

# Mechanical Properties, Microstructural Characterization, and Wear Resistance of Additively Manufactured and Cast CoCrMo Alloy

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**Disclosures:** Ghayoor, Parikh and Morrison (3A, 4 – Smith & Nephew, Inc)

**INTRODUCTION:** CoCrMo alloys are widely used in the fabrication of biomedical devices, such as orthopedic and dental implants, because of their excellent mechanical properties and biocompatibility [1]. During the past decades, additive manufacturing (AM) has been experiencing rapid development because it offers more design freedom in the production of integrated complex components compared with the traditional manufacturing methods, such as casting and forging [2]. One of the most widely used AM techniques is laser powder bed fusion (LPBF), which consists of spreading a layer of metal powder onto a platform and laser melting a predefined slice pattern from the computer-aided design (CAD) file to the layer below it. This procedure continues layer by layer until the desired component is completely manufactured. The main objective of this study is to compare the mechanical properties, microstructure, and wear performance of the additively manufactured Co-28Cr-6Mo alloy via LPBF process with casting.

**METHODS:** Three (3) CoCrMo coupons were printed using an LPBF printer and then heat-treated in a vacuum furnace; and three (3) samples were cut out of a CoCrMo femoral, which was produced via casting followed by hot isostatic pressing (HIP). The density of samples was measured using Archimedes' method. One sample per condition was mounted, polished, and etched with 10 wt.% chromic acid for microstructural characterization using optical microscopy and scanning electron microscopy (SEM). Microhardness of the samples was measured using a Knoop indenter, and the average value from 5 random measurements is reported. Five (5) tensile coupons per condition were tested according to ASTM E8. Knee femoral components with the same articular surface geometry/specifications (surface roughness, etc.) were fabricated using traditional and additive manufacturing (LPBF) and articulated against UHMWPE tibial inserts (non-crosslinked) for 5 million cycles (Mc) on a knee simulator (n=3 per group). Gravimetric wear of inserts was measured over the course of testing using load-soak controls (n=2) to correct for fluid absorption. Cumulative volume loss was calculated using the approximate density of UHMWPE (0.93 g/cm<sup>3</sup>), and the slope of the least squares best-fit line of cumulative volume loss vs. cycles was defined as the wear rate. Mean wear rates were compared statistically using a two-tailed t-test ( $\alpha=0.05$ ).

**RESULTS:** The relative densities of AM and cast CoCrMo alloy were 99.9% and 99.6%, respectively, showing that AM achieved a higher density. The microstructure of the cast CoCrMo alloy, Figure 1(a), consisted of large grains and coarse carbide precipitates within the grains. In contrast, the microstructure of AM CoCrMo alloy, Figure 1(b), shows much smaller grains and finer carbide precipitates mainly along the grain boundaries. Table 1 shows the yield strength (YS), ultimate tensile strength (UTS), and elongation at break (EL) of AM CoCrMo coupons that were printed in horizontal orientation (parallel to the build plate) and vertical orientation (perpendicular to the build plate), and cast CoCrMo coupons. In comparison with the cast CoCrMo alloy, the AM CoCrMo alloy demonstrated ~11% increase in YS ( $p<0.05$ ), ~27% increase in UTS ( $p<0.05$ ), and ~160% increase in EL ( $p<0.05$ ). The microhardness testing showed that the AM CoCrMo had a hardness of  $365 \pm 21$  HK0.5, 8% higher than cast CoCrMo ( $338 \pm 21$  HK0.5) ( $p<0.05$ ). Finally, the difference between mean wear rates of tibial inserts paired with cast and AM CoCrMo was not statistically significant ( $p>0.05$ ).

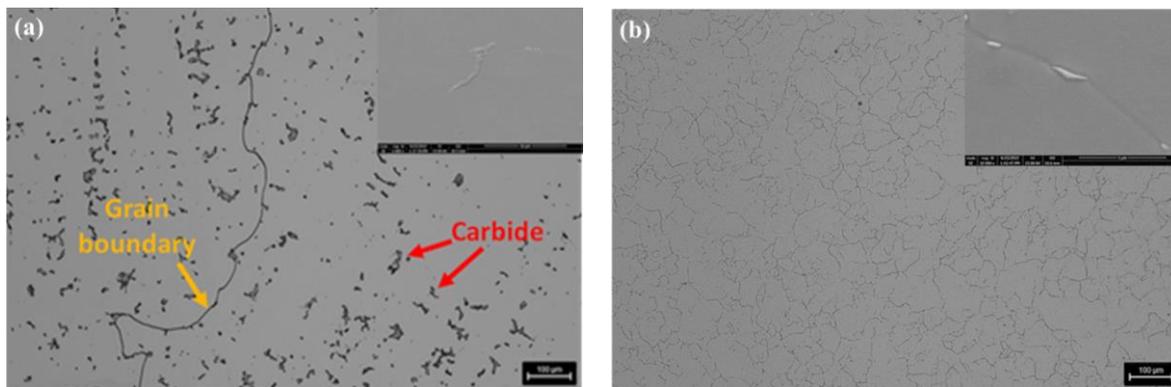
Table 1. Tensile properties of AM CoCrMo alloy (horizontal & vertical orientations) and cast CoCrMo alloy

| CoCrMo Alloy    | YS (MPa)     | UTS (MPa)     | EL (%)         |
|-----------------|--------------|---------------|----------------|
| AM - Horizontal | $684 \pm 18$ | $1171 \pm 9$  | $28.7 \pm 1.4$ |
| AM - Vertical   | $697 \pm 11$ | $1169 \pm 16$ | $28.1 \pm 3.0$ |
| Cast            | $619 \pm 4$  | $918 \pm 16$  | $10.8 \pm 2.5$ |

**DISCUSSION:** The AM CoCrMo coupons showed both enhanced strength and ductility compared to the cast CoCrMo coupons, and this could be attributed to the formation of a smaller grain size and finer carbide precipitates within the microstructure of AM samples, as shown in Figure 1. Increased hardness is associated with improved abrasion resistance; therefore, in total joint replacement applications, results indicate that AM CoCrMo will be at least as resistant to damage from third-body particulate (bone cement, bone chips, etc.) as cast CoCrMo. Knee simulator wear testing results further support the use of AM CoCrMo as a bearing material against UHMWPE in total joint replacement applications.

**SIGNIFICANCE/CLINICAL RELEVANCE:** This study supports that CoCrMo joint replacement devices fabricated using laser powder bed fusion will perform at least as well as CoCrMo devices fabricated using traditional manufacturing.

**REFERENCES:** [1] G. Mani *et al.* Journal of Biomedical Materials Research Part B: Applied Biomaterials 112, no. 6 (2024): e35431. [2] C. Yap *et al.* Applied physics reviews 2, no. 4 (2015).



**Figure 1:** (a) microstructure of cast CoCrMo alloy (size of carbide in the inset is  $\approx 50 \mu\text{m}$ ), and (b) microstructure of AM CoCrMo alloy (size of carbide in the inset is  $\approx 2 \mu\text{m}$ )