Comparison

The comparison of friction and wear behaviour of C/C and C/C-SiC composites in all environments is discussed in this chapter. The results from unidirectional and reciprocating sliding are also compared in this chapter.

7.1. Comparison of unidirectional and reciprocating sliding

7.1.1. Dry Environment

Fig. 7.1 and 7.2 shows the comparison of friction and wear behaviour respectively, for C/C and C/C-SiC composites in unidirectional and reciprocating sliding in case of dry environment.

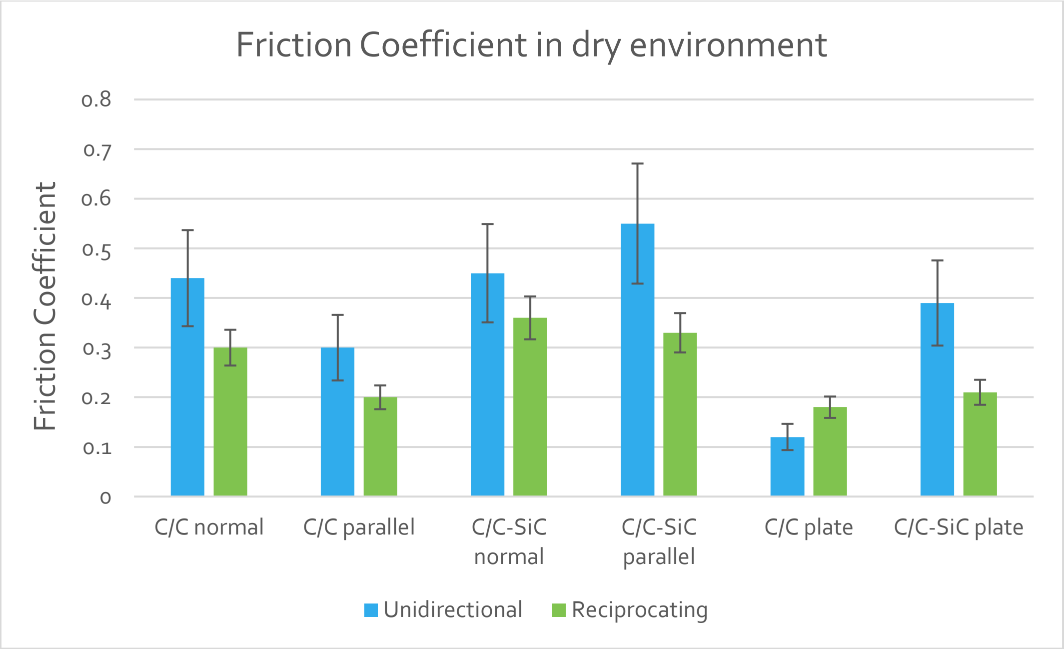

Fig. 7.1. Bar diagram showing variation of friction coefficient with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under dry environment.

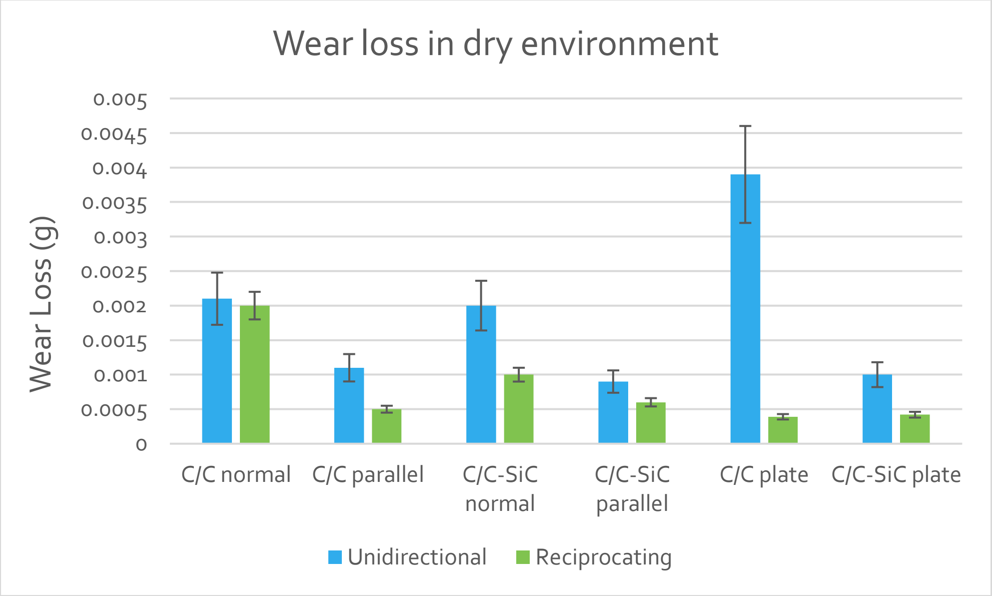

Fig. 7.2. Bar diagram showing variation of wear loss with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under dry environment.

It can be observed from Fig. 7.1 that friction coefficient for unidirectional sliding was more as compared to reciprocating sliding except for C/C composites in non-conformal hertzian contacts. This may be attributed to the fact that due to generation of high and localized stresses, and repeated sliding over same area in case of non-conformal contacts for C/C composites, disruption of friction film took place readily. A maximum of 40% variation and a minimum of 20% variation in friction coefficient were observed in case of C/C-SiC parallel and C/C-SiC normal respectively for low conformity contacts. C/C normal showed 32% variation and C/C parallel showed 33% variation in friction coefficient.

The comparison of wear loss for unidirectional and reciprocating sliding is shown in Fig. 7.2. It can be observed that C/C and C/C-SiC composites wore out more readily in unidirectional sliding as compared to reciprocating sliding. For low conformity contacts, a maximum of 55% variation in wear loss was observed for C/C parallel, and a minimum of

4.76% variation was observed for C/C normal. C/C-SiC normal showed 50% variation in wear loss and C/C-SiC parallel showed 33% variation. It was observed that C/C-SiC composites showed 58% variation in wear loss for non-conformal hertzian contacts whereas C/C composites showed a very large variation of 351%.

7.1.2. Brake Oil Environment

Fig. 7.3 shows variation in friction coefficient for brake oil environment. It can be seen that maximum variation in friction coefficient was observed for C/C-SiC parallel whereas minimum variation was observed for C/C parallel in case of low conformity contacts. A variation of 50% was observed for C/C normal and a variation of 56% was observed for C/C-SiC normal.

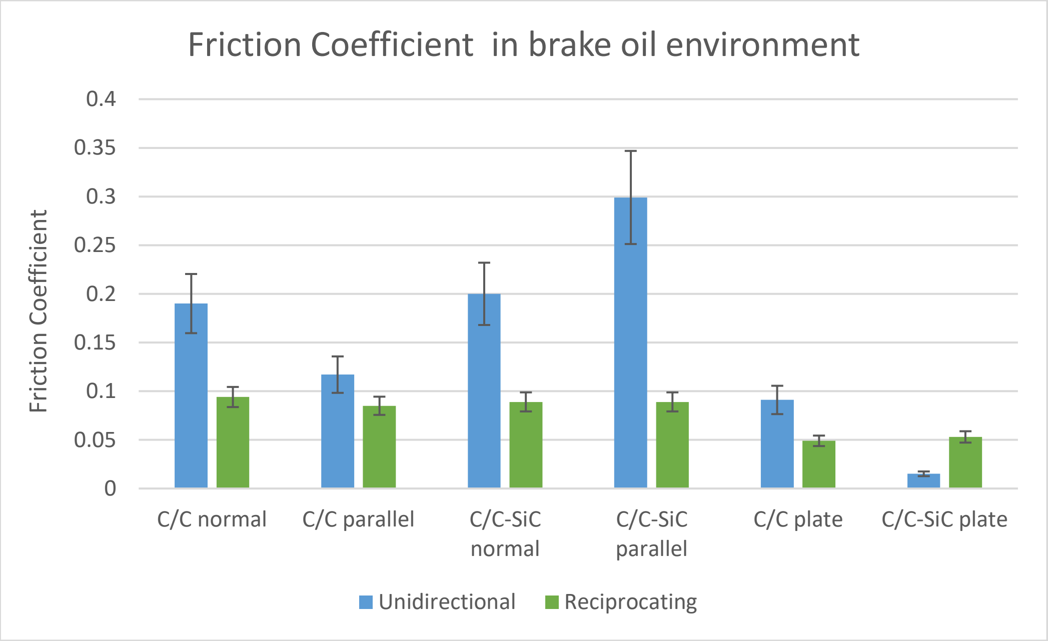

Fig. 7.3. Bar diagram showing variation of friction coefficient with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under brake oil environment.

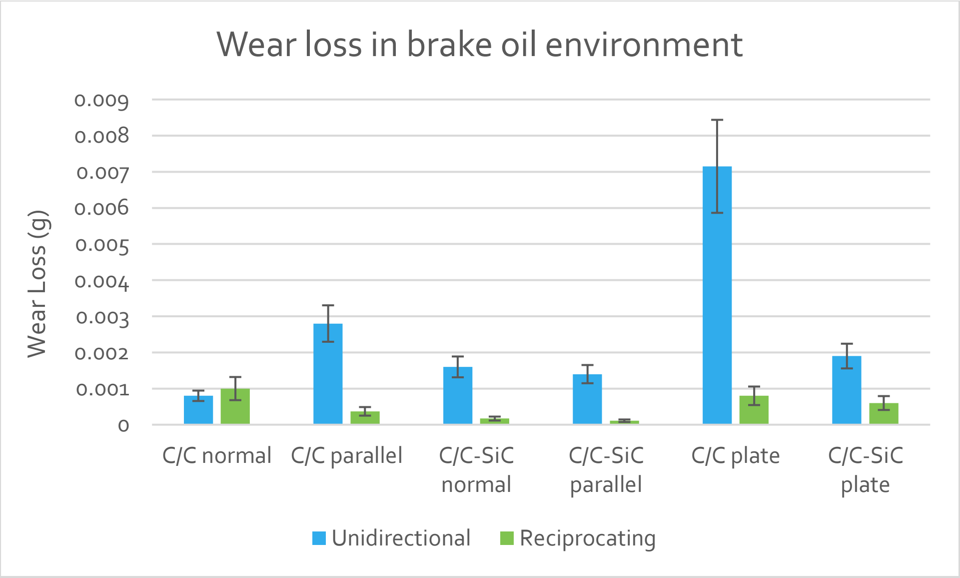

Fig. 7.4. Bar diagram showing variation of wear loss with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under brake oil environment.

In case of non-conformal hertzian contacts, a variation of 46% in friction coefficient and a variation of 251% was observed for C/C and C/C-SiC composites respectively. The friction coefficient was more in case of unidirectional sliding except for C/C-SiC composite in non-conformal contacts.

Fig. 7.4 shows the comparison of wear loss in brake oil environment. It was observed that there was very large difference in wear loss for unidirectional and reciprocating sliding in brake oil except for C/C normal. C/C composite showed almost 794% variation in wear loss in case of non-conformal hertzian contacts.

7.1.3. Freezing Environment

Fig. 7.5 shows the comparison of friction coefficient in freezing environment. Friction coefficient in case of unidirectional sliding was more as compared to reciprocating sliding. A maximum of 166% variation in friction coefficient was observed for C/C-SiC parallel and a minimum of 89% variation was observed for C/C normal for low conformity contacts. C/C parallel showed 131% variation and C/C-SiC normal showed 110% variation in friction coefficient. There was very less variation in friction coefficient in case of non-conformal contacts.

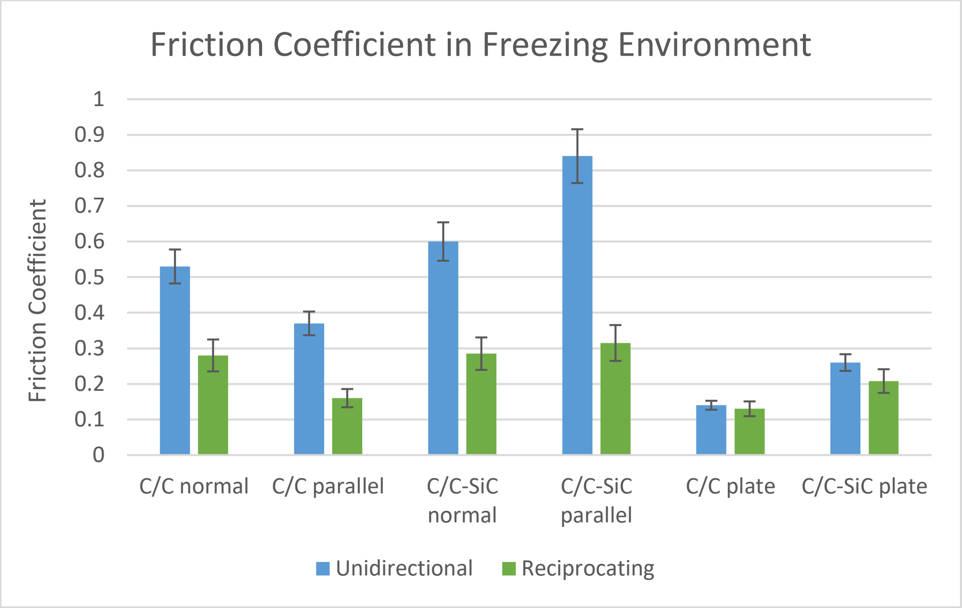

Fig. 7.5. Bar diagram showing variation of friction coefficient with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under freezing environment.

Fig. 7.6 shows comparison of wear loss in freezing environment. It can be seen that C/C composites exhibited more wear loss in reciprocating sliding as compared to unidirectional sliding in low conformity contacts. C/C normal showed 178% variation and C/C parallel showed 145% variation in wear loss. C/C-SiC normal exhibited less wear loss in reciprocating sliding whereas C/C-SiC parallel exhibited less wear loss in unidirectional sliding. A variation of 111% and a variation of 50% were observed for C/C-SiC normal and C/C-SiC parallel respectively.

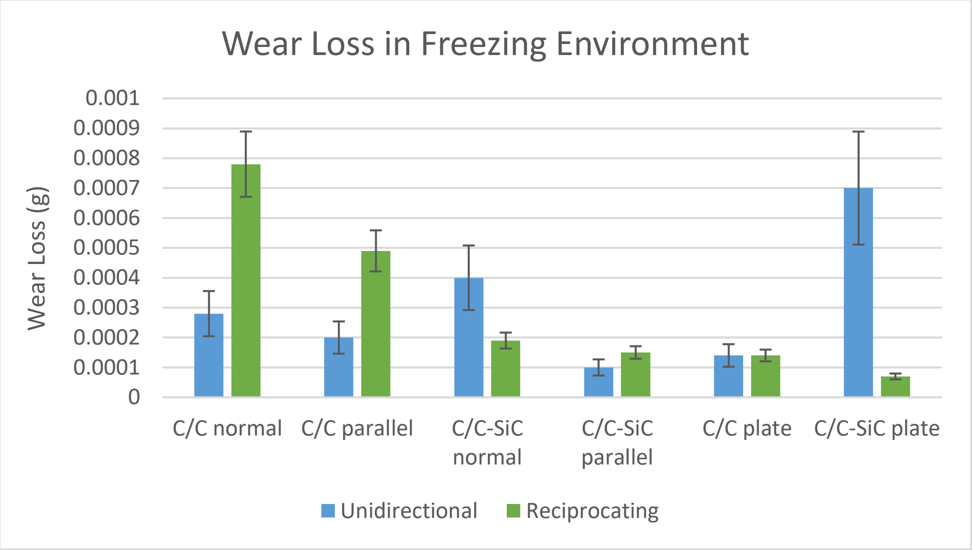

Fig. 7.6. Bar diagram showing variation of wear loss with orientation of laminates and conformity conditions for unidirectional and reciprocating sliding under freezing environment.

In non-conformal hertzian contacts, C/C composites exhibited same wear loss for unidirectional as well as reciprocating sliding. There was a variation of about 900% for C/C-SiC composites in non-conformal hertzian contacts.

7.2. Comparison of dry, oil, and freezing environment

7.2.1. Unidirectional Sliding

Fig. 7.7 shows the comparison of friction coefficient of C/C and C/C-SiC composites in dry, oil and freezing environment for unidirectional sliding. It can be observed from Fig. 7.7 that friction coefficient was highest in freezing environment in case of low conformity contacts. Lowest friction coefficient was observed for oil environment.

In case of non-conformal hertzian contacts, there was very less variation in friction coefficient among all the three environments for C/C composites. However, friction coefficient for C/C-SiC composites was reduced to a greater extent for oil environment in case of non-conformal hertzian contacts.

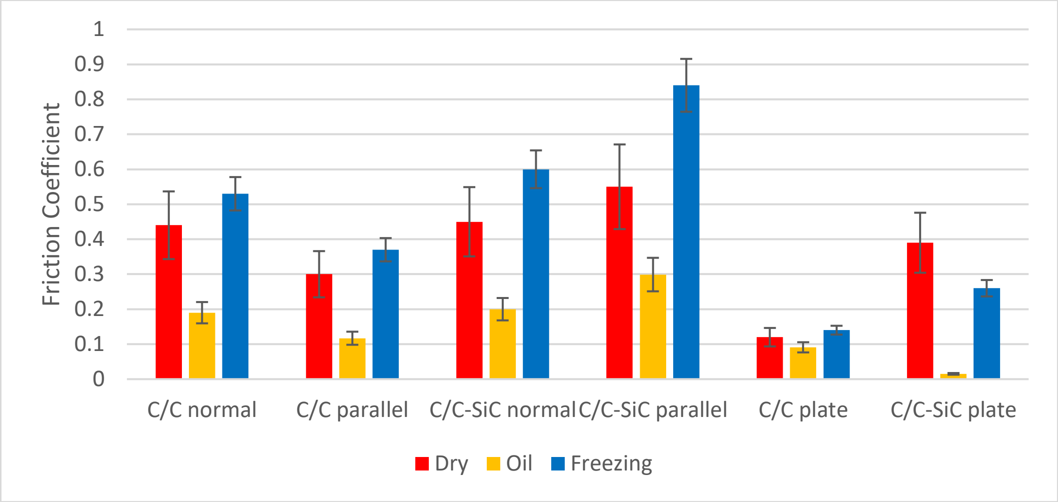

Fig. 7.7. Bar diagram showing variation of friction coefficient among all environments for different orientation of laminates and conformity conditions in unidirectional sliding.

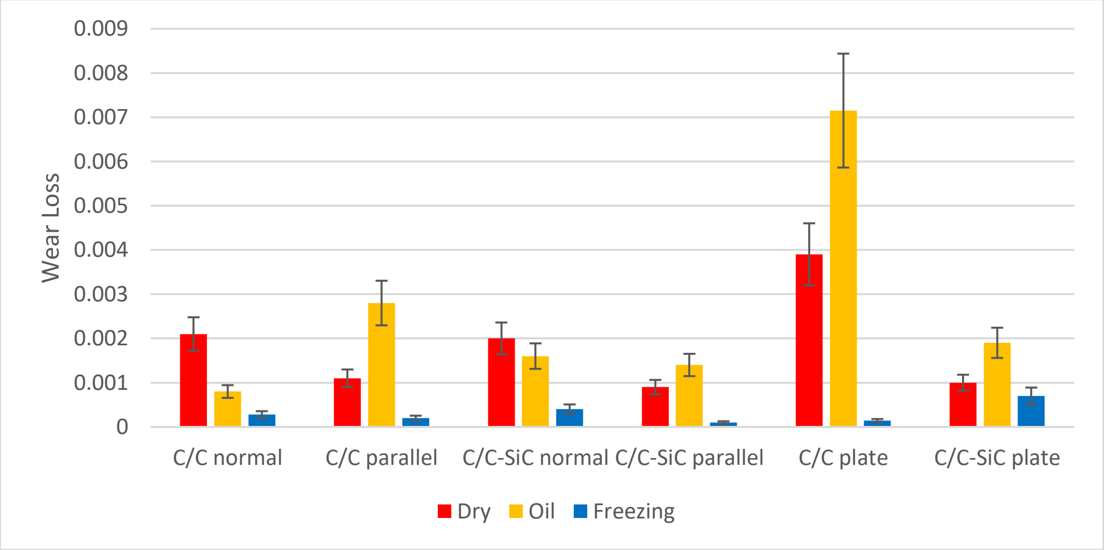

Fig. 7.8. Bar diagram showing variation of wear loss among all environments for different orientation of laminates and conformity conditions in unidirectional sliding.

Wear loss in case of freezing environment was lowest among all the three environments. In case of non-conformal hertzian contacts, wear loss for oil environment was highest.

7.2.2. Reciprocating Sliding

Fig. 7.9 shows the comparison of friction coefficient of C/C and C/C-SiC composites in dry, oil and freezing environment for reciprocating sliding. The difference in friction coefficient of C/C and C/C-SiC composites is less for dry and freezing environment. Friction coefficient for dry environment was more than that of oil and freezing environment, and the friction coefficient was lowest in oil environment.

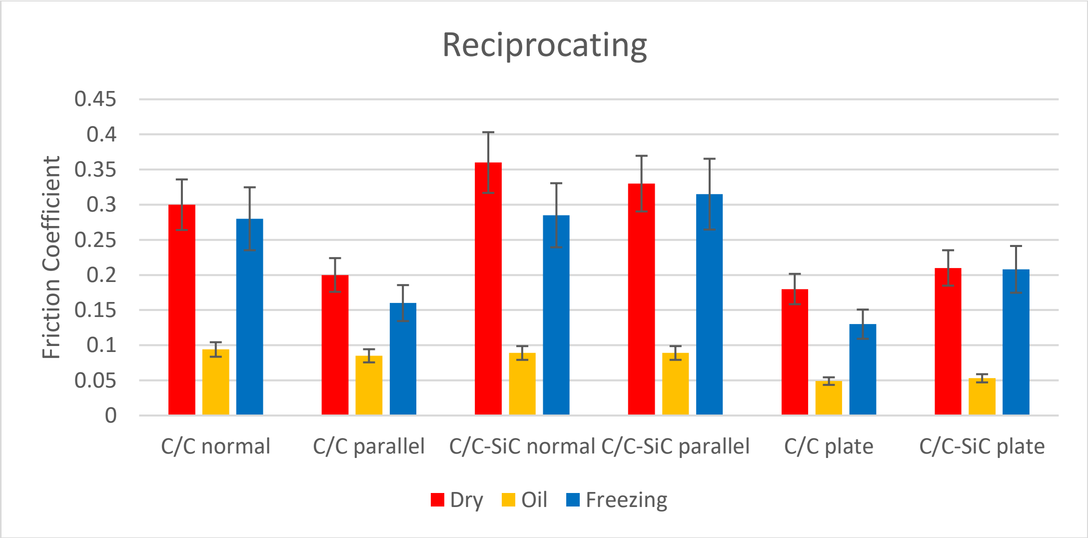

Fig. 7.9. Bar diagram showing variation of friction coefficient among all environments for different orientation of laminates and conformity conditions in reciprocating sliding.

The comparison of wear loss for reciprocating sliding among all the three environments is shown in Fig. 7.10. Highest wear loss was observed in dry environment for low conformity conditions and in oil environment for non-conformal hertzian contacts. There was lowest wear loss in freezing environment for non-conformal hertzian contacts.

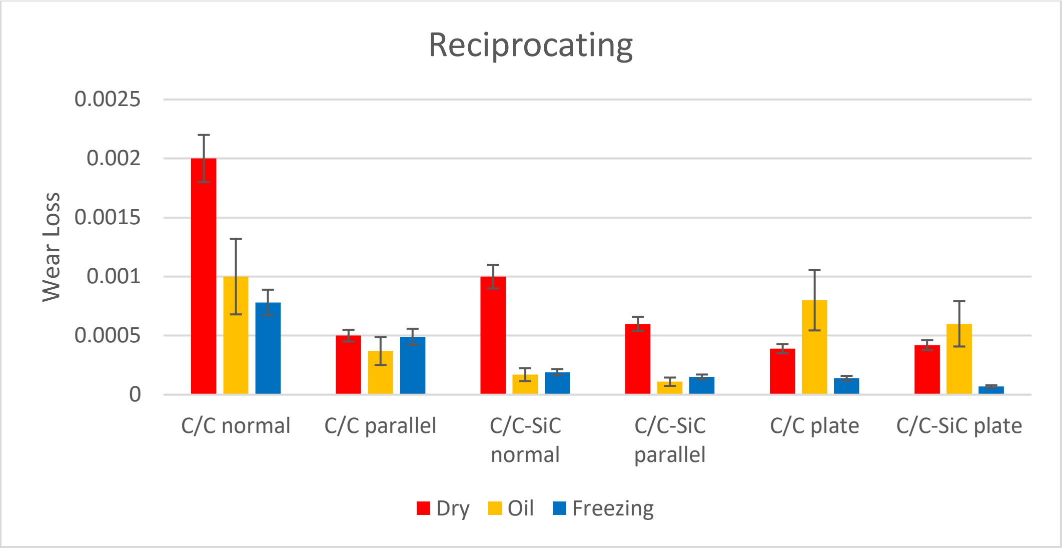

Fig. 7.10. Bar diagram showing variation of friction coefficient among all environments for different orientation of laminates and conformity conditions in reciprocating sliding.

7.2.3. Discussion

As depicted from Fig. 7.7, the lowest value of friction coefficient was observed in brake oil environment which was already expected due to presence of oil. However, the formation of friction film was less in case of brake oil environment because the oil got mixed with the wear debris and prevented its adherence to the contact surfaces. It can be observed that friction coefficient in freezing environment was more as compared to dry environment. Fibre fracture was observed in both environments (i.e., dry and freezing), but the formation of oxides was more prominent in case of freezing environment. This may be attributed to the increase in BET surface area in freezing environment which led to the hosting of more oxygen and water molecules on the surface of composites. Thus more oxides were formed which disrupted the friction film readily as compared to dry environment and hence resulted in more friction coefficient in case of freezing environment.

It can be observed from Fig. 7.8 that wear loss in brake oil environment was more for parallel orientation of laminates and less for normal orientation of laminates as compared to dry environment. This was due to more absorption of brake oil in case of parallel orientation of laminates (reason discussed in chapter 4) which softened the matrix and resulted in its easy ejection. However, less oil was absorbed in case of normal orientation of laminates and hence oil did not softened the matrix effectively. Thus the oil only lubricated the surface (normal orientation) and hence, less wear loss was shown. Furthermore, the wear loss in freezing environment was less as compared to dry environment. This was attributed to the oxide formation and increased resistance of fibres for its fragmentation (although fibre fracture occurred) in freezing environment (discussed in chapter 5). The formed oxides prevented direct contact between the contact surfaces and the fibres were not observed as small fragments which resulted in less wear loss in freezing environment as compared to dry environment.

In case of reciprocating sliding, both friction coefficient and wear loss were higher for dry environment as compared to freezing environment, as shown in Figs. 7.9 and 7.10. The sliding area is confined in reciprocating sliding due to which oxides formed in freezing environment repeatedly rolled in-between the contact surfaces (discussed in chapter 5). Thus direct contact was prevented and hence, less friction coefficient and wear loss were observed in freezing environment as compared to dry environment. However, it can also be observed from Fig. 7.10 that the wear loss in dry environment was more as compared to brake oil environment, despite softening of matrix in brake oil. This may be attributed to the change in sliding direction in case of reciprocating sliding. The change in direction generated stress in opposite direction which led to delamination and also peeling of friction film. Due to presence of brake oil, delamination and peeling were less and hence, wear loss was less in brake oil as compared to dry environment.