crack, which appears if the quenching is too drastic.

The "as cast" hardness is such that most machining operations can be carried out with appropriate tools. If much or intricate machining is involved, a saving will be effected by softening before machining, and rehardening afterwards.

The hardness in the as cast condition is lowered slightly if a lower iron content is maintained, and this can be made use of in cases where it is planned to machine as cast. Low carbon melts of this composition are found to machine more readily than those of higher carbon.

Type 5 - Grade "S" Monel Metal - Higher Hardness Range

Alloys of maximum hardness, containing above 4% silicon, are useful where highest hardness or greatest gall resistance is important. However, at the high level of silicon, the alloy loses all ductility and shows no elongation in a tensile test. These highest silicon content alloys show properties in the following range:

Table VII

Mechanical Properties of Type 5 - "S" Monel Metal, Higher Hardness Range

| | As Cast |
|---|---|
| Brinell Hardness | 340 - 390 |
| Proportional Limit (Berry strain gauge) psi | 90 - 120,000 |
| Yield Strength (0.5% ext.) psi | 90 - 125,000 |
| Tensile Strength, psi | 95 - 130,000 |
| Elongation, % in 2" | 2 - 0 |
| Reduction in Area, per cent | 2 - 0 |

Type 5 alloy may be softened, by quenching, to 240 - 290 Brinell and rehardened, by drawing, to 350 - 400 Brinell. Quenching must be handled carefully to avoid formation of internal cracks.

Hardness of "S" Monel Metal (Type 5) at Elevated Temperatures

In order to give a measure of the hardness of Grade "S" Monel Metal at elevated temperatures, a special hardness test was devised and carried out at the Research Laboratory of The International Nickel Company, Inc.

The values given are dynamic hardness and were obtained by dropping a weight of fixed amount from a constant height on to a specimen held at the temperatures indicated. A standard Brinell ball, held in the bottom of the falling weight, produces in the specimen an impression whose diameter is measured by following the usual Brinell system. The kinetic energy of the falling weight, at the time of impact with the specimen, is divided by the volume of the impression produced, the quotient being the dynamic hardness number. These dynamic hardness numbers cannot be converted to Brinell hardness numbers, but are useful as a comparison in the table following:

Table VIII

Dynamic Hardness at High Temperatures

| Temp. °F. | "S" Monel | 18-8 Rod | Annealed 0.70 Carbon Steel |
|---|---|---|---|
| 70 | 699 | 370 | 292 |
| 300 | 642 | 297 | 282 |
| 400 | 714 | 256 | 235 |
| 500 | 647 | 239 | 241 |
| 600 | 634 | 210 | 221 |
| 700 | 634 | 197 | 221 |
| 800 | 641 | 186 | 211 |
| 900 | 621 | 183 | 221 |
| 1000 | 601 | 176 | 241 |
| 1100 | 548 | 191 | 260 |
| Ordinary Brinell Hardness | | | |
| 70 | 354 | 192 | 161 |

It will be noted that the hardness of the "S" Monel Metal decreases very little as the temperature is raised.

## NON-GALLING COMPARISONS

Grade "S" Monel Metal has been tested in a gall testing machine involving a disk surface rotating against a fixed disk at 750°F. in steam and in air without lubrication under a dead load of twenty pounds on one inch diameter circular surfaces.

These tests show that Grade "S" Monel Metal will operate in rubbing contact without seizure.

In air at 750$^{o}$F.

| | |
|---|---|
| against | Itself |
| " | Stainless Iron |
| " | Rolled Monel Metal |
| " | Cast Iron |

In steam at 750$^{o}$F.

| | |
|---|---|
| against | Stainless Iron |
| " | Cast Iron |
| " | Itself* |

* When one of the two parts in contact is harder than the other.

Another test was made, in which a rod turned with a cone shaped end was rotated in an unlubricated conical hole of the same material, using a drill press. A load was applied by a twenty pound weight on the end of the drill press handle to give an effective pressure at the working end of the rod of about 300 pounds. Rotation was continued until the specimen seized, or until 20 minutes had elapsed without seizure. The test was found to be very severe, only the best materials failing to seize at once. Results obtained on silicon Monel Metal are as follows:

| | | AS CAST | | SOFTENED | | REHARDENED | |
|---|---|---|---|---|---|---|---|
| Si. | Fe. | Seconds To Seizure | Brinell Hardness | Seconds To Seizure | Brinell Hardness | Seconds To Seizure | Brinell Hardness |
| 1.25 | 2 | 1* | 114 | 1* | 97 | 1* | 104 |
| 2.75 | 2 | 1* | 193 | 1* | 116 | 1* | 162 |
| 3.25 | 2 | 1* | 228 | 1* | 116 | 1* | 180 |
| 3.75 | 2 | 294 | 262 | 2 | 137 | No seizure | 239 |
| 4.25 | 2 | No seizure | 329 | 488 | | No seizure | 317 |
| 4.75 | 2 | No seizure | 387 | No seizure | 315 | No seizure | 372 |

* These immediate seizures occurred in less than one second.

The preceding data seems to indicate that at least 3.75% silicon is required for resistance to severe galling conditions. The superiority of the cast or rehardened alloys, in comparison to those that have been softened, demonstrates the importance of hardness.

In discussing the Type 4 silicon Monel Metal it is mentioned that the amount of microscopically visible silicides is increased by increasing the copper content. In practice, the 3.75% silicon alloy is most commonly chosen as the base composition for non-galling alloy, but the striking effect of increased copper on gall resistance appears at even lower silicon contents. Two alloys were made up, each containing 3.25% silicon. One alloy contained copper in the Monel Metal ratio while the other had a higher copper content, about 3% of the nickel in the Monel Metal base had been replaced by copper. The comparison of the gall resistance of the two alloys is as follows:

The Effect of Increased Copper on Hardness and Gall Resistance

| | AS CAST | | SOFTENED | | REHARDENED | |
|---|---|---|---|---|---|---|
| Copper Content | Seconds To Seizure | Brinell Hardness | Seconds To Seizure | Brinell Hardness | Seconds To Seizure | Brinell Hardness |
| As in Monel | 1/2 | 180 | 2 | 116 | 1/2 | 228 |
| Monel + 3% Cu | No seizure | 240 | 1/2 | 149 | 570 | 286 |

In the above the higher copper alloy did not seize in the as cast condition and showed marked improvement in the rehardened condition.

In the above data no reference is made to the very hard alloys, over 3.75% silicon (Type 5), but the specimen of this composition ran the full 20 minutes test period without seizure in all conditions of heat treatment. For comparison similar tests were made on certain standards as follows:

| | Seized After |
|---|---|
| Hot Rolled Inconel | 1 sec. |
| S. A. E. 3140 Steel, quenched | 81 sec. |
| 89% Copper, 11% Tin | 175 sec. |
| 80% Copper, 10% Tin, 10% Lead | No seizure |

## PHYSICAL PROPERTIES AND CHARACTERISTICS

The important physical constants for silicon hardened Monel Metal are as follows:

Table IX

| | |
|---|---|
| Density (sp. gr.) | 8.50 to 8.80 |
| Specific Gravity (lbs. per cu. in.) | 0.317 to 0.318 |
| Melting point (1.5% Si.) | 2450°F. |
| (3.5% Si.) | 2350°F. |
| Specific Heat | 0.127 |

Mean Coefficient of Linear Expansion

The coefficient of linear expansion of silicon Monel, of composition corresponding to Type 4, Table I, has been determined to be as follows:

Table IX-A

| Temperature Range | | (Increase in Length per Unit Length) per deg. F. | per deg. C |
|---|---|---|---|
| 70°F to | 212°F | .0000068 | .000013 |
| 70 | 600 | .0000082 | .000015 |
| 70 | 850 | .0000084 | .000015 |
| 70 | 1000 | .0000087 | .000016 |

For comparison, the mean coefficient of linear expansion of rolled Monel Metal is:-

Table IX-B

| Temperature Range | | (Increase in Length per Unit Length) per deg. F. | per deg. C. |
|---|---|---|---|
| 70°F to | 212°F | .0000074 | .000013 |
| 70 | 600 | .0000084 | .000015 |
| 70 | 850 | .0000089 | .000016 |
| 70 | 1000 | .0000092 | .000017 |

Very small differences in the expansion coefficients were found in samples tested in the as cast, soft (quenched) and rehardened (drawn) conditions. These differences are negligible for practical purposes.

Comparison of a freshly quenched specimen with a specimen of same composition after holding at 850°F. for 68 days showed the following negligible change in rate of expansion:

Table X

Increase in Length Per Unit Length

| | | Specimen cast and quenched | Same after 68 days at 850°F |
|---|---|---|---|
| 70°F to | 212°F | .0000068 | .0000078 |
| 70 | 600 | .0000082 | .0000086 |
| 70 | 850 | .0000084 | .0000090 |

## Growth

Twelve inch samples of high silicon (Type 2) and grade "S" (Type 5) Monel Metal have been softened, machined, rehardened and held at 850°F for four months. At the end of the period no measurable change in length had occurred.

## Magnetic Properties

Monel Metal containing as little as 2.5% silicon is non-magnetic even at -30°F. Higher silicon contents render it non-magnetic to still lower temperatures. If the iron content of the alloy is increased, more silicon, more copper, or both, must be added to obtain a given low permeability at low temperatures.

## FOUNDRY PRACTICE

Molding: Regular Monel Metal practice is followed for the increased silicon alloys, but care should be taken to attach castings closely to risers of generous height and cross section. Pattern shrinkage of 1/4 inch per foot is adequate. A refractory, open sand should be used.

Melting and Casting: The alloys are successfully produced from electro-nickel and copper, boiler punchings (if high iron is desired) and 95% scrap, block or shot. Gas or oil fired crucible furnaces, or electric induction furnaces may be used. In any furnace, only low sulphur materials, fuel and additions, should be used and a neutral atmosphere is desired.

Silicon is usually added just before pulling the crucible from the pit, or just before tapping the electric furnace.

Melting conditions should be such as to provide a small carbon content (0.04-0.10%) to insure against excessive oxidation of the melt. Carbon contents in excess of 0.25% are probably undesirable because of the possible formation of graphite in the presence of considerable silicon, with impairment of ductility.

The addition of 0.5% manganese is desirable if the charge is not chiefly Monel Metal scrap. About 0.1% magnesium should be well stirred into the melt in the ladle before pouring.

The addition of silicon causes a lowering of the melting point. The Grade "S" Monel Metal, with increased copper and iron, has a melting point as low as 2200°F. Good results are obtained by pouring any given alloy about 250-400°F. above the melting point.

## HEAT TREATMENT

Monel Metal castings containing silicon above 3% respond to heat treatment and can be softened and hardened.

For softening, hold one hour at 1650°F. then quench. Oil quenching is recommended for alloys of silicon content up to 3.75%, as it will reduce the likelihood of cracks forming in quenching. However, the hardest alloys (above 3.75% Si) will not soften unless quenched in water, which may cause cracking.

For rehardening, hold the quenched castings at 1100°F. for 3 to 4 hours. Castings may be cooled in the furnace or removed and cooled in the air. The hardness will be slightly higher as the cooling rate is slower through the range 1100°F. to 600°F. The hardness as cast usually can be increased by applying this hardening heat treatment.

All heat treatments should be conducted in sulphur-free atmospheres.

## MACHINING

Grade "S" Monel Metal is harder but less tough (sticky or stringy) than regular Monel Metal. Slower cutting speeds and lighter feeds should be used on Grade "S" Monel Metal, particularly in the as cast and in the rehardened conditions. It can be machined quite readily in the soft (quenched) condition.

An estimate of the machinability of the various silicon Monel Metal alloys has been made. In these tests a fixed depth of cut was used and comparison made at practical revolution speeds. The feed of the cutting tool was increased until the limit seemed to have been reached. It was possible to adjust the feed so that tool damage was roughly the same for the bars being compared. The rate of feed under these conditions gives a measure of the ease of machinability. The results are given in Table XI.

Table XI

COMPARATIVE MACHINABILITY

| | | High Monel | Silicon Metal | Grade | "S" | Hard (over 3.75% Si) | |
|---|---|---|---|---|---|---|---|
| | | As Cast | Water Quench-ed | As Cast | Water Quench-ed | As Cast | Water Quench-ed |
| Cut, inch | | .100 | .100 | .100 | .100 | .100 | .100 |
| Surface Speed, ft. per min. | | 24 | 24 | 24 | 24 | 19 | 19 |
| "Circle C" tool | Feed, inch per rev. | .031 | .050 | .019 | .042 | .016 | .032 |
| | Length of cut | 3.25 | 3.25 | 2.5 | 3.4 | 3.25 | 3.25 |
| | Appearance of tool | A | A | C | B | D | C |
| "Rex AA" | Feed, inch per rev. | .031 | .050 | .019 | .042 | .016 | .032 |
| | Length of cut | 3.25 | 3.25 | 2.5 | 3.4 | 3.25 | 3.25 |
| | Appearance of tool | D | B | C | C | D | D |

Key

A = Edge not dulled at all.
B = Edge fairly sharp.
C = Edge slightly rounded.
D = Edge definitely rounded and dulled.

In all conditions except A, the tools would require grinding after the test for further good machining.

Quenched bars of a given composition machine about twice as fast as corresponding "as cast" bars. Quenched high silicon Monel Metal, up to 3% silicon, machines about as fast as regular Monel Metal in the as cast condition. High silicon Monel Metal and Grade "S" Monel Metal (quenched) probably can be machined with high speed steel tools on automatic equipment such as is used for the more refractory valve trim alloys. Carboloy tools probably can be used to advantage for the high silicon Monel Metal alloys, although they are not satisfactory for removing sand cast surfaces.

There are some indications that by keeping the carbon content of the hardest silicon Monel Metal below 0.10%, about 50% increase in the rate of machining, as cast, is obtained.

## GRINDING

Grade "S" Monel Metal will grind well to give a smooth, hard and accurate seating surface. Allowance for grinding after rehardening need be no greater than the allowance on tool and die steel of similar proportions. Usually grinding .0025" to .010" will suffice, often less. Best results are gained in the rehardened condition.

All the silicon Monel Metals can be finished by grinding.

## CORROSION RESISTANCE

The corrosion resistance of Grade "S" Monel Metal has been found to be higher than for Monel Metal without silicon when castings are compared. This is particularly true of acids of the type of hydrochloric.

## TYPICAL USES OF S MONEL METAL CASTINGS

Given below are some typical uses in which Monel Metal castings have proven successful:

Centrifugal Pumps:
Shaft sleeves and wearing rings in pumps handling salt water, and in pumps handling acid sludge resulting from the treatment of petroleum distillates with sulfuric acid.

Reciprocating Pumps:
Centrifugally cast liners in pumps handling the corrosive water of the Monongahela River, and in pumps handling acid sludge.

Valves:
Seats and discs for globe valves and wedges and seat rings for gate valves in steam service.
Valve bodies and discs for throttle valves.
Nuts on valve heads to avoid seizing.
Bushings in valves handling water at 3500# pressure.

Boiler Feed Regulators:
Valves and seats.

Injectors:
Nozzles for steam injectors on locomotives.

Soot Blowers:
Valves and seats.

Sludge Burning Equipment:
Burner tips, plug cocks, plungers for blow-off valves and pump parts, all handling acid sludge containing sulfuric acid.

Colloid Mills:
Rotors and stators in colloid mills making emulsions.

Your nearest source of supply can furnish additional information or write to The International Nickel Company, Inc., 67 Wall Street, New York, N. Y.

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