Conclusions are drawn from the above studies are summarised:

**5.1 Cu-CeO₂ nanocomposites**

The content of CeO₂ nanoparticles in Cu-CeO₂ nanocomposite coating increased with the concentration of CeO₂ particles in the plating bath. X-ray diffraction analysis of the coating revealed that the crystallite structure was crystalline fcc and its preferred orientation was (220) for electrodeposited copper and Cu-CeO₂ nanocomposite coatings. The average crystallite size calculated was ~32 nm for copper and ~35 nm for Cu-CeO₂ nanocomposite coatings. Cu-CeO₂ nanocomposite coatings showed improved microhardness and wear resistance than electrodeposited copper coating. From the electrochemical impedance studies, it was found that the charge transfer resistance (Rct) of Cu-CeO₂ nanocomposite coating was 1.475 x 10³ ohm/cm², which was higher than that of electrodeposited copper coating. This indicates that Cu-CeO₂ nanocomposite coatings were more corrosion resistant than electrodeposited copper coating. The Tafel polarization studies showed the decreased corrosion current for all the Cu-CeO₂ nanocomposite coatings than electrodeposited copper. The corrosion rate of Cu-CeO₂ nanocomposite coatings was less than that of electrodeposited copper coating. It revealed that Cu-CeO₂ nanocomposite coatings were more corrosion resistant than electrodeposited copper.
5.2 Cu-TiO₂ nanocomposites

The amount of TiO₂ nanoparticles in Cu-TiO₂ nanocomposite coatings increased with the addition of TiO₂ in the plating bath. The average crystallite size calculated was ~32 nm for electrodeposited copper and ~33 nm for Cu-TiO₂ nanocomposite coatings. The structure was crystalline fcc and its preferred orientation was (220) for both electrodeposited copper and Cu-TiO₂ nanocomposite coatings. The microhardness and wear resistance of the Cu-TiO₂ composite coatings were higher than electrodeposited copper. The charge transfer resistance \( (R_{ct}) \) of Cu-TiO₂ nanocomposite coating was 1.15 × 10³ ohm/cm², which was higher than that of electrodeposited copper. The Tafel polarization studies showed the decreased corrosion current for all the Cu-TiO₂ nanocomposite coatings than electrodeposited copper coating. The corrosion rate of Cu-TiO₂ composite coatings was less than that of electrodeposited copper. It revealed that Cu-TiO₂ nanocomposites were more corrosion resistant than electrodeposited copper in 3.5% NaCl solution.

5.3 Cu-ZrO₂ nanocomposites

The content of ZrO₂ nanoparticles in Cu-ZrO₂ nanocomposite coating increased with concentration of ZrO₂ nanoparticles in the plating bath. The average crystallite size calculated was ~32 nm for electrodeposited copper and ~30 nm for Cu-ZrO₂ nanocomposite coatings. The structure was crystalline fcc for electrodeposited copper and Cu-ZrO₂ nanocomposite coatings and its preferred orientation was (220). The microhardness and wear resistance of the Cu-ZrO₂ composite coatings were higher than electrodeposited copper. The charge transfer resistance \( (R_{ct}) \) of Cu-ZrO₂ nanocomposite coatings increased to 1.1 × 10³ ohm/cm², which was higher than that of electrodeposited copper. The Tafel polarization
studies showed decreased corrosion current ($i_{corr}$) for all the Cu-ZrO$_2$ composite coatings than electrodeposited copper coating. The corrosion rate of Cu-ZrO$_2$ nanocomposite coatings was less than that of electrodeposited copper coating. It revealed that Cu-ZrO$_2$ nanocomposites were more corrosion resistant than electrodeposited copper in 3.5% NaCl solution.

5.4 Cu-PANI nanocomposites

Polyaniline nanoparticles were prepared and used to develop Cu-PANI nanocomposite coatings onto copper substrate. The average crystallite size calculated was $\sim$32 nm for electrodeposited copper and $\sim$27 nm for Cu-PANI nanocomposite coatings. The structure was crystalline fcc for both electrodeposited copper and Cu-PANI nanocomposite coatings and its preferred orientation was (220). The microhardness of the Cu-PANI nanocomposite coatings was higher than electrodeposited copper. The charge transfer resistance ($R_{ct}$) of Cu-PANI nanocomposite coating was $1 \times 10^3$ ohm/cm$^2$, which was higher than that of electrodeposited copper (220 ohm/cm$^2$). The Tafel polarization studies showed the decreased corrosion current for all the Cu-PANI nanocomposite coatings than electrodeposited copper. The corrosion rate of Cu-PANI nanocomposite coatings is less than that of electrodeposited copper. It revealed that Cu-PANI nanocomposites had more corrosion resistant than electrodeposited copper in 3.5% NaCl solution.

5.5 Cu-MWCNT nanocomposites

Cu-MWCNT nanocomposite coatings on copper substrate were deposited. The X-ray diffraction analysis of the coating revealed that the structure of electrodeposited copper and Cu-MWCNT nanocomposite coatings was crystalline
fcc and its preferred orientation was (220). Surface morphology of the nanocomposite coating exhibited uniform distribution of crystallites (MWCNT nanoparticles) on copper matrix. Vickers microhardness and Taber abrader test results indicated that the microhardness and wear resistance of the composite coatings increased with MWCNT content in the bath. The Cu-MWCNT composite coatings were found to be more corrosion resistant than electrodeposited copper in 3.5 % NaCl solution.

Hence, based on the enhanced mechanical properties and corrosion resistance behaviour, the nanocomposite coatings are graded as:

Cu-MWCNT > Cu-PANI > Cu-TiO₂ > Cu-ZrO₂ > Cu-CeO₂