

Introduction

Aluminum – Cerium Alloys

- A base 390 alloy contains a matrix of Aluminum and Silicon which has the added benefits of high hardness, fluidity, and specific strength. However, for applications in engines it is desirable to have increased high temperature strength.
- Cerium is explored as an addition to the alloy along with Ni coated graphite to increase the mechanical properties at elevated temperatures. A cylindrical casting provided by Eck Industries, was sand-cast from 390 alloy containing 1% cerium and nickel and received T6 heat treatment. It was heated to 530° C for 4 hours before being quenched and artificially aged for 2 hours at 180° C. This heat treatment was done to optimize the strength of the material.

Objective

The objective is to study the hardness, composition, and the crystal structure of the phases present in the microstructure using optical and scanning microscopy, hardness testing, EDS and X Ray diffraction.

Methods

- Samples were cut from the cylinder as seen below.
- The samples were mounted within hot phenolic resin and polished to conduct testing.
- Hardness testing, density testing, optical microscopy, SEM-EDS (scanning electron microscopy - energy dispersive X-Ray spectroscopy), and X-Ray diffraction were used to determine composition and grain structure.



Figure 1: Samples from cylindrical casting.



Figure 2: Density apparatus.

Results

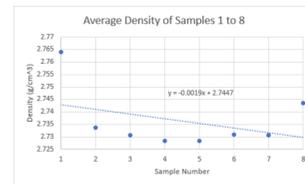


Figure 3: Density readings were collected from the 8 samples taken from the casting. The average density was 2.7447 gm/cm³. A sample of A413 was used as reference. The readings yielded an average density of 2.6639 +/-0.002% gm/cm³ of systematic error.

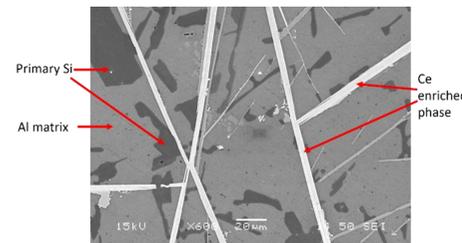


Figure 4: SEM image of the cross-section of a polished sample showing the three phases observed in the microstructure. The phases were confirmed alpha Aluminum and silicon by EDS. The long white needle type phase is rich in cerium.

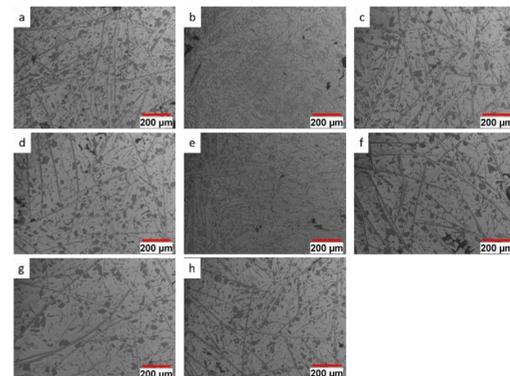
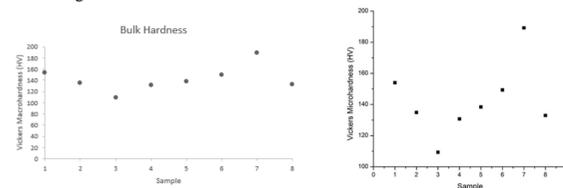


Figure 5: Microstructure of the Al-Si-Ce samples showing A390 matrix, primary Si, and Ce enriched needles. Samples a - h are in the order of 1 - 8. The images are taken at 100X magnification.



Figures 6 & 7: Macro & microhardness tests for the 8 sections of the cylinder. (Left) is the bulk macro hardness taken at a 500 gf loading for 10 seconds. An average hardness of 142.3 HV. (Right) is the microhardness test results within the Cerium needle phase. This shows a minimum hardness of 109 HV with a maximum hardness of 189 HV.

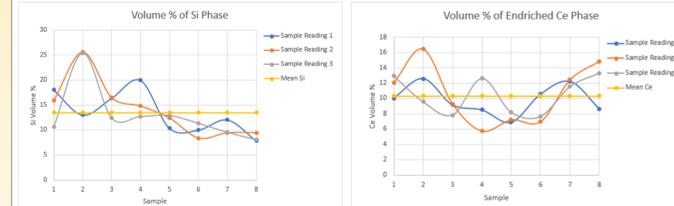
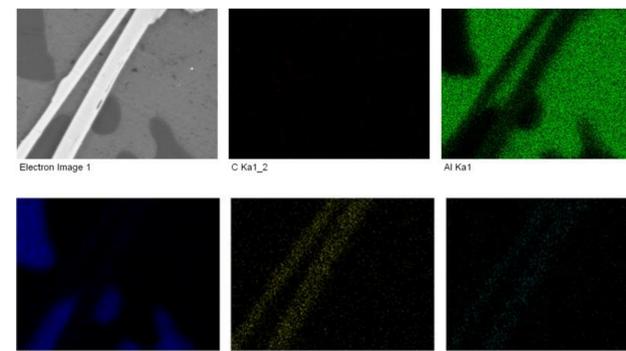
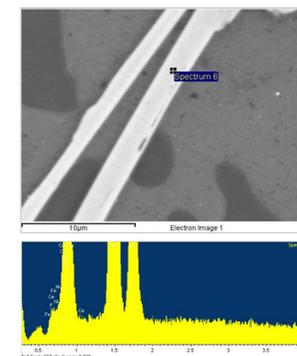


Figure 8 & 9: Volume percentage of Si and Ce phases present in the alloy. Si showed an increase towards the center of the casting while the Ce showed its highest levels near the outside of the casting.



- Figure 10: The EDS results (above) highlight a specific element based on the wavelength of the electrons produced in the test.
- Figure 11: The SEM-EDS graphical results (right) was performed using JEOL JSM-6460 LV to determine the composition within the 3 phases identified. In this figure, the test was conducted within the cerium enriched phase. The composition is within this spot is primarily Cerium, Aluminum, Silicon, Copper, Nickel, Iron, respectively.
- Table 1: The SEM numerical results (below) shows the total weight composition of the elements of each point of the SEM-EDS analysis (4 total).



Spectrum	In stats.	C	O	F	Al	Si	Fe	Ni	Cu	Zn	Ce	Total
Spectrum 4	Yes	16.20	0.66		0.86	82.28						100.00
Spectrum 5	Yes	13.05	1.16		80.43	0.74			3.36	1.25		100.00
Spectrum 6	Yes	8.27		0.00	23.62	10.13	0.86	10.63	9.65		36.84	100.00
Spectrum 7	Yes	8.14	0.64	0.00	29.77	8.40		8.90	11.09		33.05	100.00
Sum Spectrum	Yes	2.65	0.79		58.42	24.23		2.01	4.12		7.78	100.00
Max.		16.20	1.25	0.00	93.19	98.93	0.86	10.63	11.09	1.28	42.07	
Min.		2.65	0.64	0.00	0.16	0.74	0.86	0.00	0.00	1.25	0.00	

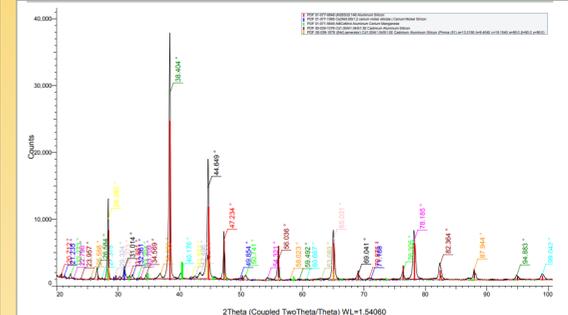


Figure 12: The results for one of the samples taken using the Bruker D8 Discover X-Ray Diffractometer to identify the phases and confirm the presence of Cerium containing phase in the material. The X-Ray Diffraction analysis of the sample confirms an Al-Si phase and cerium nickel silicide (Ce₂Ni_{0.8}Si). The Ce₂Ni_{0.8}Si peak can be observed at 2θ of 31.014°.

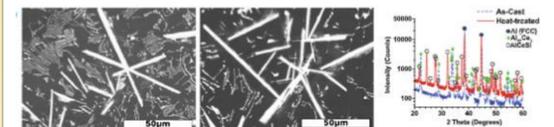


Figure 13: As-cast and heat-treated SEM images of Al-12Ce-4Si-0.4Mg with accompanying XRD spectra and phase information as published in Cerium-Based, Intermetallic-Strengthened Aluminum Casting Alloy: High-Volume Co-product Development, May 23, 2016 [1].

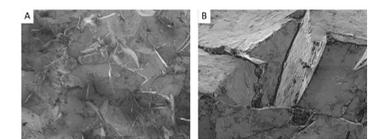


Figure 14: SEM images of the brittle fracture surface of the cylinder. Facets of the fractured surface are visible. An X-Ray map was performed, and the Ce rich regions are observed on the facets of the brittle fracture.

Conclusions

- The addition of Cerium and Ni coated graphite leads to the formation of a cerium rich needle type phase in the microstructure as confirmed by the EDS analysis. This phase presumably increases the hardness of the alloy as well as leads to an increase in the brittleness of the material.
- The fractured surface images suggest that the fracture surface preferentially goes through the Ce rich needles. The higher hardness of this cerium rich brittle phase will likely lead to an increase in high temperature properties of 390 alloy.

Literature cited

- Sims, Zachary C., et al. "High performance aluminum-cerium alloys for high-temperature applications." *Materials Horizons* 4.6 (2017): 1070-1078.
- Weiss, David. "Improved high-temperature aluminum alloys containing cerium." *Journal of Materials Engineering and Performance* 28.4 (2019): 1903-1908.
- Chowdary, Yanamandala Raghuram, et al. "Evaluation of Mechanical Properties of Al/SiC-Graphite Hybrid Metal Matrix Composites." *International Journal of Advanced Trends in Computer Science and Engineering* 2.6 (2013): 286-289.
- Sims, Zachary C., et al. "Cerium-based, intermetallic-strengthened aluminum casting alloy: high-volume co-product development." *Jom* 68.7 (2016): 1940-1947.
- Weiss, David J., et al. "Aluminum Based Alloy Containing Cerium and Graphite." U.S. Patent Application No. 16/056,993.

Acknowledgments

To: David Weiss at ECK Industries for his cooperation in providing the casting and willingness to share his knowledge in this subject. Dr. Rohatgi and the SURF committee for providing the opportunity and facilities to perform this research. The funding and help from the Foundry Educational Foundation makes much of the research possible, and lastly my colleagues and professors for their willingness to help and provide instruction.

Thank you.

Future Work

Due to the current situation, lab time and physical testing may be placed under hiatus. However, the uses of this alloy within industry will be explored further. This alloy has potential to become widespread in thermal applications such as cylinder heads and engine blocks. The thermal and mechanical properties are quite promising and will be explored further.