5. DISCUSSION

This chapter discusses the results obtained during the tests. It is arranged as follows:

- Ideal wear rate of WC-12wt%Co;
- Effect of SiC grit breakdown on WC-12wt%Co wear rate;
- Effect of wear debris on WC-12wt%Co wear rate;
- Effect of applied load on WC-12wt%Co wear rate.

5.1 "Ideal" wear rate of WC-12wt%Co

The "Ideal" wear rate of WC-12wt%Co under two-body dry abrasive wear testing using SiC abrasive paper remained constant with respect to time at both loads tested. This ideal behavior represents a wear response in which the SiC grits would maintain their effectiveness in removal of the hardmetal material as time progresses. However, this response is unrealistic, as the wear process is influenced by a variety of factors that have been mentioned in chapter 2. The results of the "Ideal" wear tests provide a foundation on which the effects of SiC grit breakdown and wear debris on the WC-12wt%Co wear rate may be evaluated. In the "Ideal" wear tests the SiC abrasive paper was changed after each test run, hence the SiC abrasive grit morphology is similar for the duration of the test, giving an approximately constant wear rate as shown in figure 4.5. The initial variation in the wear rate during the first 30 seconds is possibly due to bedding in effects of the polished specimens.

Figure 5.1 shows schematically what happens to the SiC abrasive grits as wear progresses. The stress on the specimens for each test run (2.4 seconds) is high since the grit area (grit tip) in contact with the specimen is small. The grossly exaggerated schematics of the WC grains and SiC grits show that the SiC grit size was greater than the WC grain size. Therefore, the contact zone between a single SiC grit and the specimen includes many WC grains causing the hardmetal to respond as a homogeneous solid under wear. Plowing was found to be the dominant wear mechanism leading to the formation of grooves with material pile-up along the groove edges (refer to the SEM micrographs of the worn surfaces in section 4.4.1.1). Similar observations were made by Sin et al [2]. The size of the grooves varied from 6µm to 51µm due to the non-uniform SiC grit size distribution. The sizes of the grooves also depend on the stress exerted on the specimen by the sample holder and the weights. There was smearing of material on the side and leading edge of the grooves. Pits, material pile-up, cracked WC grains and fragments of severely worn WC grains were also observed. These features are characteristic of WC-Co alloys worn under hard abrasion mode (see section 2.2.1.9.1) in which the ratio of SiC hardness to the WC-12wt%Co hardness is greater than 1.2, i.e. 2.0 > 1.2.

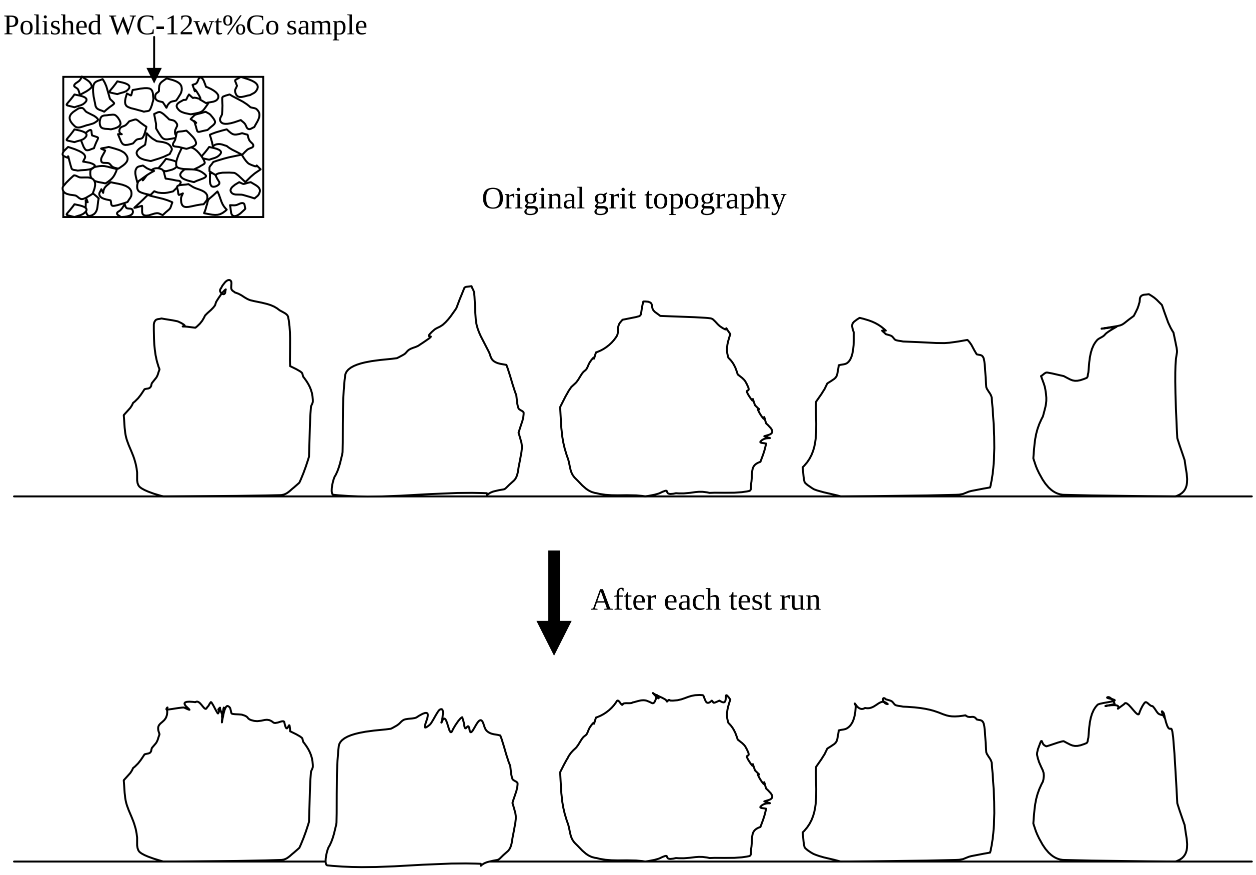

Figure 5.1: Schematic diagram of SiC abrasives before and after wear for the "ideal" wear condition.

5.2 Effect of SiC breakdown on WC-12wt%Co wear rate

The SiC abrasive break down under two-body dry abrasive wear resulted in a decrease in WC-12wt%Co wear rate at both loads tested. This effect was determined by performing the wear tests and retaining the SiC abrasive paper for the duration of the wear tests but removing the wear debris periodically after each test run (i.e. after every 2.4 seconds). The decrease in wear rate occurred because of the reduction in the effective contact stress on the specimens. During wear, the SiC abrasives were also subjected to wear and fractured. The asperities of the abrasives were initially in contact with the specimen and these were removed as wear progressed resulting in an increase in grit/specimen contact area. Since the load remained constant during a wear test, the stress on the specimens was reduced, resulting in the observed decrease in wear rates.

Figure 5.2 shows that as wear progressed, the SiC grits blunted with time and the effective grit/specimen contact area increased. As the abrasives blunted their cutting ability was reduced resulting in lower wear rates. This is in agreement with the conclusions by Viswanadham et al [1] and Sin et al [2]. The increased grit/specimen contact area also leads to a wider distribution of the contact stress. The amount of material removed decreased with time. This shows that the SiC blunting decreased with time, resulting in a decrease in WC-12wt%Co wear rates at longer time periods.

From the SEM micrographs, there was a greater degree of severe cracking and fragmentation of worn WC grains but fewer wear grooves compared to the "Ideal" wear condition. The possible reason is that the mechanisms for the groove formation and WC grain cracking were different. During wear the hardmetal is subjected to stress due to the applied load. For a constant load, the stress distribution area widens as the grit/material surface contact area increase as mentioned above. At high contact stresses, abrasives cut through the WC grains and Co forming deep grooves as also observed by Larsen-Basse et al [11]. At lower stresses, the Co binder is extruded out of the hardmetal surface by compressive stresses ahead of and to the sides of the abrasive leading to cracking and fragmentation of the WC grains. There were a greater degree of areas of visible WC grains compared to the "Ideal" wear condition due to Co removal by extrusion. The wear mechanisms were predominantly cracking and fragmentation of WC grains due to Co binder removal by extrusion which were also observed by Larsen-Basse et al [11,22] for hard abrasive wear.

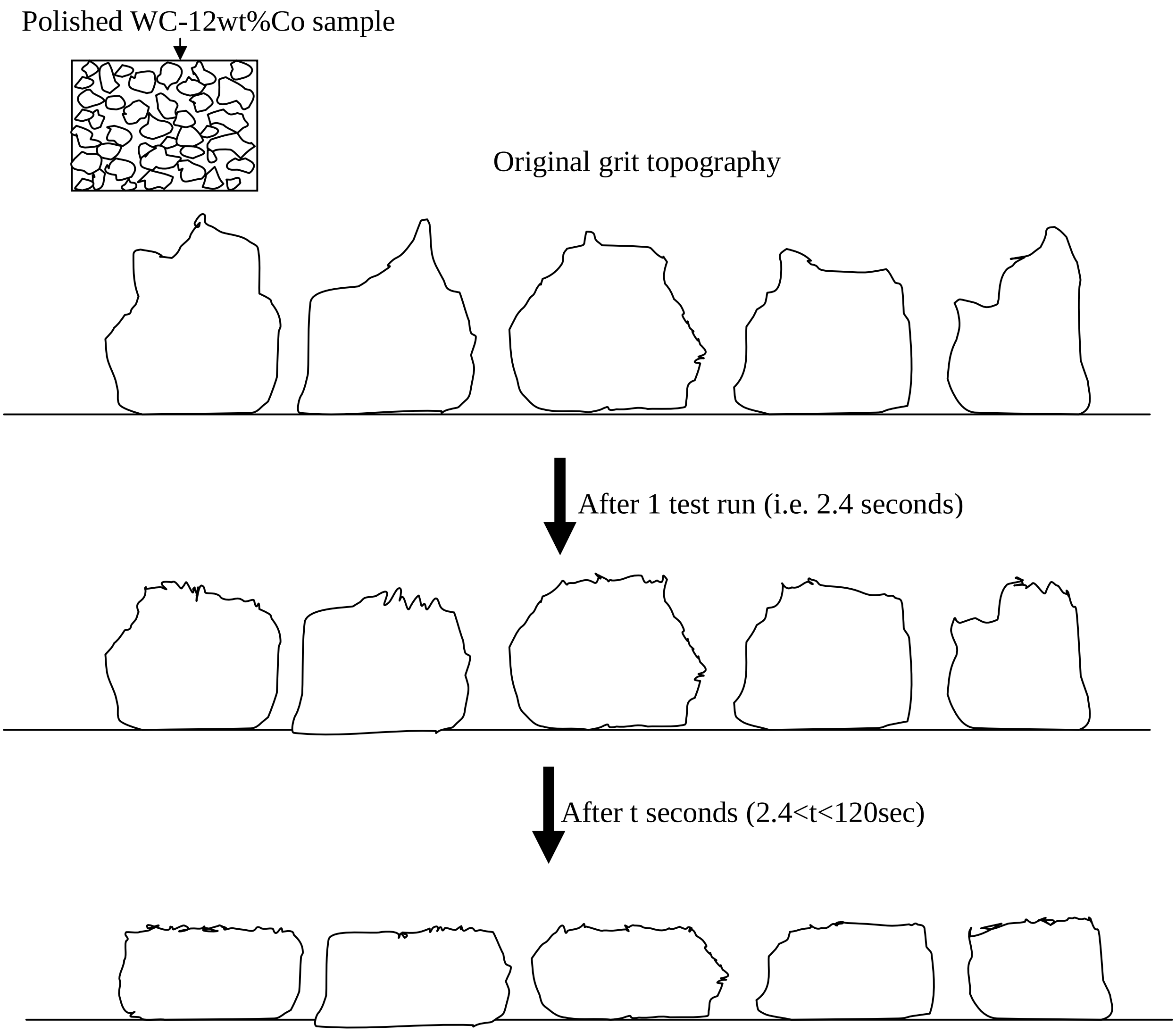

Figure 5.2: Schematic diagram of the SiC abrasive grits before and after wear under "No debris" wear condition. The grits become blunt and the grit/sample contact area increases.

5.3 Effect of wear debris on WC-12wt%Co wear rate

In reality, the material wear rate is affected by the abrasive breakdown, wear debris and other factors such as temperature and humidity. As wear progresses, the abrasives are also subjected to wear, forming wear debris. Sin et al [2] had reported that the wear debris clog the interstices between the abrasives increasing the effective grit diameter resulting in a reduction in wear rate. In the present work when the wear debris and the SiC abrasive paper were retained for the duration of a wear test, the WC-12wt%Co wear rate decreased. As discussed in section 5.2, as wear progressed, grits broke down, blunted and the effective grit/specimen contact area increased leading to a reduction in WC-12wt%Co wear rate.

When the wear debris and the SiC abrasive paper were retained during a wear test, the debris became "trapped" between the abrasive grits as shown schematically in figure 5.3. This trapped wear debris clogged the interstices between the grits thereby increasing the grit diameter; thus causing a further increase in the effective grit/specimen contact area. This caused a further reduction in wear rate with time as seen in figure 4.8. A statistic analysis of the 2.16N load results showed a significant difference in 95 percent confidence interval as shown in appendix 1.

The dominant wear features observed from the plan views were grooving, severe cracking and fragmentation of WC grains. There was a greater degree of cracking and fragmentation of WC grains compared to the "Ideal" and "No debris" conditions. This is because the stress on the specimens was lower due to the increased grit diameter by the debris. The wear mechanisms were for hard abrasive wear i.e. grooving and cracking and fragmentation of WC grains due to Co binder extrusion similar to those for the "No debris" wear condition.

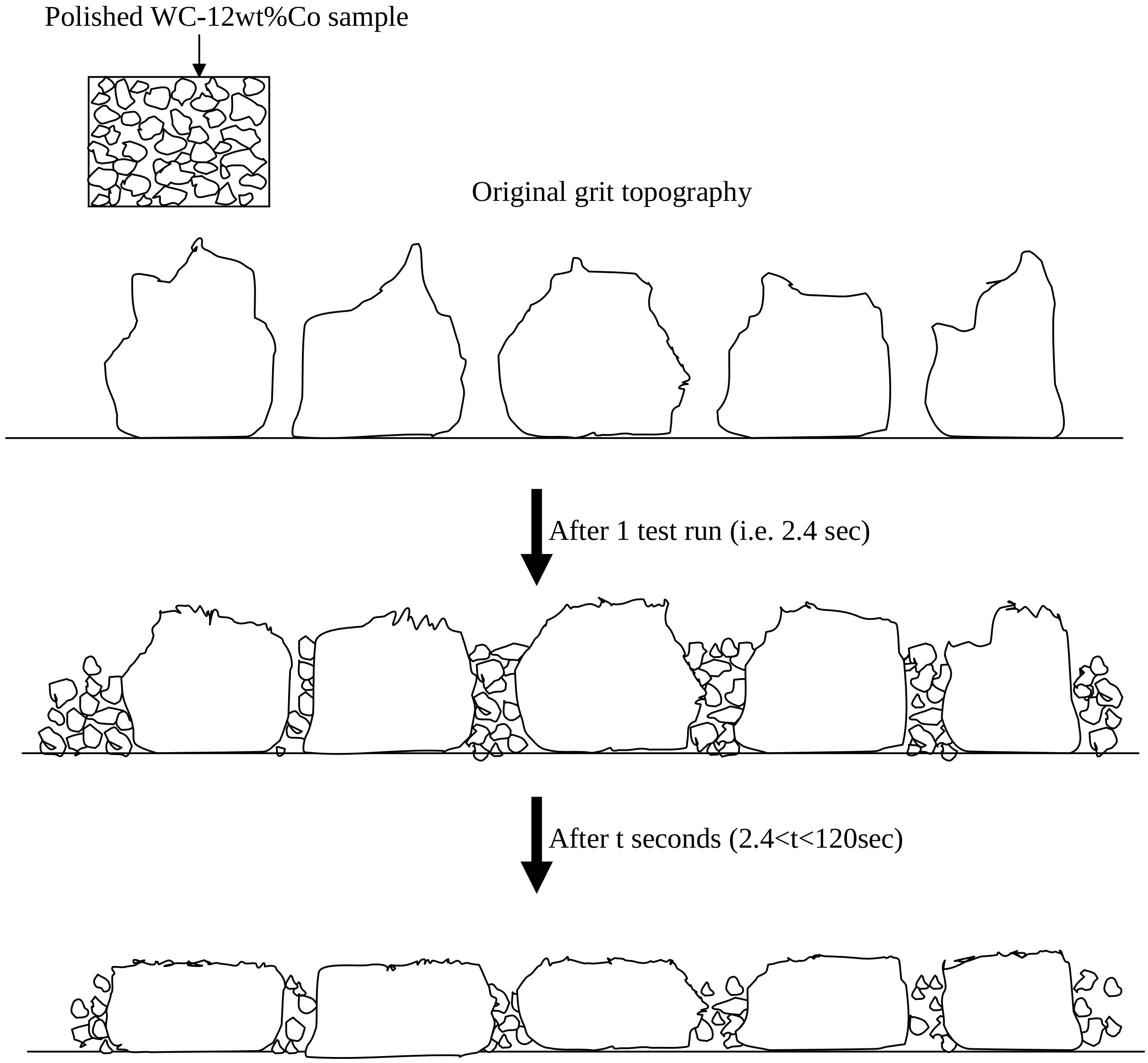

Figure 5.3: Schematic diagram of SiC abrasives before and after "With debris" wear condition.

5.4 Effect of applied load on WC-12wt%Co wear rate

The applied load was increased by 25% and the WC-12wt%Co wear rate in the "Ideal" wear condition increased by 43% as shown in figure 5.4. These findings confirm that the wear rate increases as the load is increased, in agreement with other authors [1,2,9,14,15,17,26]. Due to the difference in hardness values, the SiC grits indent the specimen. As the load increased, the depth of penetration of the abrasives into the specimen increased resulting in an increased material mass loss; also concluded by Viswanadham [1]. This resulted in deeper groove formation at the high loads. Sin et al [2] concluded that the linear dependence of wear rate on the applied load was due to the increase in the number of SiC grits in contact with the specimen as the load increases. Therefore the asperities that did not make contact at low load are now making contact. This results in greater mass loss at high load since there would be more grits in contact with the specimen.

For the “No debris” wear conditions, the wear rate was initially greater for high load compared to low load due to the increase in depth of penetration of the grits to the specimen in agreement with the literature [1]. The reason for the decreased wear rate could be the reduced stress as the abrasives deteriorate and become blunt. There was greater grit deterioration at high load due to increased stress on the abrasives resulting in a greater increase in effective grit/surface contact area than at low load. The increased effective grit/surface contact area led to the low wear rate and a greater degree of cracking and fragmentation of the WC grains. In these experiments the size of the wear debris removed was similar for both loads (see figure 5.5) but the amount of debris removed was more at high load than at low load. This increase in the amount of debris collected as the applied load increased occurred because of the increase in the number of grits in contact with the specimen at high load; as also concluded by Sin et al [2]. This resulted in more grit blunting at high load than low load leading to the observed decrease in WC-12wt%Co wear rate after approximately 20 seconds in figure 5.4.

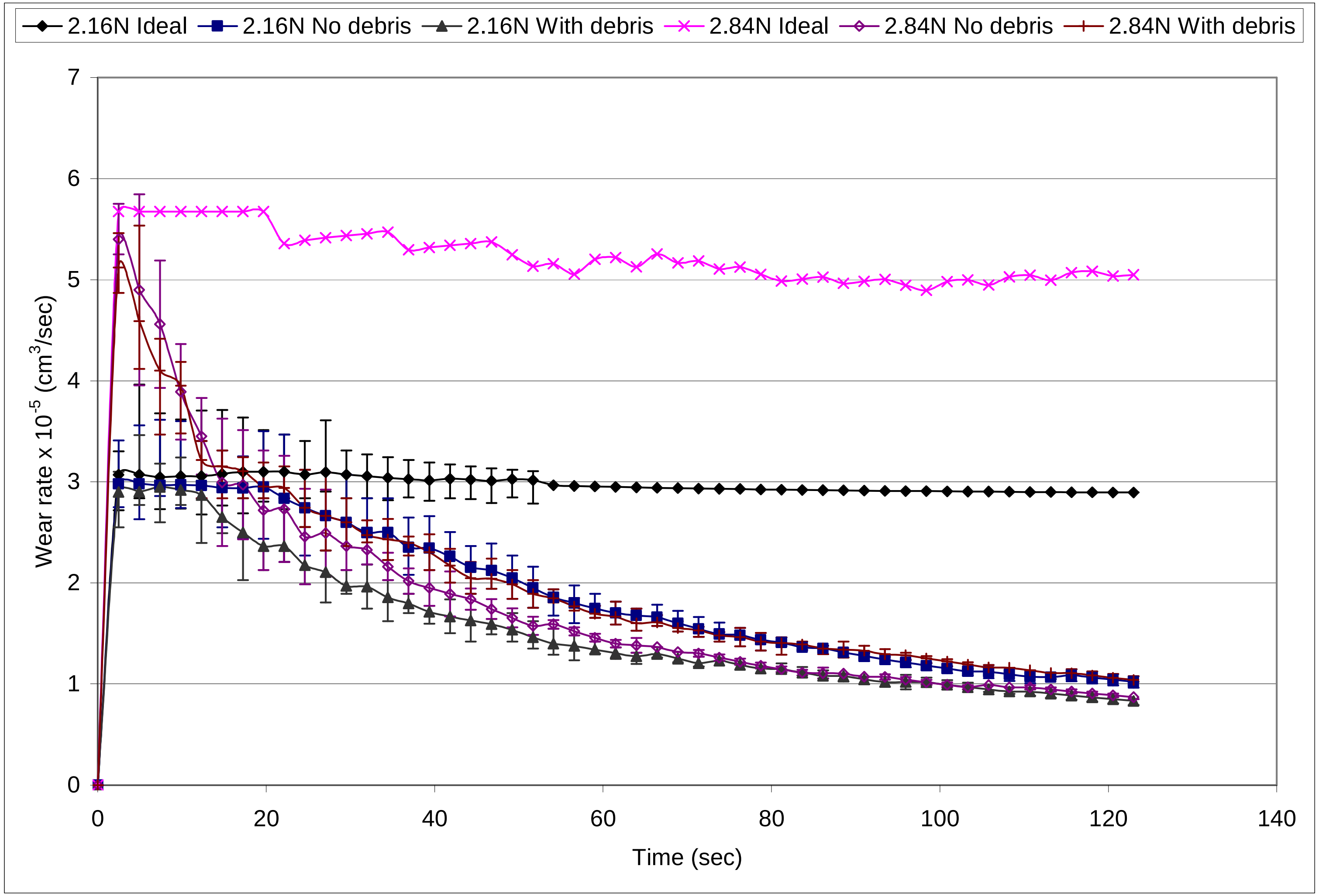

Figure 5.4: Graph of WC-12wt%Co wear rate versus time summarizing the results obtained.

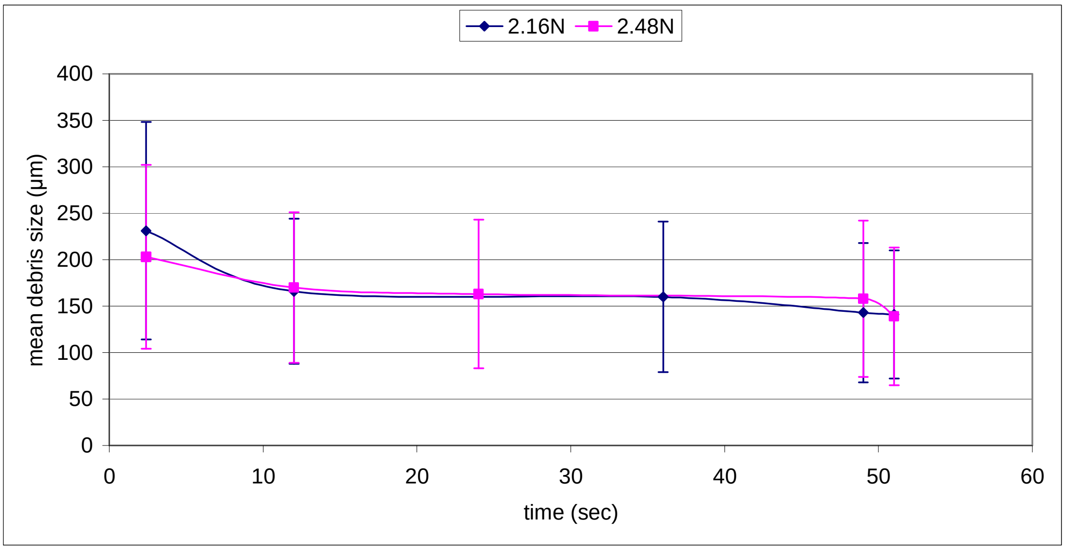

Figure 5.5: Graph of size of wear debris versus time for the 2.16N and 2.84N loads.

For the "With debris" wear condition, as the load increased, the amount of material removed also increased in agreement with the literature [1] (compare 2.16N and 2.84N for "With debris" conditions in figure 5.4). The "No debris" wear rate was lower than the "With debris" wear rate at 2.84N. At high load more SiC grits are in contact with the surface, therefore more SiC grits are worn. As time progresses, clogging occurs under the "With debris" condition increasing the effective grit diameter. The number of less worn grits was "more" in the "With debris" condition than the "No debris" condition. This resulted in the slightly higher wear rate observed. A statistic analysis in appendix 2 showed a significant difference in results for the 'No debris" and "With debris" conditions under 2.84N load for 95 percent confidence interval.

The wear mechanisms observed in all conditions at high load were grooving and cracking and fragmentation of WC grains due to Co binder removal by extrusion. The grooves were deeper compared to those observed at low load because the depth of penetration of the grits to the specimen was greater at high load. There was also a greater degree of cracking and fragmentation of WC grains due to the increased effective grit/surface contact as grits deteriorate and debris formed.