

## LIST OF FIGURES

---

Figure No.	Caption	Page No.
Fig.2.1.	Classification of composite materials based on the matrix used	10
Fig.2.2.	Classification of composite materials based on the reinforcement used	12
Fig.2.3.	Type of reinforcements used in metal matrix composites	14
Fig.2.4.	Classification of the synthesis techniques to develop MMCs	16
Fig.3.1.	(a) Schematic diagram of stir-casting technique (b) Pictorial view of stir-casting technique (c) Photographic image of cast composite	59
Fig.3.2.	Process flow chart of development of copper-based hybrid composites	61
Fig.3.3.	Schematic and dimensional measurement of tensile test specimen	67
Fig.3.4.	Schematic diagram of the pin-on-disc machine	70
Fig.3.5.	Schematic diagram of wear test specimen	71
Fig.4.1.	SEM morphology of (a) WC-particles, (b) Cr-particles, (c) B <sub>4</sub> C-particles, (d) Al <sub>2</sub> O <sub>3</sub> -particles, (e) BN-particles and (f) ZrO <sub>2</sub> -particles	75
Fig.4.2.	Particle size distribution of (a) WC-particles, (b) Cr-particles, (c) B <sub>4</sub> C-particles, (d) Al <sub>2</sub> O <sub>3</sub> -particles, (e) BN-particles and (f) ZrO <sub>2</sub> -particles	77
Fig.4.3.	EDAX spectrum of (a) WC-particles, (b) Cr-particles, (c) B <sub>4</sub> C-particles, (d) Al <sub>2</sub> O <sub>3</sub> -particles, (e) BN-particles and (f) ZrO <sub>2</sub> -particles	78

	particles	
Fig.4.4.	The EDAX spectrum of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3, and (e) HC-4	80
Fig.4.5.	HR-SEM micrograph of (a) CC, (b) HC-3 and (c) HC-4	81
Fig.4.6.	HR-SEM morphology of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3, (e) HC-4, corresponding color dot mapping with color coding (a')–(e') and respective EDAX spectrum with report (a'')–(e'')	83
Fig.4.7.	XRD pattern of the CC and binary reinforced hybrid composites	84
Fig.4.8.	The variation of properties of binary reinforced hybrid composites (a) Brinell hardness, (b) Compression strength, (c) Ultimate tensile strength	89
Fig.4.9.	The SEM micrograph of fractured surface of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3, and (e) HC-4	90
Fig.4.10.	The EDAX spectrum of fractured surface of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3 and (e) HC-4	91
Fig.4.11.	The EDAX Spectrum of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8	93
Fig.4.12.	Microstructure of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8	94
Fig.4.13.	(a) Microstructure of CC and sections of $\Sigma 3$ CSL perpendicular to the $\{110\}$ tilt axis with position of various facets and micrograph of intersections of $(100)_{\text{CSL}}$ with other facets (b) $(100)_{\text{CSL}}$ and 9R facets, (c) $(100)_{\text{CSL}}$ and $(010)_{\text{CSL}}$ facets (d) $(100)_{\text{CSL}}$ and $(110)_{\text{CSL}}$ facets (Ref 38)	94

Fig.4.14.	HR-SEM micrograph of (a) HC-5, (b) HC-6, (c) HC-7 and (d) HC-8	95
Fig.4.15.	HR-SEM morphology of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7, (e) HC-8, corresponding color dot mapping with color coding (a')-(e') and respective EDAX spectrum with report (a'')-(e'')	97
Fig.4.16.	(a) HR-XRD pattern of CC and developed copper hybrid composites, (b) HR-XRD Bragg peak broadening (at $2\theta = 95.097$ degree)	98
Fig.4.17.	Variation of the FWHM with wt. % of $B_4C$	100
Fig.4.18.	Williamson–Hall (W-H) plot for the CC, HC-5, HC-6, HC-7, and HC-8	100
Fig.4.19.	The variation of properties of tertiary reinforced hybrid composites (a) Brinell hardness, (b) Compression strength, (c) Ultimate tensile strength	104
Fig.4.20.	The SEM micrograph of fractured surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7, and (e) HC-8 at $70\times$ magnification	105
Fig.4.21.	The SEM micrograph of fractured surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7, and (e) HC-8 at $2000\times$ magnification	106
Fig.4.22.	The EDAX spectrum of fractured surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7, (e) HC-8	107
Fig.5.1.	Variation of coefficient of friction with sliding distance at normal load of (a) 9.81 N, (b) 19.62 N, (c) 29.43 N and (d) 39.24 N at a constant speed of $2.43 \text{ m.s}^{-1}$	133
Fig.5.2.	Variation of average coefficient of friction with normal load at a constant sliding speed of $2.43 \text{ m.s}^{-1}$ and constant sliding	134

	distance of 8,748 m	
Fig.5.3.	The variation of the average coefficient of friction with hardness under 9.81, 19.62, 29.43 and 39.24 N for CC, HC-1, HC-2, HC-3 and HC-4 at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m.	135
Fig.5.4.	Variation of cumulative volume loss with sliding distance at normal load of (a) 9.81 N, (b) 19.62 N, (c) 29.43 N and (d) 39.24 N for a constant sliding speed of 2.43 m.s <sup>-1</sup>	137
Fig.5.5.	Variation of wear rate with normal load at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	138
Fig.5.6.	Variation of wear rate with Brinell hardness at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	139
Fig.5.7.	SEM micrographs of worn surface of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3 and (e) HC-4 at load of 9.81 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	141
Fig.5.8.	SEM micrographs of worn surface of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3 and (e) HC-4 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	142
Fig.5.9.	EDAX spectrum of worn surface of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3 and (e) HC-4 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	144
Fig.5.10.	SEM morphology of wear debris of (a) CC, (b) HC-1, (c) HC-2, (d) HC-3 and (e) HC-4 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	145
Fig.5.11.	AFM morphology of worn surface of (a) CC, (b) HC-1, (c) HC-	146

	2, (d) HC-3 and (e) HC-4 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	
Fig.5.12.	Variation of coefficient of friction with sliding distance at normal load of (a) 9.81 N, (b) 19.62 N, (c) 29.43 N and (d) 39.24 N at a constant speed of 2.43 m.s <sup>-1</sup>	148
Fig.5.13.	Variation of average coefficient of friction with normal load at a constant sliding speed of 2.43 m.s <sup>-1</sup> and constant sliding distance of 8,748 m	149
Fig.5.14.	The variation of the average coefficient of friction with Brinell hardness under 9.81 N, 19.62 N, 29.43 N and 39.24 N for CC, HC-5, HC-6, HC-7 and HC-8 at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	150
Fig.5.15.	Variation of average coefficient of friction with B <sub>4</sub> C reinforcement at normal load of 9.81, 19.62, 29.43 and 39.24 N for a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	151
Fig.5.16.	Variation of cumulative volume loss with sliding distance at normal load of (a) 9.81 N, (b) 19.62 N, (c) 29.43 N and (d) 39.24 N for a constant sliding speed of 2.43 m.s <sup>-1</sup>	153
Fig.5.17.	Variation of wear rate with normal load at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	154
Fig.5.18.	Variation of wear coefficient with hardness at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	155
Fig.5.19.	Variation of wear rate with B <sub>4</sub> C reinforcement at normal load of 9.81, 19.62, 29.43 and 39.24 N for a constant sliding speed of	156

	2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	
Fig.5.20.	SEM micrographs of worn surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8 at load of 9.81 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	158
Fig.5.21.	SEM micrographs of worn surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> , for sliding distance of 8,748 m	159
Fig.5.22.	EDAX spectrum of worn surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	161
Fig.5.23.	SEM morphology of wear debris of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	163
Fig.5.24.	AFM morphology of worn surface of (a) CC, (b) HC-5, (c) HC-6, (d) HC-7 and (e) HC-8 at load of 39.24 N and sliding speed of 2.43 m.s <sup>-1</sup> for sliding distance of 8,748 m	164
Fig.5.25.	Variation of average coefficient of friction with normal load at a constant sliding speed of 2.43 m.s <sup>-1</sup> and constant sliding distance of 8,748 m	166
Fig.5.26.	Variation of wear rate with normal load at a constant sliding speed of 2.43 m.s <sup>-1</sup> and sliding distance of 8,748 m	167