Chapter 6

CONCLUSIONS AND SCOPE

6.1 Main Conclusions

- *Insitu* formed Al_3Zr particles refine the Al-Mg matrix and also improve mechanical properties including % elongation as compared to base alloy.
- Presence of large Al_3Zr particles not only improve the wear resistance but also extend the working range in respect to applied load and sliding velocity. Hence, these composites can be used at higher loads/sliding velocities while being in mild wear regime, which widens their scope in different applications especially the applications requiring low wear and high coefficient of friction.
- Presence of *insitu* formed nano size ZrB_2 particles in hybrid composites also refine Al-rich grains. UTS, YS and hardness of the hybrid composites shows remarkable improvement as compared to base alloy and even % elongation is improved.
- The contributing strengthening mechanisms in hybrid (ZrB_2+Al_3Zr)/Al-Mg composites are dislocation, Orowan, grain-refining & solid solution. Among these mechanisms solid-solution and Orowan are predominant strengthening mechanisms.

- Wear rate with load shows that load/sliding velocity range is extended in hybrid composites and these can be used at higher loads/sliding velocity while being in mild wear regime. This phenomenon is further extended with increase in vol.% of ZrB_2 particles.
- COF of hybrid composite increases with increasing vol.% of ZrB_2 particles.
- Hybrid composite retains UTS almost equivalent to base alloy even at 200°C.
- The transition of mild to severe wear is shifted to higher temperature with incorporation of Al_3Zr and ZrB_2 particles in the Al-Mg alloy.
- Coefficient of friction increases continuously with test temperature.
- Mild/oxidative and severe/oxidative-metallic wear is observed at different combinations of parameters.

6.2 Scope of the Work

Tables 6.1 to 6.3 present a comparison of ambient temperature tensile properties, wear rate and coefficient of friction between present work and earlier work.

Table 6.1 – Comparison of tensile properties with previous work [Gautam and Mohan, 2015].

Composite	**YS (MPa)**	**UTS (MPa)**	**% Elongation**	**% improvement in UTS w.r.t. base alloy**	**Reference**
15vol.%Al_3Zr/AA5052 **(10vol.%Al_3Zr+3vol.%ZrB_2)/ AA5052**	**84.6** **116.5**	**118.5** **150.3**	**11.00** **13.01**	**33.15** **68.88**	**Present work**
Al–2Mg–2.5FeCu (*exsitu*)	74.0	98.0	4.45	-	[Mandal et al., 2008]
Al–2Mg–5Fe (*exsitu*)	74.0	112.0	1.65	-	[Mandal et al., 2006]
Al–2Mg–5FeNi (*exsitu*)	69.0	105.0	1.26	-	[Mandal et al., 2006]
2024Al/8.1 vol.%ZrB_2 (*insitu*)				about 50	[Tian et al., 2014]
AA6061–10% ZrB_2 (*insitu*)				31.77	[Dinaharan et al., 2011]
AlSi5/SiC/13p (*exsitu*)	49.0	148.0	2.00		[Cocen et al., 2002]
Al-20vol.%SiC (*exsitu*)	64.6	127.0	7.20		[Min et al., 2009]
ZL102/7wt.%TiB_2 (*insitu*)				24.90	[Han et al., 2002]
ZL104/6wt.%TiB_2 (*insitu*)				14.70	[Han et al., 2002]

Table 6.2 – Comparison of wear properties with previous work.

Material	Wear rate* (x10^{-12} m^3/m)	% reduction in wear rate w.r.t. base alloy	Reference
30 vol.%Al_3Zr/AA5052 **(10vol.%Al_3Zr+5 vol.%ZrB_2)/ AA5052**	**2.84** **3.32**	**52.59** **11.66**	**Present work**
AA6061-10 wt.% ZrB_2 (*insitu* composites)		38.87	[Dinaharan et al., 2012]
LM 13 alloy	3.8		[Akubulut et al., 1998]
LM 13-4 wt.% B_4C composite (*exsitu* composites)	4.85		[Radhika et al., 2015]
Al-20 wt.% Al_3Fe composite (PM composites)	3.01		[Agarwal et al., 2014]

*Load 40 N, sliding velocity 1 m/s

Table 6.3 – Comparison of COF with previous work for brakes and clutches.

Material	**Coefficient of friction**	**Reference**
30 vol.%Al_3Zr/AA5052 **(10vol.%Al_3Zr+5 vol.%ZrB_2)/ AA5052**	**0.37-0.71** **0.42-0.67**	**Present work**
Cast iron/ Cast iron	0.15-0.2	[Carvill, 1994]
Cast iron/Steel	0.15-0.2	
Woven asbestos/Cast iron or steel	0.3-0.6	
Molded asbestos/ Cast iron or steel	0.2-0.5	
Impregnated asbestos/ Cast iron or steel	0.32	
Steel band/Cast iron	0.18	

It is clear from Tables 6.1, 6.2 & 6.3 that in present study 15vol.%Al_3Zr/AA5052 *insitu* composite and (10vol.%Al_3Zr+3vol.%ZrB_2)/AA5052 hybrid composite exhibit higher/comparable UTS and YS w.r.t. previous work, and the ductility (11-13%) of these composites is much higher. Further, minimum wear rate and maximum coefficient of friction as compared to other materials mentioned in Table 6.2 and 6.3 is indicative of their suitability in tribological applications especially in clutch and brake systems.