Siemens Energy - Industrial Gas Turbine UTSR Fellowship

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Purpose

Through the University Turbine Systems Research Fellowship I was given the opportunity to work at Siemens Energy in Orlando this summer. I was employed in the Metallic Materials group under the Materials and Technology division. The purpose of the materials and technology group at Siemens is to support the turbine design and frame groups, completing the research and development of new materials and ideas in order to improve efficiency and capabilities of the engines while upholding all the economic considerations of new and existing technologies.

Overview

The largest project that I was tasked with this summer was the evaluation of several single crystal blade and vane alloys for use in advanced gas turbine designs. The alloys were evaluated based on several criteria including, castability, response to heat treatment, mechanical properties and of course, economics. The goal was to help form a complete view of and understand how all aspects of the alloy development and all factors affecting the alloys potential use in an engine. The three alloys researched over the summer fellowship were CMSX-486, PWA1484 and CMSX-8 (B/C). All three are commercially available single crystal, Ni-base superalloys.

Mechanical Properties

One of the main responsibilities of the materials department at Siemens is to supply the turbine design groups material design curves for physical, mechanical and environmental interaction properties; whether this is for new technology developed by the company's ongoing research or for the existing or purchased technology. After a large amount of experimental testing, design curves may be created using engineering principles and statistics. Out of the 3 alloys under consideration in this project, CMSX-8 (B/C) is the newest and the smallest amounts of experimental data exist pertaining to it at Siemens and in the literature. In order for the turbine design team to estimate the mechanical response of the potential blade and vane components, estimated property design curves needed to be supplied to the design curve database, Mvision. Data received from Cannon-Muskegon via technical reports were analyzed and design curves were generated using accepted Siemens engineering design procedures. An example of the data entered for design curve generation is shown in Figure 1. Several design curves were created including: density, thermal expansion, elastic modulus, creep, etc.

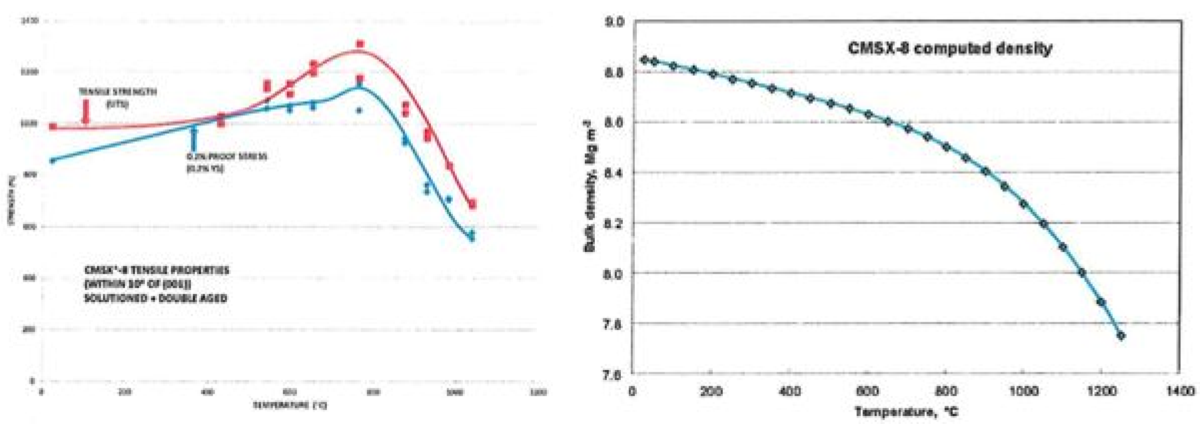

Figure 1 Selected properties of CMSX-8 (B/C) analyzed and used to create estimated design curves for initial alloy selection.[1]

Heat Treatment

A properly heat treated part will have homogenous properties across the entire casting and provide optimal properties at the most economic heat treatment times and temperatures. Also, the ability to refurbish the alloys at set intervals in order to extend the life of a carefully engineered and expensive part is a high economic driver. The three alloys were microstructurally observed in the as-cast condition and then as they were subjected to various heat treatments. Examples of the As-Cast microstructures may be observed in Figure 2.

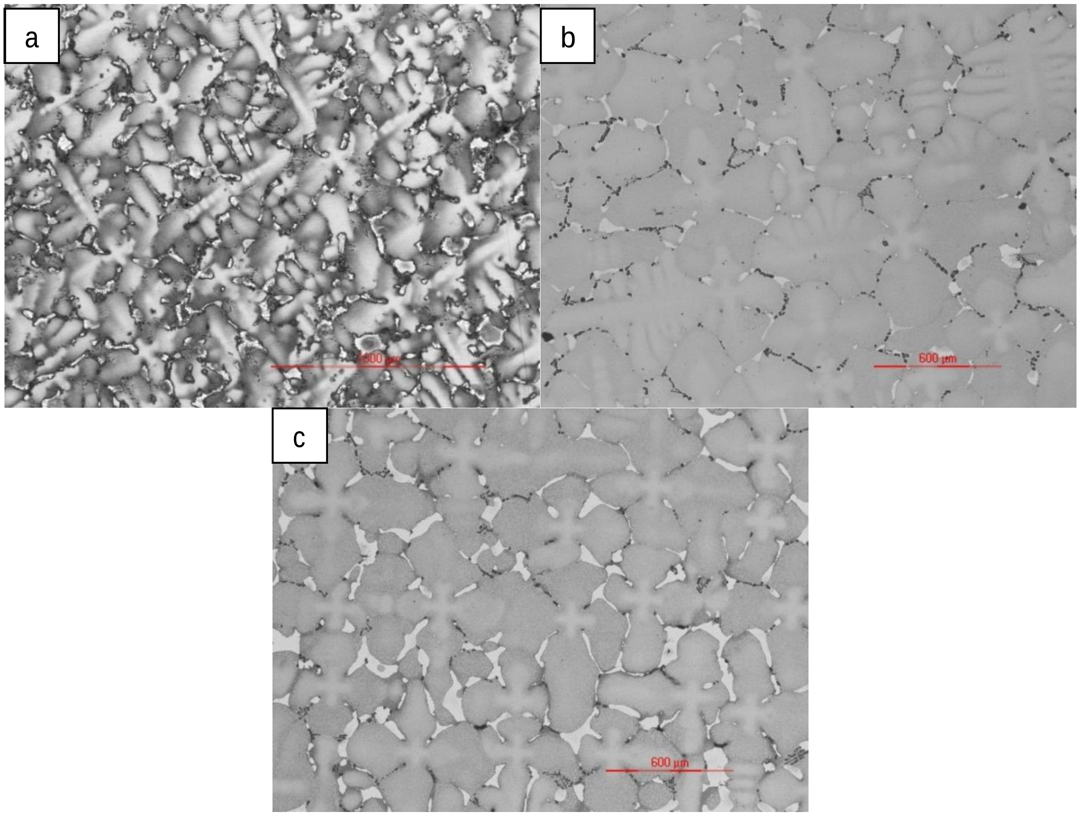

Figure 2 The as-cast microstructures of the three alloys chosen for study: a) CMSX-486, b) PWA1484 and c) CMSX-8 (B/C).

As observed in Figure 2, the as-cast structures are heavily dendritic, exhibiting high levels of microsegregation, as well as high volume fractions of eutectic phases (high contrast areas) and various carbides and borides (lower contrast areas). CMSX-486 is the least homogenous of the three and is considered “unsolutionable” from the casting house. For this reason, it is most often used without a solution heat treatment and utilized with only a double ageing precipitation heat treatment. Generally, the goal of a heat treatment is to put the gamma prime, γ', phase back in to solution and use the energy from high temperatures to diffuse the more highly segregated areas into a more homogenous structure. The casting houses of the other two alloys claim they can be fully solutioned.

While completing heat treatments it is necessary to avoid incipient melting of segregated areas of lower melting point constituents. These areas are often the higher contrast areas in Figure 2 which are the gamma prime eutectic phases. Incipient melting will often appear as a small pore in the middle of the eutectic phase. For this reason, an initial volume fraction of as-cast porosity was calculated and the results are shown in Table 1 as well as several heat treatment temperatures investigated. Other reasons for completing heat treatment would be to change the morphology of secondary phases such as carbides which the above alloys also contain.

Table 1 THe %Vf of porosity and evolved incipient melting over 4 hour heat treatment times over for sevaral temperatures.

Alloy	Temperature, C	Average %Vf of Incipient Melting/Porosity
CMSX-486	1230	0.21
CMSX-486	1240	0.46
CMSX-486	1250	0.69
CMSX-486	1260	1.00
CMSX-486	1270	2.22
PWA1484	As-Cast	0.06
PWA1484	1300	0.24
PWA1484	1310	0.26
PWA1484	1320	0.29
PWA1484	1330	0.33
CMSX-8 (B/C)	As-Cast	0.05

The alloys were subjected to several heat treatments at varying temperatures for four hour hold times, in order to observe the alloy's response with the goal of finding an economical and optimal range of interest and to further downselect to one alloy. A micrograph example of one heat treatment steps is shown in Figure 3. All gamma prime and gamma prime eutectic has been solutioned and the dendrite segregation is less apparent. Some porosity and areas of incipient melting are observed in the interdendritic region.

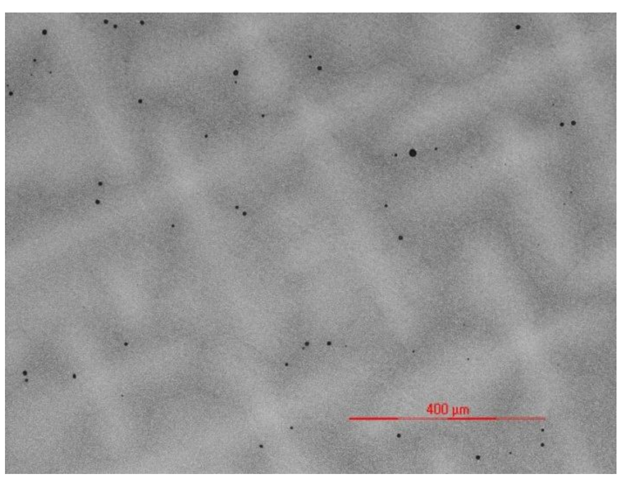

Figure 3 PWA1484 heat treated at 1330C for 4 hours.

In conjunction with the porosity and incipient melting measurements, the amount of gamma prime eutectic remaining after heat treatment will also affect properties. An effective heat treatment should reduce the eutectic phase to as low as economically feasible in order to ensure the most homogenous properties across the entire component. In order to accurately and numerically determine the volume fraction of eutectic, a software analysis program was used to develop a technique with which to measure the remaining volume fraction. The technique involves thresholding different levels of brightness and contrast in order to measure selected phases. Thresholding was also used to determine the amount of unsolutioned or partially solutioned gamma prime that was still observable in optical microscopy. An example of the technique is shown in Figure 4. Using this technique, the results reported from the casting house can be independently compared and confirmed.

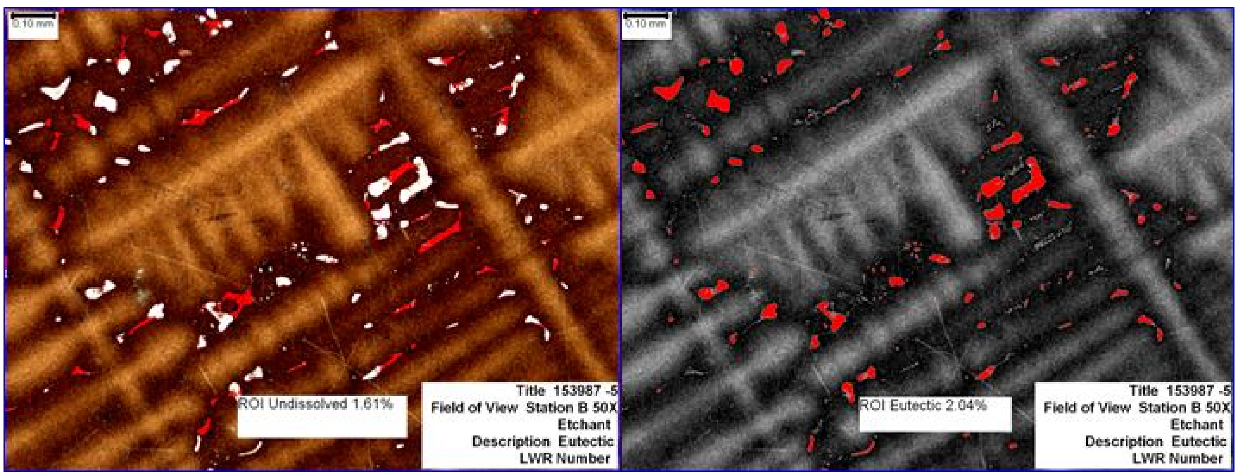

Figure 4 Using the PAXIT Software to analyze gamma prime eutectic phase percentages and large partially solutioned gamma prime in PWA1484.

Conclusions

Several experiments and analysis procedures were used in order to evaluate three alloys for possible use in the development of a new industrial gas turbine. The downselection is ongoing; however, a more well-defined picture of the alloys' potential use has been developed. CMSX-486 although a more economically advantageous alloy cannot be solution heat treated and therefore could not be restored/rejuvenated at selected intervals which would make the expense over the lifetime of the part greater than other alloys that can be rejuvenated. A better understanding of all three alloys has been achieved. Design curves were created from which estimated properties may be used in order to judge the aerospace, mechanical and heat transfer response of an actual component for an engine.

Internship Impressions

This summer I was able to work with many practicing engineers who have helped encourage and guide my education, research and career goals. The corporate culture of Siemens encouraged groups and people within each group to work together. It was very good to see how willing people were to take time out of their day to answer my questions and make the work environment one that I looked forward to coming in to everyday. The people at Siemens displayed technical expertise while remaining friendly and open about their work which made working as an intern there very beneficial to me and hopefully to them as well.

The highlight of the internship was getting to see the manufacturing plant. It is a huge benefit as an engineer to see the processes that go in to creating an actual manufactured part. Understanding the manufacturing processes and seeing completed parts definitely aided me as a young engineer to get a grasp on the technology more quickly and also made me even more interested in gas turbine technology.

Acknowledgments

I would like to than the Southwest Research Institute and Siemens for allowing me to learn a wide range of topics relating to a field that I hope to gain employment in after I graduate and be paid for this opportunity. I would also like to thank Cynthia Klein, Allister James, Ray Snider and Sachin Shinde for many technical and valuable conversations. Finally, I would like to thank Kevin Sheehan for allowing me to work in his group at Siemens and all the other Siemens employees in Orlando and Charlotte that I was able to work with.

References

1. J.B. Wahl, K. Harris, "New Single Crystal Superalloys CMSX-7 and CMSX-8", technical release, 2012.