Chapter 6

Conclusion

and

Future scope

6.1 Conclusion

The growing utilization of polymeric hydrogels is increasingly influencing biomedical areas such as tissue sealants, controlled drug delivery, actuators, and other technological fields. A wide variety of synthetic approaches, ranging from traditional chemical processes to advanced molecular biology methods have been employed to fabricate hydrogel to mimic natural processes found in living systems. In this thesis work, we have successfully developed facile synthetic procedures for fabricating adhesive hydrogels to address the significant challenge of achieving strong adhesion between wet surfaces. Again, as environmental pollution intensifies, the use of hydrogel for certain environmental remediation is also significantly rising. Therefore, easy and effective methods have been developed to synthesize photocatalytic hydrogel to remove organic dyes from water to tackle pollution. In addition, electric-field responsive hydrogel has also been synthesized and investigated the bending behavior for possible implementation in actuators. The effect of various parameters on the swelling behavior and the mechanical strength of all the synthesized hydrogels has been examined. The significant outcomes of this work are summarized below:

6.1.1 Chapter 1

This introductory chapter provides a comprehensive overview of hydrogel material, including their classification and key properties. It also briefly describes the synthesis and characterization methods of hydrogel material employed in this thesis work. However, this chapter mainly focuses on the diverse range of stimuli-responsive hydrogels emphasizing their potential applications in drug delivery and bending. It also outlines the applications of hydrogel in crucial areas such as adhesives and photocatalysis and highlights their importance in various fields. The final section of this chapter outlines the objectives and plan of research of this thesis work. It aims to address specific challenges and contribute to developing promising hydrogel materials.

6.1.2 Chapter 2

i. A series of adhesive hydrogels based on gelatin (gel), acrylic acid (AAc), and dopamine (DA) have been prepared following a free radical graft polymerization method. Here, ammonium persulfate (APS) and *N*,*N*/-methylenebisacrylamide (MBA) have been employed as a free radical initiator and crosslinker respectively.
ii. The synthesized hydrogel exhibits strong adhesion to various surfaces and reaches up to 6.5 KPa for tissue surfaces under submerged conditions.
iii. The hydrogel also demonstrates robust mechanical strength including high stretchability, reversibility, self-healing, and dynamic adhesion to different surfaces while maintaining long-term reusability.
iv. The hydrogel's swelling behavior shows a low degree of swelling, ensuring the retention of the adhesive property in a fully swollen state.
v. The hemolysis tests reveal the biocompatible nature of the hydrogel depicting its potential applications in biomedical fields.

6.1.3 Chapter 3

i. A simple route has been developed to synthesize dopa-g-Gel/AAc/AAm adhesive hydrogel utilizing gelatin (gel), acrylic acid (AAc), acrylamide (AAm), and dopamine (DA) as precursors.
ii. The hydrogel exhibits strong and repeatable adhesion to diverse surfaces (hydrophilic and hydrophobic) including tissue surfaces. It shows effective adhesion under both dry and submerged conditions.
iii. Along with excellent mechanical strength, the flexibility of the hydrogel can be determined by its repeatable stretching behavior with no significant decrease in its tensile strength up to 3 cycles. It also exhibits stimuli-free self-healing properties.
iv. The swelling behavior of the hydrogel depicts its pH-sensitive swelling behavior, enabling control release of drug from the hydrogel material.
v. The biocompatible nature of the hydrogel can be depicted from the hemocompatibility, cytotoxicity, and degradability tests.

6.1.4 Chapter 4

i. A sustainable approach has been developed for synthesizing photocatalytic hydrogel by photopolymerizing 2-acrylamido-2-methylpropane sulfonic acid (AMPS) and acrylamide (AAm) utilizing visible light in the presence of g-C_3N_4 as a photoinitiator.

ii. The developed hydrogel possessing anionic functional groups allows rapid permeation of cationic dyes and shows their effective removal from water through the synergistic effect of both adsorption and photodegradation.

iii. The hydrogel can be significantly compressed up to a strain of 230 % while maintaining its mechanical strength of 0.55 MPa.

iv. The hydrogel demonstrates recyclable dye removal behavior without losing its photocatalytic behavior for up to 5 cycles.

6.1.5 Chapter 5

i. A series of electric-field responsive hydrogels have been developed by impregnating PANI into a polyelectrolyte hydrogel based on starch, acrylic acid (AAc), acrylamide (AAm), and g-C_3N_4.

ii. The hydrogel exhibits a maximum tensile strength of 1.02 MPa and compressive strength of 14.79 KPa. It maintains repeatable compression for up to 20 cycles.

iii. Under the application of an electric field, the hydrogel shows bending behavior and reaches a maximum bending actuation of 110° under a low electric field of 10 V.

iv. Furthermore, the hydrogel exhibits repeatable actuation in response to a cyclically applying electric field of 10 V.

v. The influence of various parameters has been investigated to determine the rate of bending actuation of the hydrogel.

vi. Therefore, the rapid and controllable bending actuation exhibited by the synthesized hydrogel reveals its promising applications as actuators and soft robotics.

6.2 Future scope

Adhesive hydrogels developed in this work have been examined through various *in vitro* analyses. However, this work still requires extensive *in vivo* studies, to deliver their clinical applications. Furthermore, the excellent photocatalytic behavior of the hydrogel can be utilized for different environmental remediation. Moreover, the requirement of low electric voltages in the synthesized electric-field responsive hydrogel is advantageous for various biomedical applications and hence requires further studies. Considering the mentioned potential of the developed hydrogel, further studies of this work are pointed out as follows:

- *In vivo* study of the adhesive hydrogel for wound healing and drug delivery applications
- Development of adhesive hydrogel for its applications in sensing
- Development of photocatalytic hydrogel with enhanced properties for its application in the removal of other pollutants from water sources
- Development of electric-field responsive hydrogel for showing actuating behavior such as walking, gripping, etc.