

TABLE OF CONTENTS

Certificate	ii
Acknowledgments	v
Abstract	ix
Table of contents	xi
List of figures	xvii
List of tables	xxiii
List of abbreviations and symbols	xxiv
Preface	xxx
Chapter-1 Introduction	1-6
Chapter-2 Literature Review	7-56
2.1. Copper metal	7
2.2. Composites	7
2.3. Hybrid composites	9
2.4. Classification of composite materials	10
2.4.1. Classification based on matrix	10
2.4.1.1. Metal matrix composites (MMCs)	10
2.4.1.2. Polymer matrix composites (PMCs)	10
2.4.1.3. Ceramic matrix composites (CMCs)	11
2.4.1.4. Carbon-carbon composites (CCCs)	11
2.4.2. Classification based on the reinforcement	12
2.4.2.1. Fiber reinforced	12
2.4.2.2. Particle reinforced	12
2.4.2.3. Structural composites	13

2.4.2.3.(a).Sandwich composites	13
2.4.2.3.(b).Laminated composites	13
2.5. Type of reinforcements used in metal matrix composites	13
2.6. Advantages of metal matrix composites and hybrid composites	15
2.7. Synthesis techniques to develop copper-based metal matrix composites and hybrid composites (MMCs)	15
2.7.1.In-situ process	16
2.7.2.Deposition techniques	17
2.7.3.Two-phase processes	17
2.7.3.1.Compo-casting/rheo-casting	17
2.7.3.2.Spray deposition	17
2.7.4.Solid phase processes	18
2.7.4.1. Diffusion bonding	18
2.7.4.2. Powder metallurgy	18
2.7.5.Liquid phase processes	19
2.7.5.1. Melt stirring	19
2.7.5.2. Gas pressure infiltration	19
2.7.5.3. Squeeze casting	19
2.8. Stir-casting technique	20
2.9. Properties of copper metal matrix composites and hybrid composites	22
2.9.1.Microstructural and physical properties	22
2.9.2.Mechanical properties	28
2.9.2.1.Strengthening mechanisms in composites and hybrid composites	32
2.9.3.Dry sliding friction and wear behaviors of metal matrix	39

composites and hybrid composites	
2.9.4.Dry sliding friction and wear behavior of copper composites and hybrid composites	45
2.10. Worn surface characterizations and analysis	49
2.11. Electrical properties of metal matrix composites	52
2.12. Formulation of the problem	54
Chapter-3 Experimental Procedure	57-72
3.1. Materials selection for development of copper-based hybrid composites	57
3.2. Development of copper-based hybrid composites	58
3.3. Characterizations	62
3.3.1.X-ray diffraction analysis of hybrid composites	62
3.3.2.Microstructural evaluation of hybrid composites	63
3.3.3.Density measurement of hybrid composites	64
3.3.4.Hardness measurement of hybrid composites	64
3.3.5.Compression strength measurement of hybrid composites	65
3.3.6.Measurement of tensile strength of hybrid composites	66
3.3.7.Electrical resistivity measurement of hybrid composites	67
3.3.8.Dry sliding friction and wear testing of materials	68
3.3.9.Examination of worn surfaces	71
Chapter-4 Results and Discussion	73-130
Microstructural, Physical and Mechanical Properties	
4.1. Morphological study of reinforcing particles	74
4.2. Binary reinforced copper-based hybrid composites	79
4.2.1.Microstructural study	79
4.2.2.Physical properties	85

4.2.3.Mechanical properties	87
4.3. Tertiary reinforced copper-based hybrid composites	92
4.3.1.Microstructural study	92
4.3.2.Physical properties	101
4.3.3.Mechanical properties	102
4.4. Comparison of physical and mechanical properties of binary and tertiary reinforced copper-based hybrid composites	108
4.5. Discussion	109
4.5.1.Binary reinforced copper-based hybrid composites	110
4.5.2.Tertiary reinforced copper-based hybrid composites	119
Chapter -5 Results and Discussion	131-182
Dry Sliding Friction and Wear Behaviors	
5.1. Dry sliding friction and wear	131
5.2. Dry sliding friction and wear of binary reinforced copper-based hybrid composites	132
5.2.1. Dry sliding friction	132
5.2.1.1.Variation of coefficient of friction with sliding distance	132
5.2.1.2.Variation of average coefficient of friction with normal load	133
5.2.1.3.Variation of average coefficient of friction with hardness	134
5.2.2. Dry sliding wear	136
5.2.2.1.Variation of cumulative volume loss with sliding distance	136
5.2.2.2.Variation of wear rate with normal load	137
5.2.2.3.Variation of wear rate with hardness	139

5.2.3. Examination of worn surfaces	140
5.2.3.1. Worn surfaces at normal load of 9.81 N	140
5.2.3.2. Worn surfaces at normal load of 39.24 N	140
5.2.3.3. EDAX spectrum of worn surfaces at 39.24 N	143
5.2.4. Examination of wear debris	143
5.2.5. AFM analysis of worn surfaces	146
5.3. Dry sliding friction and wear of tertiary reinforced copper-based hybrid composites	147
5.3.1. Dry sliding friction	147
5.3.1.1. Variation of coefficient of friction with sliding distance	147
5.3.1.2. Variation of average coefficient of friction with normal load	148
5.3.1.3. Variation of average coefficient of friction with hardness	150
5.3.1.4. Variation of average coefficient of friction with B ₄ C content	151
5.3.2. Dry sliding wear	152
5.3.2.1. Variation of cumulative volume loss with sliding distance	152
5.3.2.2. Variation of wear rate with normal load	153
5.3.2.3. Variation of wear coefficient with hardness	155
5.3.2.4. Variation of wear rate with B ₄ C content	156
5.3.3. Examination of worn surfaces	157
5.3.3.1. Worn surfaces at normal load of 9.81 N	157
5.3.3.2. Worn surfaces at normal load of 39.24 N	157
5.3.3.3. EDAX spectrum of worn surfaces at 39.24 N	160

5.3.4. Examination of wear debris	162
5.3.5. AFM analysis of worn surfaces	162
5.4. Comparative study of friction and wear behaviors of binary and tertiary reinforced copper hybrid composites	165
5.5. Discussion	167
5.5.1. Binary reinforced copper-based hybrid composites	167
5.5.2. Tertiary reinforced copper-based hybrid composites	175
Chapter -6 Conclusions and Future Scope	183-188
References	189-206
List of Publications	207-208