Optimization of Niobium and Silicon Concentrations in Monel Alloys for Mechanical Property Enhancement

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Introduction

- Monel alloys' phase transformations and microstructure from heat treatment remain poorly understood [1]
- Niobium and Silicon are thought to improve mechanical properties since they promote a material-strengthening precipitate [2] [3]
- The initial focus on microhardness hypothesized that silicon-rich precipitates with minimal niobium boost the material's microhardness. [3]
- **Goal of research**: enhance mechanical properties through heat treatment by acquiring knowledge of the material's phase transformations

Method

1cm by 1cm samples underwent the following heat treatment schedule for analysis:

- Solution annealing at 950°C for 24 hours
- Water quenching
- Artificial aging at 600°C at varying aging times (0, 1, 3, 7, and 14 hours)
- Water quenching

Samples were microhardness tested according to ASTM E384.

Results were used to generate hardness curves, which is aging time (hours) vs. microhardness (H_v).

Materials

Table 1. Monel alloys investigated in this experiment with their respective Si and Nb compositions in wt%.

Alloy	1	2	3	4	5	6	7	8
Si (wt%)	3.00	2.95	2.96	4.41	2.98	2.94	4.42	2.90
Nb (wt%)	1.49	1.32	1.90	0.50	0.51	1.42	2.70	2.60

Results & Discussion

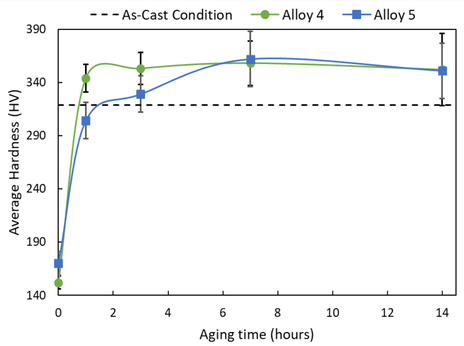

Figure 1. Average Hardness (H_v) vs Aging time (hours) of Alloys 4 and 5 compared to its average as-cast microhardness.

- Artificial aging with higher silicon and lower niobium contents yielded greater microhardness compared to its as-cast condition (**Figure 1**)

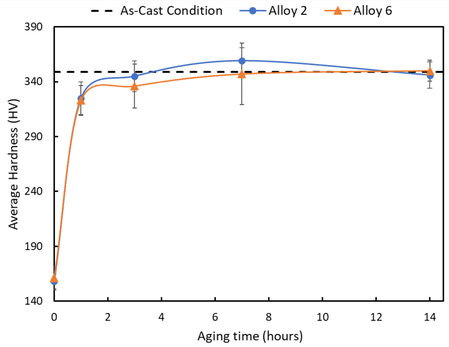

Figure 2. Average Hardness (H_v) vs Aging time (hours) of Alloys 2 and 6 compared to its average as-cast microhardness.

- Alloy 2 and 6 (Nb content between 1.00wt% and 1.50wt%) demonstrated increased microhardness compared to the as-cast condition after 7 hours of aging (**Figure 2**)

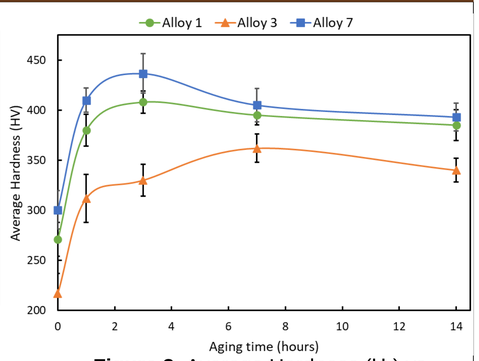

Figure 3. Average Hardness (H_v) vs Aging time (hours) of Alloys 1, 3, and 7.

- Most alloys demonstrated a decrease in microhardness after 7 hours of aging (**Figure 3**)

References

[1] A. G. Evgenov, G. I. Morozova, V. I. Lukin, Special features of phase transformations in an alloy of the Ni-Cu-Si-Fe-Mn system - metal science and heat treatment. SpringerLink (2006).
[2] C. Farnin, The Influence of Nominal Composition on the Solidification Behavior, Tensile Properties, and Weldability of Cast Monel Alloys. ResearchGate (2023).
[3] P. Mukhopadhyay, G. K. Dey, Precipitation in the nicu-base alloy Monel K-500. Materials Science and Engineering (2003).

Conclusions

- Alloys with less than 1.50wt% Nb peak in microhardness after 7 hours of aging
- Alloys with less than 1.50wt% Nb and have 3.0wt% Si exhibit improved microhardness compared to its as-cast condition

Future Work

- Additional analysis of the as-cast condition of alloys 7 and 8
- Scanning Electron Microscopy and Light Optical Microscopy to observe phase and precipitates morphologies
- Energy Dispersive Spectroscopy to note the elemental composition of precipitates
- X-ray Diffraction to understand crystal structures of phases and precipitates
- From spectroscopy, diffraction, and microscopy, determine potential causes for decrease in microhardness
- Repeat experiment to measure changes in tensile properties through tensile testing

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