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Report No. 344/51
Watertown Arsenal

June 2, 1938

PART I

CENTRIFUGAL CASTINGS OF NICKEL COPPER AND NICKEL COPPER ALUMINUM ALLOYS

Object

To summarize all data on centrifugally cast cylinders of nickel copper (monel) and nickel copper aluminum (K monel) alloys.

References

Letter W.A. 400.112/2225 from International Nickel Company to Watertown Arsenal, February 1, 1938, comments on previous reports.

Report No. 344/59, Spectrographic Analysis by Spark Etching of Grain Boundary Material in Forged and Cast Monel Metals. S. Vigo, February 9, 1938.

Report No. 122/13, A Qualitative Spectrographic Study of Some Monel Metals. S. Vigo, August 4, 1937.

Report No. 344/55, Microscopical Examination of K Monel. M. R. Norton, April 12, 1937.

Report No. 344/51-1 and /51-2, Experimental Monel Type Castings. P. R. Kosting, March 17, 1937.

Report No. 122/3, Quantitative Spectrographic Determination of Magnesium and Titanium in Monel Metal. J. S. Walker, July 1, 1936.

Report No. 344/56, Metallographic Structures of K Monel, U. S. Army Air Corp. R. R. Kennedy, November 4, 1936.

Report No. 344/53, Investigation of K Monel Metal as a Material for Recoil Mechanism Cylinders. P. C. Cunnick, R.I.A. 36-3212, April 5, 1937.

Report No. 344/29, Experimental Centrifugal Castings of Various Copper Nickel Alloys. S. L. Conner, July 1, 1935.

Report No. 314.4/1, K Monel Metal Centrifugal Castings CE-74, -75, -76, -77, C-491, C-492. H. G. Carter, July 25, 1934.

Conclusions

To cast recuperator cylinders of monel metal by the centrifugal process, "alloyed" monel metal is necessary to meet the requirements of strength.

K Monel metal, with 2.9% Al and 0.3% Ti, kept within narrow limits, and made synthetically, shows the most promise, but difficulty with grain size and grain boundary films and dirt is encountered.

Grain boundary films and dirt have yet to be adequately controlled. Processing to eliminate Al_2O_3 has yet to be worked out. A trial of basic lined furnaces is justifiable.

Centrifugally cast K Monel cylinders are a commercial possibility.

Summary of Work

The possibility of using centrifugally cast cylinders of nickel copper alloys for recoil mechanisms was studied. The physical properties required by the engineer were 80,000 p.s.i. Tensile Strength and 35,000 p.s.i. Yield Strength (.2% set) with good ductility. At present, the cylinders are machined from solid bars or forgings with considerable waste of metal.

Initial studies showed that the centrifugal casting process was feasible. Castings of satisfactory quality of nickel copper (monel) alloy were made but the strength was low. The use of alloying agents to strengthen the metal was necessary. Mn, Mg, and Si were tried but difficulties were encountered. Al addition (K Monel) was the most promising.

K Monel is a heat-treatable alloy - to soften, it is quenched from high temperatures; to harden, it is held at intermediate temperatures and then slowly cooled.

The first castings of K Monel were water quenched from the mold, and intergranular cracks usually resulted. Studies revealed that some castings, when water quenched from softening temperatures, cracked. The practice of air cooling from the mold was adopted. Such air cooled castings, when tested in tension, showed good ductility but very high strength. Efforts to soften the alloy by heat treatment, and so to raise the ductility, quite often but not always caused cracks. Rehardening would sometimes lower ductility appreciably. Heat treatment to cause diffusion, and thereby the elimination of dendrites, usually but not always brought about embrittlement if quenched from high temperatures.

Studies were made to determine the cause of the unexpected brittleness in these castings. The pig was suspected; lead was once accidentally picked up; sulfur was blamed. Spectrographic and microscopic methods of identifying constituents gave inconclusive results.

Pb, Ca, Mg (up to 0.0094% Mg) were almost exclusively in the grain boundary, in the castings tested and also in forgings of good quality. Quasi-quantitative measurements of these elements gave negative results, i.e. the spectrographic indications of quantity present so far tried did not tie up with chemical analyses.

Al, Fe, Ti and probably Si were proportionately higher at the grain boundary than Ni, Cu, and Mn. Ni, Cu, and Mn predominated in the grain.

Neither identification nor conclusions were made as a result of the microscopic study at high magnification.

Grain boundary films and deposits and a generous supply of "black specks" throughout the matrix were characteristic of the castings. But the presence of Ni-Al-Cu-Ti at the grain boundary is not surprising as this is probably the hardening agent which is known to come out at the grain boundary even in forgings of good ductility. Grain boundary material per se is not necessarily excessively detrimental to ductility. This hardening agent usually occurs as easily resolvable elongated particles or links, and not as films or as round nonresolvable particles. The "black specks" may have been occasionally noticed in forgings shipped by the International Nickel Company but are unusual. That they are Ti-C-N has not yet been denied. Their presence has been shown not to be detrimental in forgings.

Sulfur analysis shows very low sulfur, though the poorer casting had the higher sulfur. Analysis for lead showed it to be under the usual limits for monel.

The reason for embrittlement is not yet apparent. However, the use of aluminum in the foundry is not an easy accomplishment due to picking up Al_2O_3. In general, loss of ductility and loss of pressure tightness result. Processing to eliminate Al_2O_3 must therefore be undertaken. The International Nickel Company indicated that cryolite plays an important part in the fluxing of aluminum oxide. It is our practice to dilute the cryolite with bottle glass (SiO_2). The action of the diluted cryolite on the furnace lining is materially reduced, but the difficulty with poor ductility of metal was not increased, probably due to the use of powerful "deoxidizers", as calcium silicide. By switching from an acid lining to a basic lining, a slag rich in cryolite might be usable with attendant reduction in Al_2O_3 content of the metal.

In connection with low ductility, it is noted that the Al and Ti contents usually are high. In the original castings of 1934, Al ran 3-1/2% and Ti 1%. Later, Al ran 4-1/2% and Ti 1/3%, or Al 4% and Ti 1%. It is desirable to have Al 2.9% and Ti 0.3%. For control analyses, the spectrograph is usable, and work has been done indicative of the required technique.

The International Nickel Company approves of the composition limits set up in Report No. 344/51-2, page 3. They also suggest that the tensile requirements be set at 100,000 p.s.i. minimum Tensile Strength, 50,000 p.s.i. minimum Yield Strength 0.2% set, 15% minimum elongation. Most castings would meet this, but the strength is beyond the needs of the engineers and it would be advisable to lower the strength and increase ductility. This requires a heat treatment cycle in processing. This heat treatment reveals if the metal is normal or not in that when softened, the material is or is not embrittled. Thus, maintaining the specifications at 80,000 p.s.i. Tensile Strength, 35,000 p.s.i. Yield Strength 0.2% set, and 25% Elongation will ensure quality castings. However, it has not yet been demonstrated that such quality can be maintained.

It may be that this ductility is too much to expect from the metal but this is not believed to be so.

The use of electrolytic nickel and copper in place of pig should give softer metal but is not expected to ensure high ductility. The foundry will have better faith in their product if it is made synthetically.

The melting practice must be considered not definitely settled. Processing to remove all "oxygen" from the metal before adding Al and then finish deoxidizing with calcium silicide and even magnesium will have to be considered. Magnesium was once a "cure all" in the foundry where Ni-rich castings were made. Correct foundry practice will eliminate centrifugally cast cylinders with areas of porosity at mid-section and poor ductility.

Refinement of as-cast grain size so that one grain will not extend the full wall thickness of the finished cylinder is desirable.

K Monel metal will machine slightly harder than monel metal, but should be easier to hone because of its increased hardness.

Rock Island Arsenal reported that no distortion of cylinders resulted from various machining operations starting from forgings, but that grinding operations and honing and lapping failed to give a satisfactory polish to K Monel metal. Rock Island Arsenal does not recommend the use of K Monel forgings in place of monel for recuperator cylinders. Here, again, differences must be checked carefully.

It is concluded that to cast recuperator cylinders of monel metal, "alloyed" metal is necessary, that

K Monel shows the most promise, that Al and Ti must be kept within small limits, that experimentation with furnaces that are basic lined instead of acid lined is justified, even though castings can now be made which, when heat treated, comply with specifications.

Respectfully submitted,

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