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Quenching and partitioning treatment of a low-carbon martensitic stainless steel fabricated by selective laser melting

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Abstract: Martensitic stainless steels have gained renewed interest recently for their use in automotive, aerospace, and defense applications due to their ultra-high yield strengths and reasonable ductility. However, the toughness of high-strength martensitic stainless-steel shows insufficient under the same strength condition. In this study, Quenching and partitioning (Q&P) treatment was applied to a commercial low-carbon martensitic stainless steel, to improve toughness in martensite stainless steel without compromising the strength. Due to the fine grain and heterogeneous microstructure of the additively manufactured martensitic stainless steel, the quench interruption temperature was optimized with consideration of the carbon concentration in untransformed austenite after partitioning to lower the Ms temperature to room temperature. After partitioning at an appropriate temperature, a significant fraction of austenite was retained through the enrichment of carbon into the untransformed austenite. Moreover, homogeneous microstructure indicated that the effective elimination of the prior selective laser melting formed heterogeneous microstructure of the martensitic stainless steel, and the results of the microstructure analysis show that the austenite retained by the Q&P process is uniformly embedded in the martensitic matrix. The electrochemical results show an effective avoidance of passivation losses and exhibit good corrosion resistance. The significant improvement of ductility and impact toughness in the proposed alloy is mainly a result of the gradual transformation induced plasticity (TRIP) effects, which are caused by carbon-rich retained austenite with heterogeneous stability and carbide-free martensite formed in the Q&P process.

NOMENCLATURE

Ms = Temperature at which martensitic transformation begins during continuous cooling of subcooled austenite
Mf = Temperature at which martensitic transformation is completed during continuous cooling of subcooled austenite

1. Introduction

Martensitic stainless steels have gained renewed interest recently for their use in automotive, aerospace, and defense applications due to their ultra-high yield strengths and reasonable ductility [1]. However, the toughness of high-strength martensitic stainless steels shows insufficient under the same strength conditions [2]. In this study, a quenching and partitioning process was used in the as-built AISI 410 stainless steel manufactured by selective laser melting (SLM), to improve toughness in martensite without compromising the strength.

Quenching and partitioning (Q&P) technology for steels contains two steps: (1) quenching from a fully or partially austenitizing temperature to a temperature between the martensite start (Ms) temperature and martensite finish (Mf) temperature, aiming to produce a controlled fraction of martensite; (2) holding isothermal or nonisothermal for carbon partitioning,[3] instead of carbide precipitation in the conventional tempering martensite. However, due to the heterogeneity and fine grain size distribution of the additively manufactured steel along the build direction, the Q&P process has not been sufficient to investigate the microstructure and mechanical properties of the additively manufactured stainless steel.

In this study, Q&P process promotes carbon-rich retained austenite via inhibiting carbide precipitation. The significant improvement of ductility and impact toughness in the proposed alloy is mainly a result of the gradual transformation induced plasticity (TRIP) effects, which are caused by carbon-rich retained austenite with heterogeneous stability and carbide-free martensite formed in the Q&P process. For the first time, the effective strength-ductility tuning of the Q&P

process for additively manufactured low carbon martensitic stainless steel is demonstrated.

2. Experiment

2.1 Mechanical characteristic

For the tensile test, dogbone shaped samples were printed by SLM sy stem with a power of 300W and a scanning speed 950mm/s. The leng th of the reduced section on the samples was 30 mm, and the gauge le ngth between the gauge marks as well as tensometer contacts was 25 mm. Cubic samples with dimensions 10*10*5 mm were built to make microstructure analysis. The tensile tests were performed on an upgr aded Tiratest 2000 testing machine with a crosshead speed of 0.5 mm/ min. To investigate the microhardness variations in heat-affected zone s, the micro Vickers hardness was performed on Mitutoyo HM211 ma chine that was made from Japan with a 0.3 kgf load and 15 s dwell ti me. Repeat five points were chosen and measured in different positio ns of each sample to get an average value.

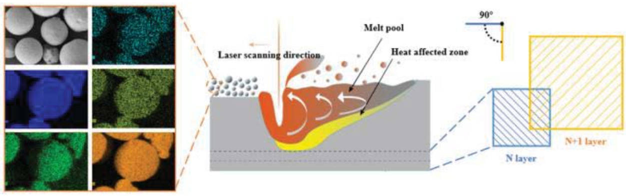

Fig. 1 SEM morphology and EDS mapping analysis of 410 SS powders and schematics diagram of SLM processing.

2.2 Post heat treatment processing

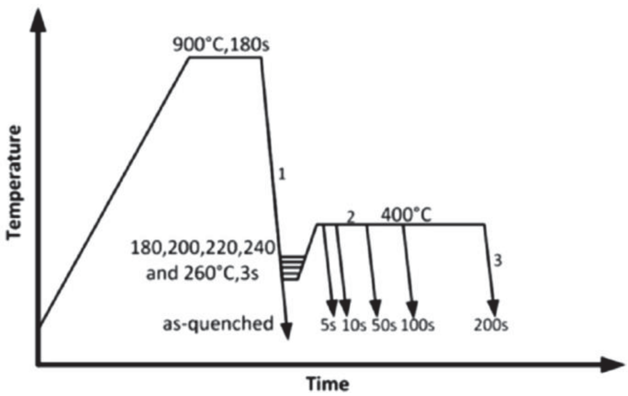

Fig. 2 Scheme of the Q&P processing.

A scheme of the applied heat treatments is shown in Fig. 2. The specimens were austenitized at900 °C for 180 s, quenched to 180 °C, 200 °C, 220 °C, 240 °C and 260 °C, isothermally treated at 400 °C for 5 s, 10 s, 50 s, 100 s and 200 s and finally quenched to room temperature in a B€ahr DIL 805 A/D dilatometer. In this paper, the code QTxxx-y identifies the specimen that was quenched to xxx _C and isothermally treated at 400 °C for y seconds. In addition to the Q&P specimens, one "as quenched" specimen was created by austenitization at 900 °C for 180 s and then directly quenched to room temperature.

Considering negligible diffusion of substitutional elements, the carbon content in austenite was calculated using the following Eq.

$$a_{\gamma}(\mathrm{nm}) = 0.3556 + 0.00453C_{\gamma} + 0.000095\mathrm{Mn} - 0.00002\mathrm{Ni} + 0.00006\mathrm{Cr} - 0.00056\mathrm{Al} + 0.00031\mathrm{Mo} + 0.00018\mathrm{V} \quad [1]$$

[1],

3. Conclusions

An alloy with an adjusted chemical composition based on the commercial AISI 410 stainless steel is investigated after being subjected to the Q&P process with various tempering temperatures. The interaction between carbon partitioning, carbide precipitation and carbide free martensite formation is studied during the application of the Q&P process to a low-carbon martensitic stainless steel with non-homogenous chemical composition.

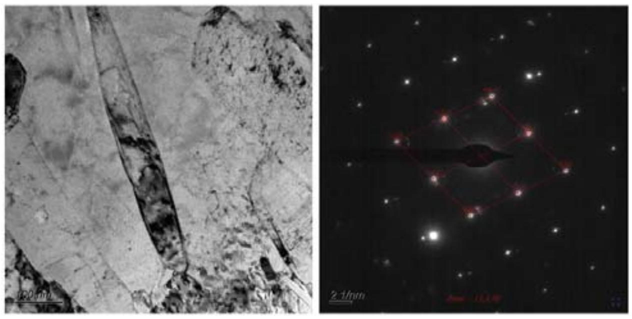

Fig. 3 Low carbon martensitic stainless steel in the distribution of reversion austenite along the grain boundaries.

To obtain a further understanding of the materials design concept on improving strength-ductility and impact toughness simultaneously, the correlation relationship of process-microstructure-properties in the proposed alloy is discussed as well.

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