5.3.8 Reversal of Sample and Counterface - Stellite 6 versus Incoloy MA956 at 750°C and 0.314 m.s^{-1}

5.3.8 Reversal of Sample and Counterface - Stellite 6 versus Incoloy MA956 at 750°C and 0.314 m.s^{-1}

5.3.8.1 Experimental Observations – Stellite 6 versus Incoloy MA956

When Stellite 6 was slid as the sample material against a Incoloy MA956 counterface, weight changes remained extremely low (Figure 5.C1a). Weight change and wear rate values were near negligible, at -0.005(6) g (the small negative value indicating a very slight weight loss) and 1.238 x 10^{-9} kg.m^{-1} respectively. This indicated a very slight removal of material from Stellite 6 as the sample material.

Coefficient of friction data (Figure 5.C2) indicated an extended unsettled run-in period of approximately 100 minutes (1,884 m), with coefficient of friction reaching as high as 1.73. This was followed by a settled ‘steady state’ period, with coefficient of friction averaging at ~0.5 for Stellite 6 as the sample with a variability of approximately 20%. The longer run-in time with Stellite 6 as the sample is indicative of a greater amount of sliding required to form stable, wear protective glaze layers.

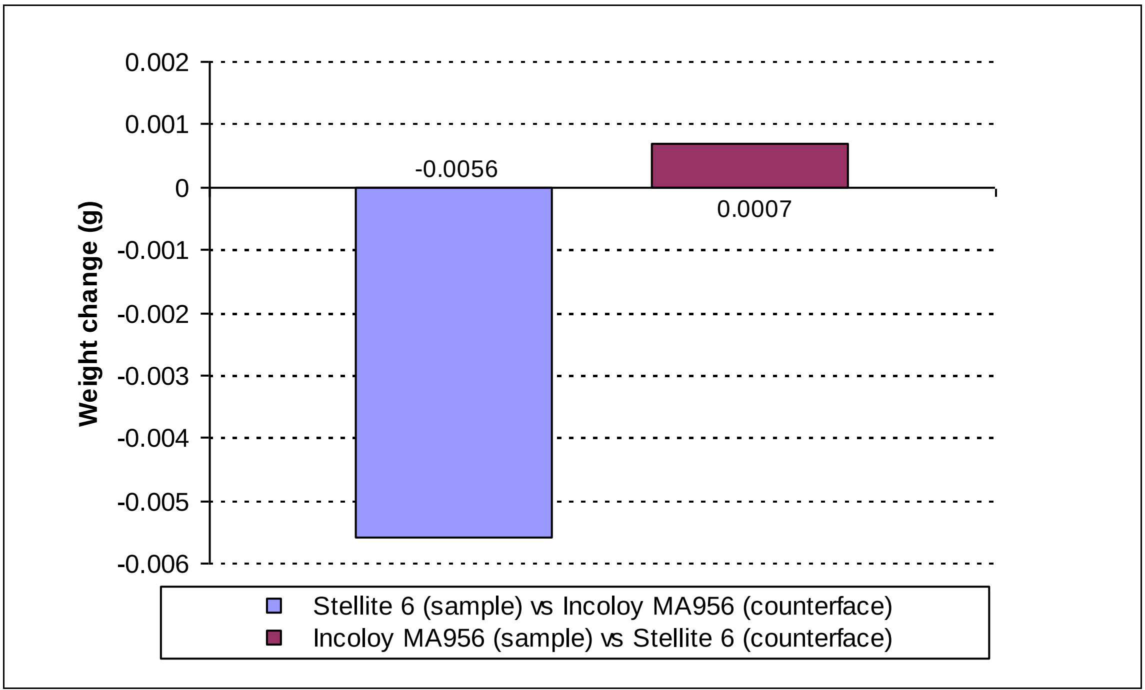
In comparison, with Incoloy MA956 as the sample slid against Stellite 6 as the counterface, a virtually negative positive weight change was recorded at (0.000(7) g – Figure 5.C1b). An extremely small negative value of wear rate of -0.155 x 10^{-9} kg.m^{-1} indicated a slight addition of material to the Incoloy MA956 sample surface. An average maximum run-in value of 0.55 was obtained for coefficient of friction during run-in with Incoloy MA956 as the sample, with a total run-in period of no more than 5 minutes (94 m). Values of coefficient of friction for steady state sliding average out at ~0.5, with a variability of no greater than ~12%.

The slight decrease in weight with Stellite 6 as the sample or increase in weight with Incoloy MA956 as the sample indicated that at 0.314 m.s^{-1} and 750°C (load 7N, 4,522 m sliding distance), whether the Stellite 6 was the sample or the counterface material, it underwent preferential wear to the Incoloy MA956. This is analogous to the preferential wear observed when sliding Stellite 6 as the sample or counteface versus Nimonic80A under the same conditions.

Figure 5.C1: Weight change versus sliding speed for Stellite 6 as the sample material worn against a Incoloy MA956 counterface at 750°C

(load = 7N, sliding distance = 4,522 m)

a) Weight change



b) Wear rate

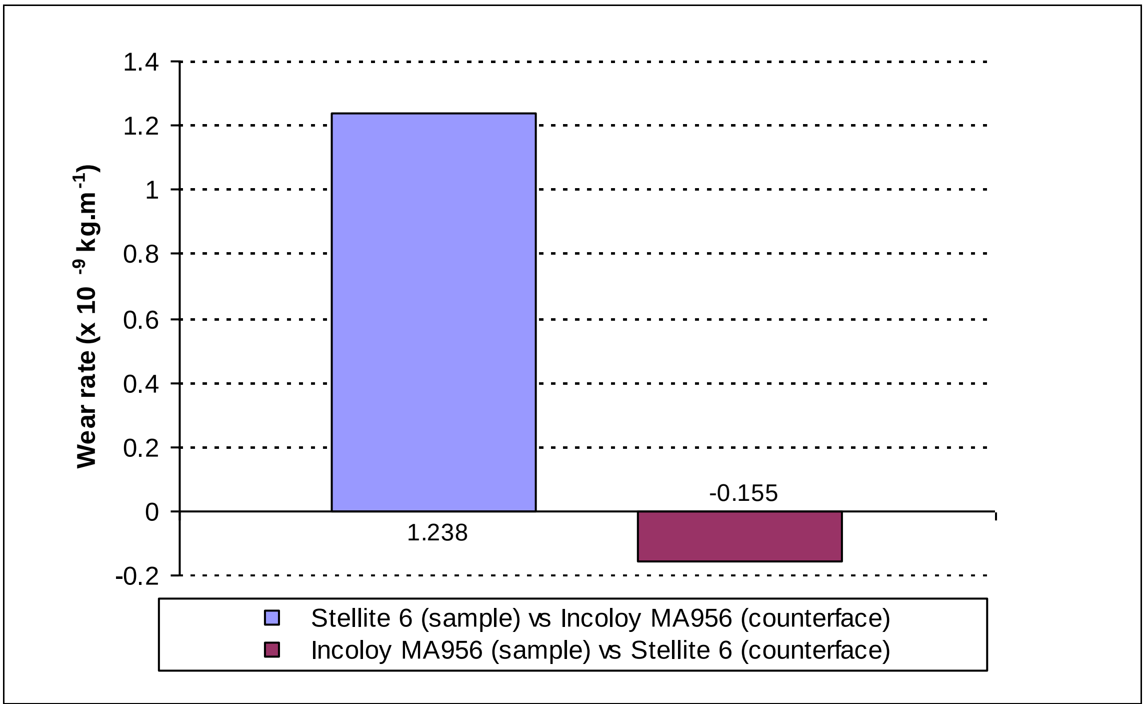
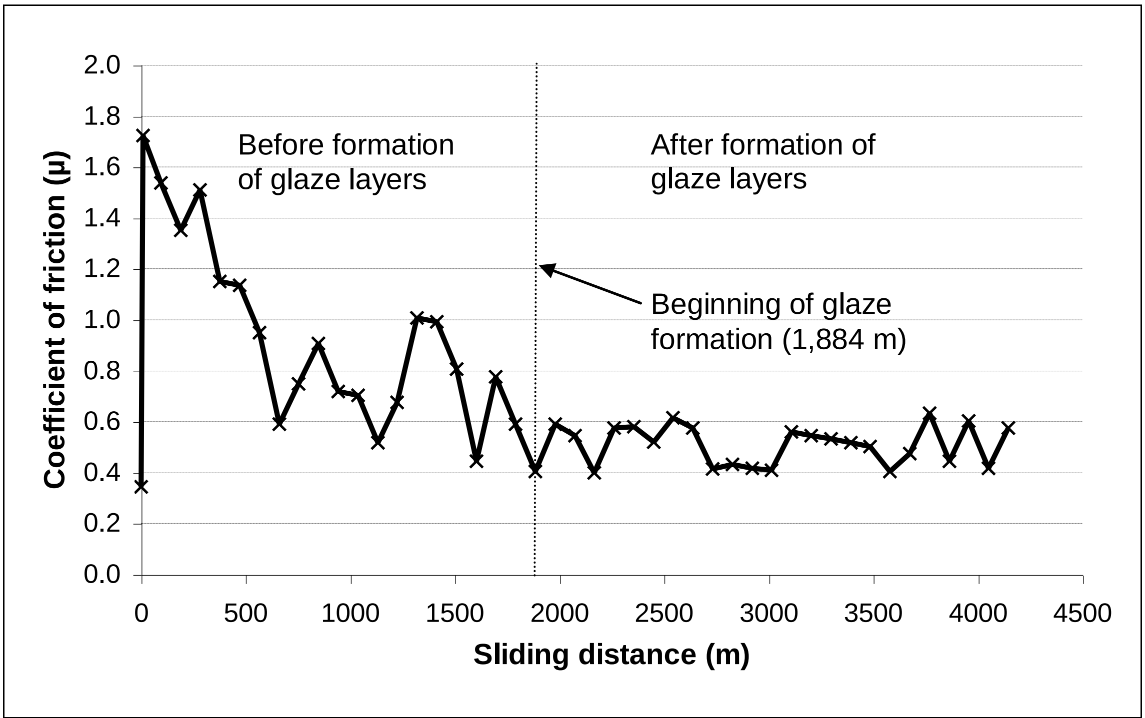


Figure 5.C2: Coefficient of friction versus sliding distance for Stellite 6 as a sample versus Incoloy MA956 at 750°C without reciprocation

(load = 7N, sliding speed = 0.314 m.s⁻¹, sliding distance = 4,522 m)



5.3.8.2 Optical and SEM Microscopy – Stellite 6 versus Incoloy MA956

Reversal of sample and counterface did not result in any significant change in glaze layer morphology (Figures 5.3.8.2 and 5.3.8.3). With Stellite 6 as the sample slid against an Incoloy MA956 counterface, an extremely thin (between 3 to 5 µm thick) but comprehensive glaze layer formed across the surface of the wear scar that when subject to both optical and SEM study, showed no difference to that formed with the Incoloy MA956 / Stellite 6 (counterface) system (Figure 5.34).

However, the Stellite 6 as a sample (versus Incoloy MA956 as a counterface) did show evidence of early enhanced removal of material, with the surface of the wear scar at a level below the level of the unworn surface. This is further evidence (in addition to the weight change / wear rate data) that the Stellite 6 as the sample material has undergone enhanced wear when slid against Incoloy MA956.

Backscatter (Figure 5.C5) indicated that the carbides did not protrude beyond the surface of the Stellite 6 sample (and into the glaze – not visible), after sliding against

Incoloy MA956. This indicates that the carbides did not take an active part in the sliding process once the glaze layer formed.

The morphological observations made for the Stellite 6 / Incoloy MA956 (counterface) were very similar to those made for the Stellite 6 / Nimonic 80A (counterface) system under the same sliding conditions (750°C, 0.314 $m.s^{-1}$ sliding speed, 7 N load, 4,522 m sliding distance), prior to the formation of the glaze layer.

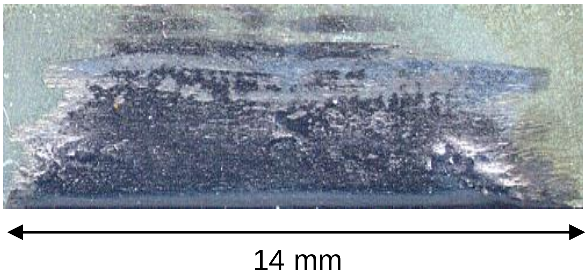
5.3.8.3 EDX and XRD Analysis – Stellite 6 versus Incoloy MA956

EDX analysis of the oxide deposits on the Stellite 6 samples indicated that the primary source of debris for the glaze layer was the Stellite 6 itself, though with a high degree of mixing of material from the Incoloy MA956 counterface. The average composition obtained for the glaze on the Stellite 6 surface (~31% Cr, ~12% Fe and ~45% Co) was not too far removed from that seen where Incoloy MA956 was the sample and Stellite 6 was the counterface (~32% Cr, ~19% Fe and ~40% Co). The higher cobalt and lower iron levels do indicate slightly more material has been sourced from the Stellite 6 sample, the primary source of material for the glaze.

XRD (Figure 5.C6) confirmed that mixing of oxide material from the Stellite 6 sample and Incoloy MA956 counterface has occurred. As well as the high cobalt-chromium phase $CoCr_2O_4$, a diffraction pattern for the iron-chromium phase $Cr_{1.3}Fe_{0.7}O_3$ was also obtained. The only metallic phase detected was the Co in the Stellite 6 sample – no iron-chromium metallic phases were detected, indicating no metallic transfer from the Incoloy 800HT counterface.

Figure 5.C3: Compacted oxide produced on Stellite 6 samples slid against a Incoloy MA956 counterface at 0.314 $m.s^{-1}$ – optical images

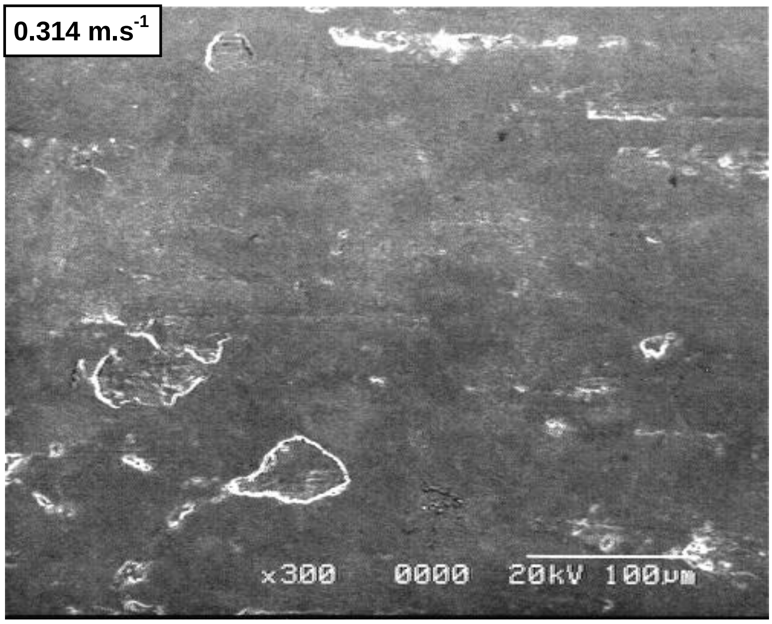
(load = 7N, sliding distance = 4,522 m, temperature = 750°C)



A smooth glaze has formed with little loose debris covering surface of wear scar

Figure 5.C4: Compacted oxide produced on Stellite 6 samples slid against a Incoloy MA956 counterface at 0.314 m.s^{-1} – SEM images

(load = 7N, sliding distance = 4,522 m, temperature = 750°C)



Smooth glaze with little loose debris, mainly Co-Cr based oxide ($CoCr_2O_4$ / Co_3O_4), only a small amount of Fe-Cr based oxide ($Cr_{1.3}Fe_{0.7}O_3$)

Figure 5.C5: Backscatter image of the side profile of a Stellite 6 sample slid against Incoloy MA956 at 0.314 m.s^{-1}

(load = 7N, sliding distance = 4,522 m, temperature = 750°C)

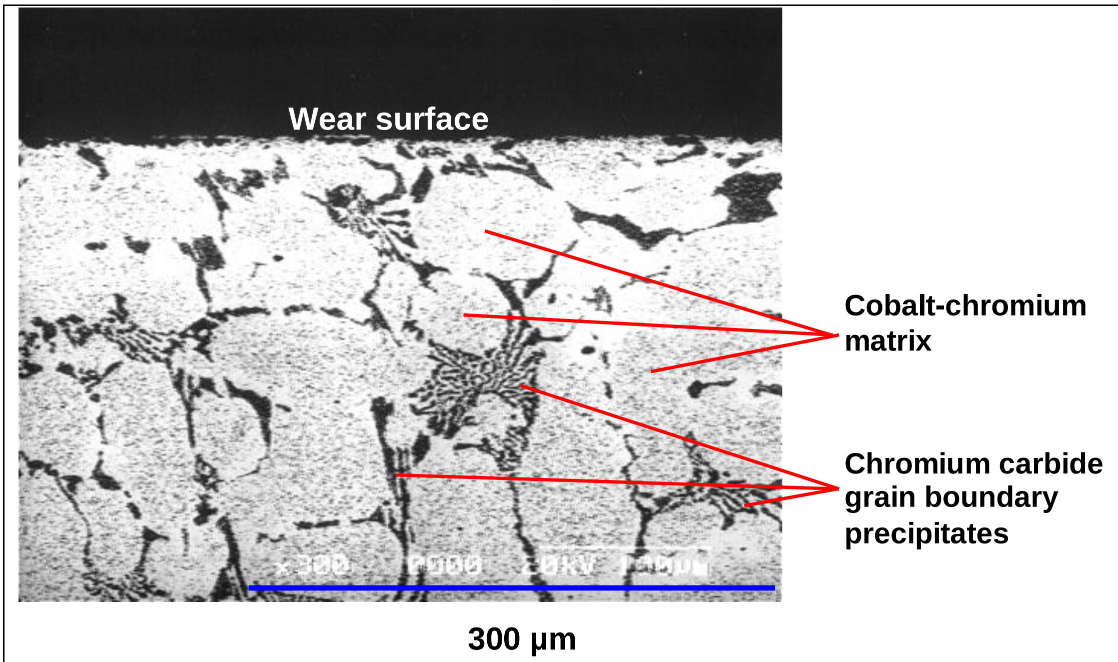
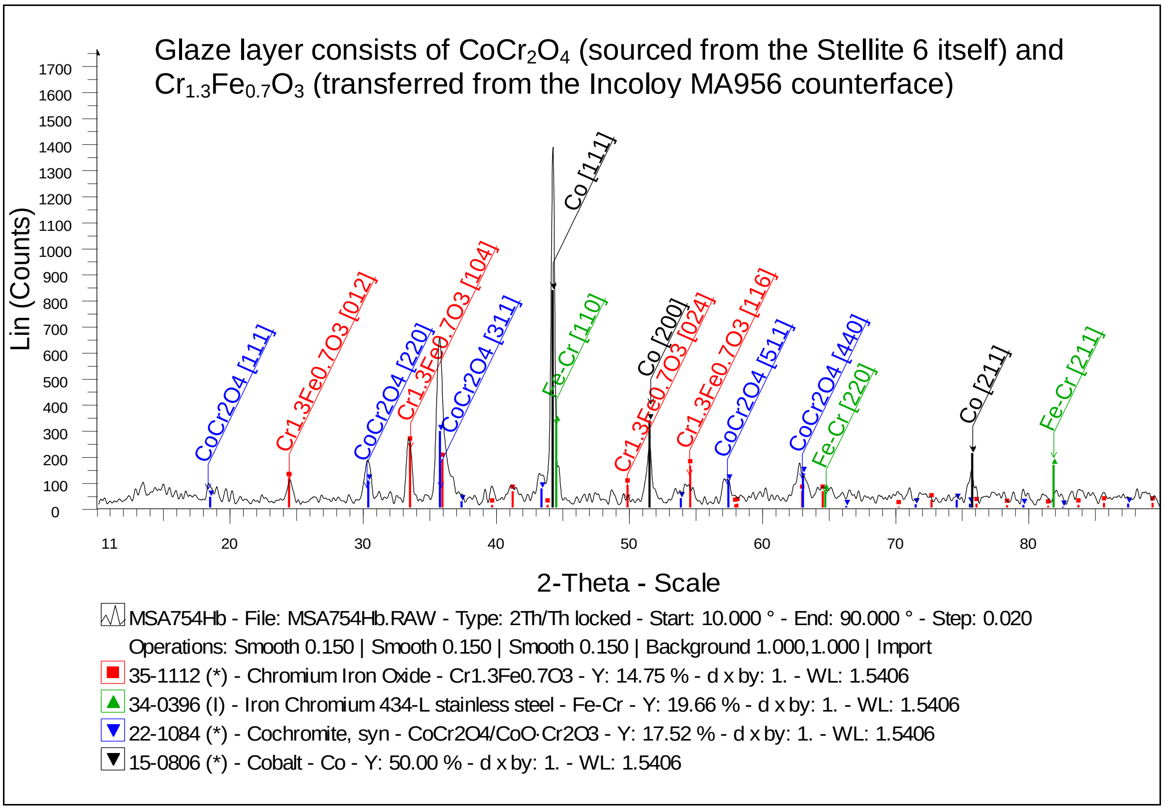


Figure 5.C6: XRD for Stellite 6 versus Incoloy MA956 – 0.314 $m.s^{-1}$

(load = 7N, sliding distance = 4,522 m, temperature = 750°C)



5.3.8.4 Hardness Data at 0.314 $m.s^{-1}$ – Stellite 6 versus Incoloy MA956

The presence of chromium carbides at the grain boundaries led to erratic values of hardness for Stellite 6 worn against an Incoloy MA956 counterface during hardness depth profiling (Figure 5.C7), in a manner similar to that observed for Stellite 6 worn against a Nimonic 80A counterface (Figure 5.22). Again, no clear pattern of variation in hardness could be observed in the sub-surface layers that would indicate a work-hardening effect, however, as with Stellite 6 versus Nimonic 80A, small differences in reflectivity enabled estimation in differences in hardness between matrix-only and carbide rich areas.

Matrix values for the Stellite 6 samples were in general between 4.4 GPa and 6 GPa. Carbide values in comparison were between 5.8 GPa and 10.85 GPa, the highly erratic nature of which can be accounted for by the difficulty in positioning the hardness indenter over a carbide rich region (the thickness of such carbides was in general between 10 and 15 μm). In practice, carbide hardness was probably much higher, as hinted by a value of 18.04 GPa being obtained for a region of carbides at a depth of 0.84 µm into the material.

The glaze layers formed on the wear scar surfaces of the Stellite 6 samples were of variable hardness, though values (Table 5.C1 - mean value 9.93 GPa) in general were greater that those obtained for the Stellite 6 matrix (mean value 5.39 GPa) and roughly equivalent to that of the carbides (mean value 9.42 GPa). However, the Vickers micro-indenter even with a 50 g load did more often than not penetrate the extremely thin glaze layers (no more than 3 µm thick) into the Stellite 6 sample material underneath. It is therefore probable that hardness values for the glaze layer were greater than those actually obtained.

Figure 5.C7: Variation in hardness with increasing distance from the sliding surface for both the cobalt rich matrix and the carbide precipitates in Stellite 6 slid against an Incoloy MA956 counterface

(sliding speed = 0.314m.s^{-1}, load = 7N, temperature = 750°C, sliding distance = 4,522 m, hardness values in GPa, Vickers indenter, 50 g load)

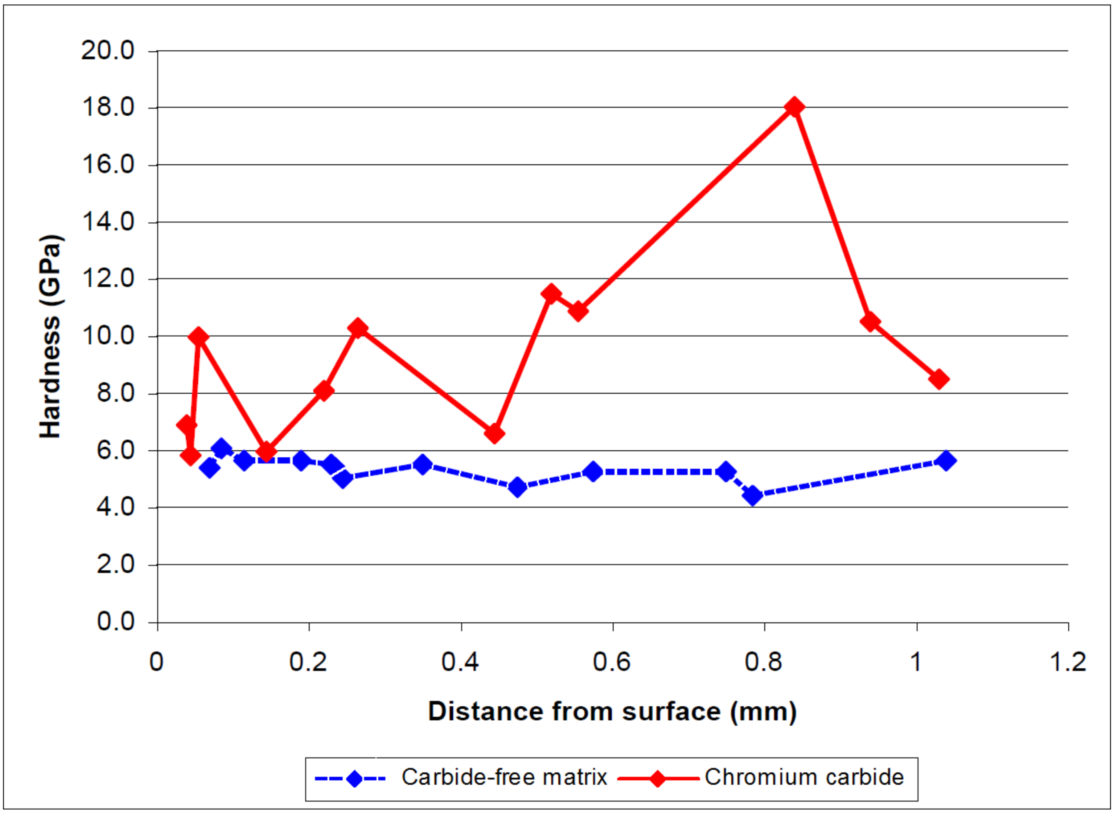


Table 5.C1: Hardness data for glaze, Stellite 6 versus Incoloy MA956

(sliding speed = 0.314m.s^{-1}, load = 7N, temperature = 750°C, sliding distance = 4,522 m, hardness values in GPa, Vickers indenter, 50 g load)

14.21	Mean hardness of glaze = 9.93 GPa
10.29	
11.48	
7.58	
6.06	

Figure 5.C8: Compacted oxide produced on Stellite 6 samples slid against a Incoloy MA956 counterface at 0.314 m.s^{-1} – optical images

(load = 7N, sliding distance = 4,522 m, temperature = 750°C)

15 mm

Highly worn wear scar, with some transfer of metallic material to form asperities. Glaze layers have formed primarily on the peaks of the asperities, with some unincorporated loose debris collecting in the counterface wear track.

5.3.8.5 Incoloy MA956 Counterface – Stellite 6 versus Incoloy MA956

A highly worn wear scar was formed on the Incoloy MA956 counterface on sliding against a Stellite 6 sample (Figure 5.C8). Material up to a depth of 1.5 mm was removed from the counterface early during the wear process, with some readhesion of metallic debris taking place during the early run-in stage to form asperities in the wear scar. Evidence of this readhesion is the height of the asperities, some of which rise up to 1.5 mm above the original surface of the Incoloy MA956 counterface.

The later generation of glaze was restricted to the peaks of these asperities, where they were in contact with the Stellite 6 sample surface. Other loose oxide has also collected within the Incoloy MA956 counterface wear track.

As for the compositions of the asperities and the glaze, it is unclear whether they were formed from readhered Incoloy MA956 debris, transferred Stellite 6 material or a mixture of both.