Heat Treatment of Additively Manufactured Parts

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Introduction

As a novel manufacturing technology additive manufacturing (AM) has many advantages such as energy saving, reduced material waste, faster design-to-build time, design optimization, reduction in manufacturing steps, and product customization compared to conventional manufacturing processes. Heat treatment is widely used to improve the properties of conventional manufactured steel parts. The response of additively manufactured steel parts to heat treatment may be different from conventionally manufactured steel parts due to variations in as-deposited alloy microstructure. An understanding of heat treatment processes for additively manufactured steel parts is necessary to develop their heat treatment process parameters.

In the present work 20MnCr5, AISI 8620, and AISI M2 are selected to investigate the heat treatment effects on additively manufactured parts. The parts were fabricated by selective laser melting (SLM). 20MnCr5 and AISI 8620 parts were carburized and compared the properties with the carburized wrought parts. AISI M2 part was through hardened (quenching and tempering) and compared the properties with the through hardened wrought part. The objective of the present project includes

- Understand the effects of the post processing heat treatments on SLM additively manufactured parts
- Determine the effects of processing parameters for heat treatments on SLM additively manufactured parts
- Compare the carburizing performance of AM and wrought parts.

Methodology

The project focused on the following tasks:

Task 1 – Literature Review

Task 2 – Alloy Selection

Task 3 – Characterize the powders used for SLM

Task 4 – Characterize the as-fabricated SLM parts

Task 5 – Characterize the as-received wrought parts

Task 6 – Conduct the heat treatment on SLM and wrought parts simultaneously

Task 7 – Characterize the heat-treated SLM and wrought parts

Task 8 – Conduct the mechanical testing on the heat-treated SLM and wrought parts

Salient results

As it is shown in the table below mainly three steels were investigated in this project including M2, 20MnCr5, and AISI 8620. The additively manufactured parts for these steels were fabricated by selective laser melting (SLM) at GKN while the wrought parts are steel bars commercially available.

<table>
<tr><th colspan="2">Steels</th><th>M2</th><th>20MnCr5</th><th>AISI 8620</th></tr>
<tr><td>Manufacturing</td><td>SLM/Wrought</td><td>C</td><td>C</td><td>C</td></tr>
<tr><td rowspan="4">Microstructure Analysis of Coupons</td><td>As-received</td><td>C</td><td>C</td><td>C</td></tr>
<tr><td>Normalized</td><td>--</td><td>C</td><td>C</td></tr>
<tr><td>Carburized</td><td>--</td><td>C</td><td>C</td></tr>
<tr><td>Q&T</td><td>C</td><td>--</td><td>--</td></tr>
<tr><td rowspan="3">Mechanical Testing</td><td>Tensile</td><td>--</td><td>C</td><td>C</td></tr>
<tr><td>Impact</td><td>C</td><td>C</td><td>C</td></tr>
<tr><td>Fatigue</td><td>--</td><td>C</td><td>--</td></tr>
<tr><td colspan="2">Remaining Tasks</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
</table>

The average microhardness of as-received wrought part is much lower than that of as-fabricated SLM part because the microstructure of SLM part is tempered martensite, while the microstructure of wrought part is ferrite and pearlite. After the normalization both SLM and wrought parts have same microstructure, ferrite plus pearlite. The grain size of normalized SLM part is a little smaller than that of normalized wrought part. Due to the decarburizing during the SLM process, the total carbon concentration in SLM part is lower than the carbon concentration in the wrought part. Therefore, the hardness of the wrought part is higher than the hardness of the SLM part after the normalization.

The carburizing process was conducted on the normalized 20MnCr5 SLM and wrought parts at Caterpillar, Inc. In general, the carburized SLM part has comparable carbon concentration near the surface, case depth, and total carbon flux to the carburized wrought part after the carburizing in the same furnace at the same time (Figure 1 and Figure 2).

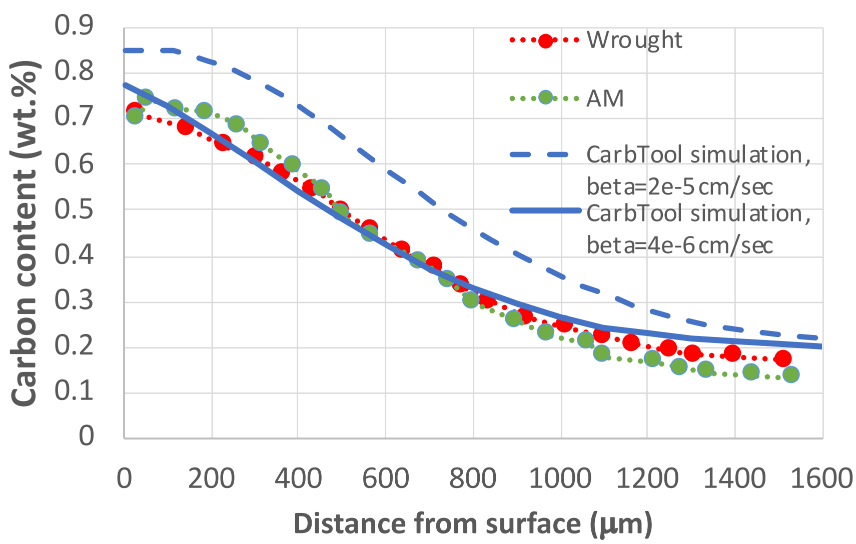


Figure 1 Carbon concentration profiles of carburized 20MnCr5 SLM and wrought parts comparing with simulation results from CarbTool.

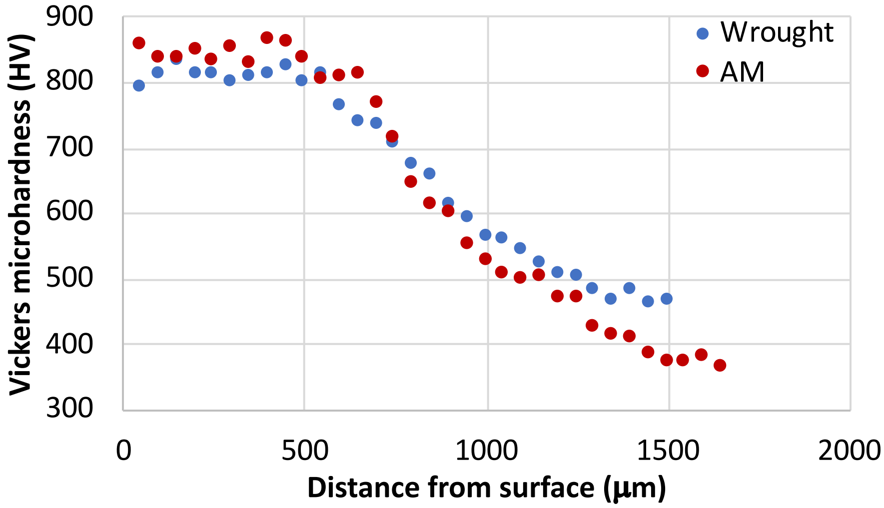
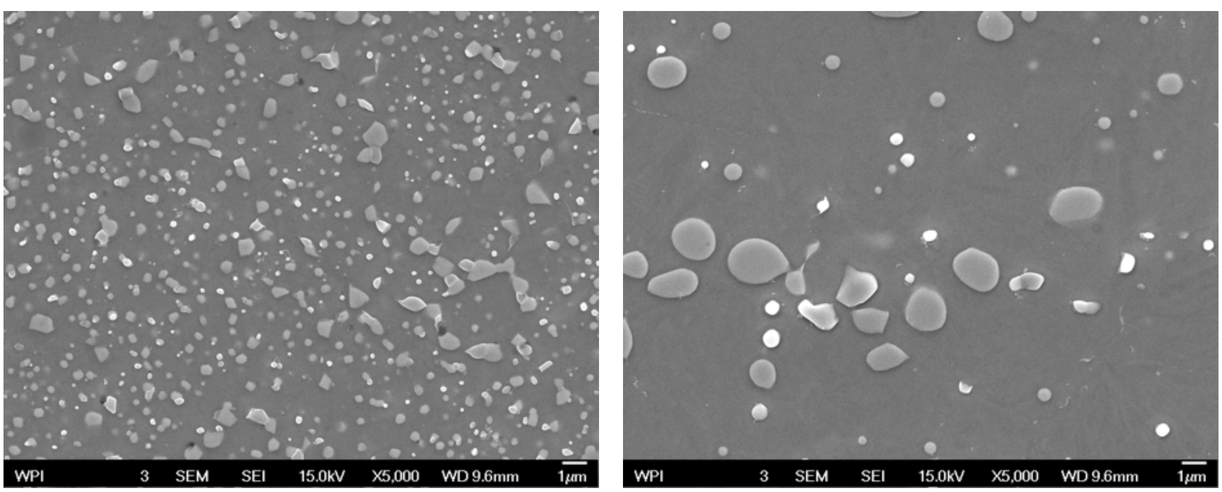


Figure 2 Vickers microhardness (0.5kgf) profiles of carburized 20MnCr5 SLM and wrought parts.

The as-fabricated SLM M2 part's microstructure is mainly two kinds of carbides, M_6C and MC distribute in the bcc iron matrix. M_6C is rich in iron, tungsten, and molybdenum, while MC mainly contains vanadium, tungsten, and molybdenum. The Vickers microhardness of the as-fabricated SLM part is much lower than the typical value of the hardened M2 wrought part.



(a) **(b)**

Figure 3 SEM micrograph of as-quenched M2 (a) SLM part (b) wrought part

The SLM part was hardened, i.e., quenched and tempered, simultaneously with the wrought part to compare the microhardness and microstructure evolution. Both as-quenched SLM and wrought parts have martensite, retained austenite, M_6C, and MC in the microstructure. But the carbides in the as-quenched wrought part are larger and more discrete than those in as-quenched SLM part (Figure 3).

The hardness of the as-quenched SLM part is lower than that of the as-quenched wrought part, which may be due to the lower carbon concentration caused by decarburization during the SLM process. Tempering causes the decomposition of the retained austenite but does not change the carbides type in both SLM and wrought part. There is almost no change in hardness for them after tempering.

In summary, the M2 part fabricated by the SLM process can be hardened through the quenching and tempering heat treatment similar to the wrought part fabricated by the conventional manufacturing process.