CHAPTER III
RESULTS AND DISCUSSION

Two types of starch were used in this work, tapioca starch and rice starch. Scanning electron micrographs of both starch types are shown in Figures 3.1 and 3.2.

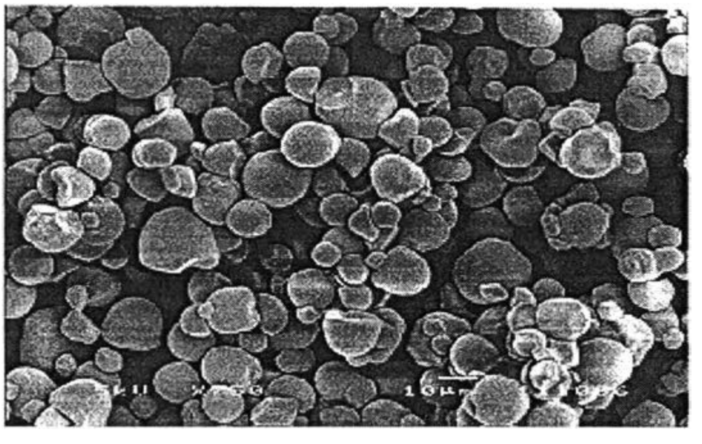


Figure 3.1 Scanning electron micrograph of tapioca starch.

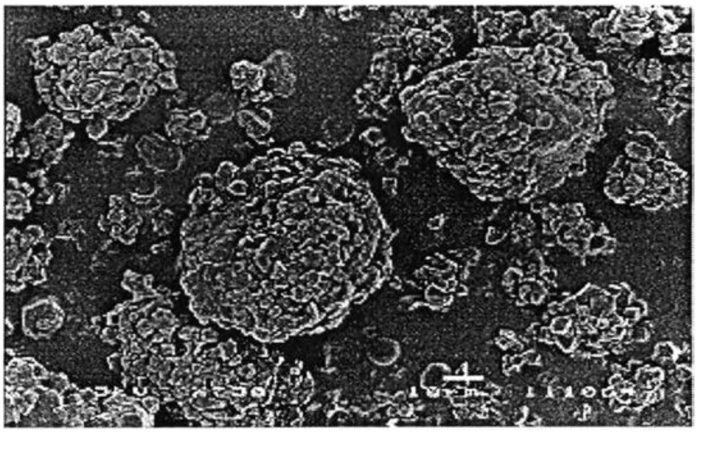


Figure 3.2 Scanning electron micrograph of rice starch.

Rice starch shows a tendency to form agglomerates. Because individual rice starch particles are small, they possess high surface energy which evidently leads to high particle-particle interaction. When the starch was blended with HDPE, the particles still existed as agglomerates while tapioca starch particles were separate entities and were well dispersed in the HDPE matrix, as can be seen in Figures 3.3 and 3.4. It was observed that there was no apparent adhesion between the starch particles and the HDPE matrix for both the tapioca starch and rice starch.

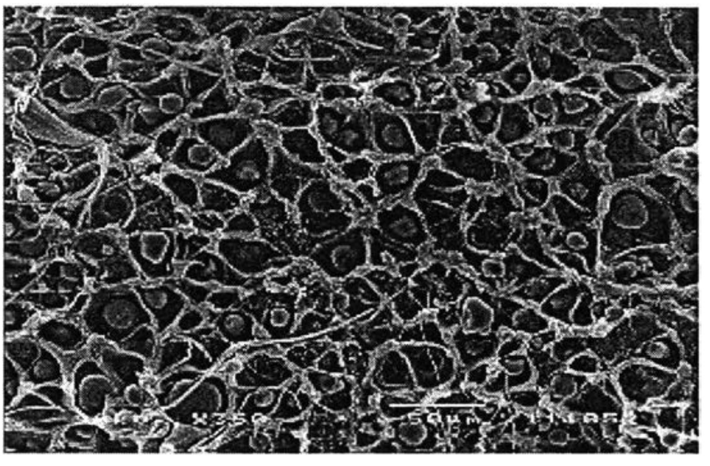


Figure 3.3 Scanning electron micrograph of tapioca starch-based HDPE blend containing 10% starch content.

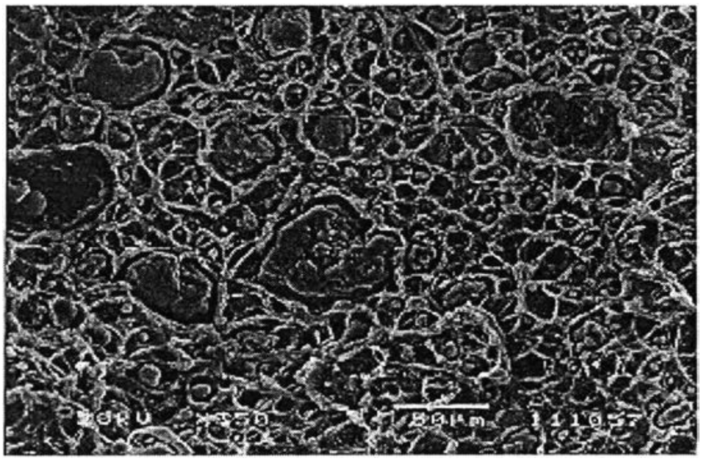


Figure 3.4 Scanning electron micrograph of rice starch-based HDPE blend containing 10% starch content.

3.1 Tensile Testing

The tensile properties determined were tensile strength at yield, percent strain at yield, and tensile modulus.

3.3.1 Tensile Strength at Yield

The tensile strength at yield of starch-based HDPE blends are shown in Figure 3.5 as a function of starch content.

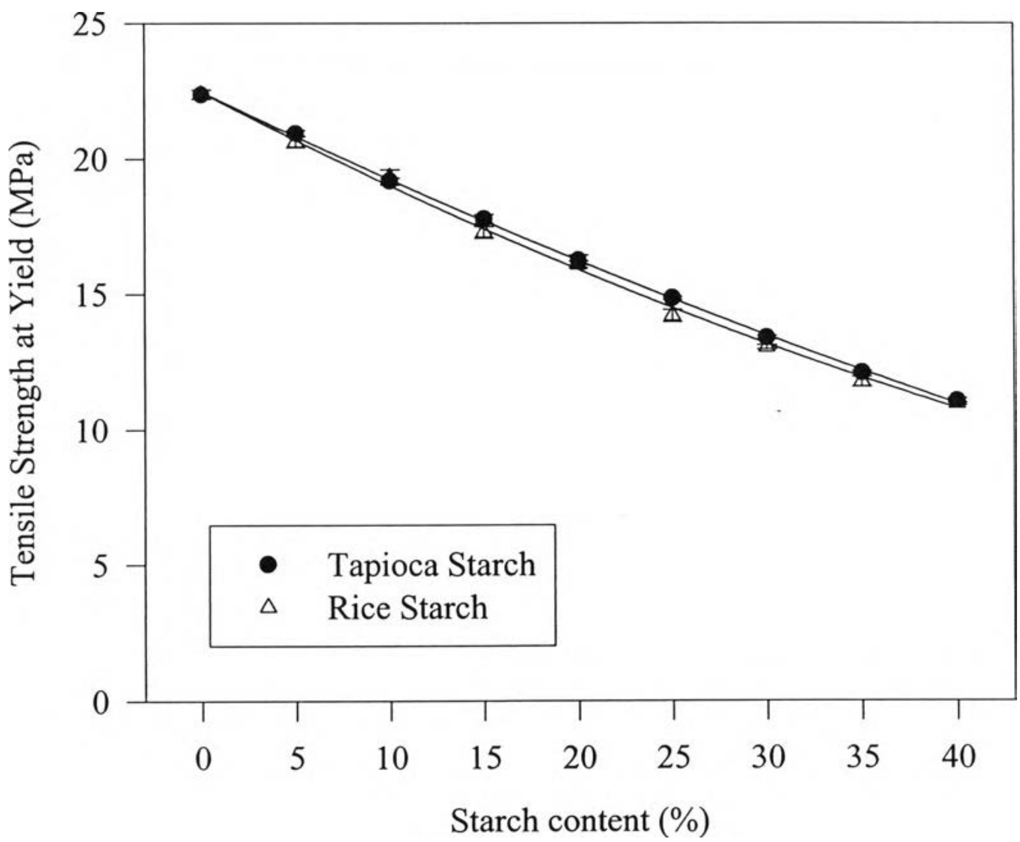


Figure 3.5 Tensile strength at yield of starch-based HDPE blends.

The tensile strength at yield decreased as the starch content increased for both tapioca starch-based HDPE and rice starch-based HDPE blends. This is due to a reduction in the effective cross-sectional area of the specimen, which carries the load during deformation. In addition, since there was no apparent adhesion between starch particles and the HDPE matrix, poor stress transfer at the starch particle-polymer interface is occurred. The starch particles cannot bear any load, which then behave as a weak point. Stress concentrations will be generated around the particles and reduce the strength of the blends.

In general, tensile strength decreased as the particle size of the filler increased. It was found that the rice starch-based HDPE blends had tensile strengths at yield slightly lower than that of tapioca starch-based HDPE blends. This was thought to be due to the agglomeration of the small rice starch particles to form larger particles which lead to the lower tensile strength of the rice starch-based HDPE blends.

3.1.2 Percent Strain at Yield

Figure 3.6 shows the plot of percent strain at yield of starch-based HDPE blends as a function of starch content. The percent strain at yield of both tapioca starch-based and rice starch-based HDPE blends decreased with increasing starch content.

The decrease in elongation at yield using rigid fillers arises from the fact that the actual elongation experienced by the polymer matrix is much greater than the measured elongation of the specimen. Although the specimen is part filler and part matrix, all of the elongation will come from the polymer if the filler is rigid. As the starch content increases, the polymer matrix will be decreased which therefore leads to the decrease in elongation.

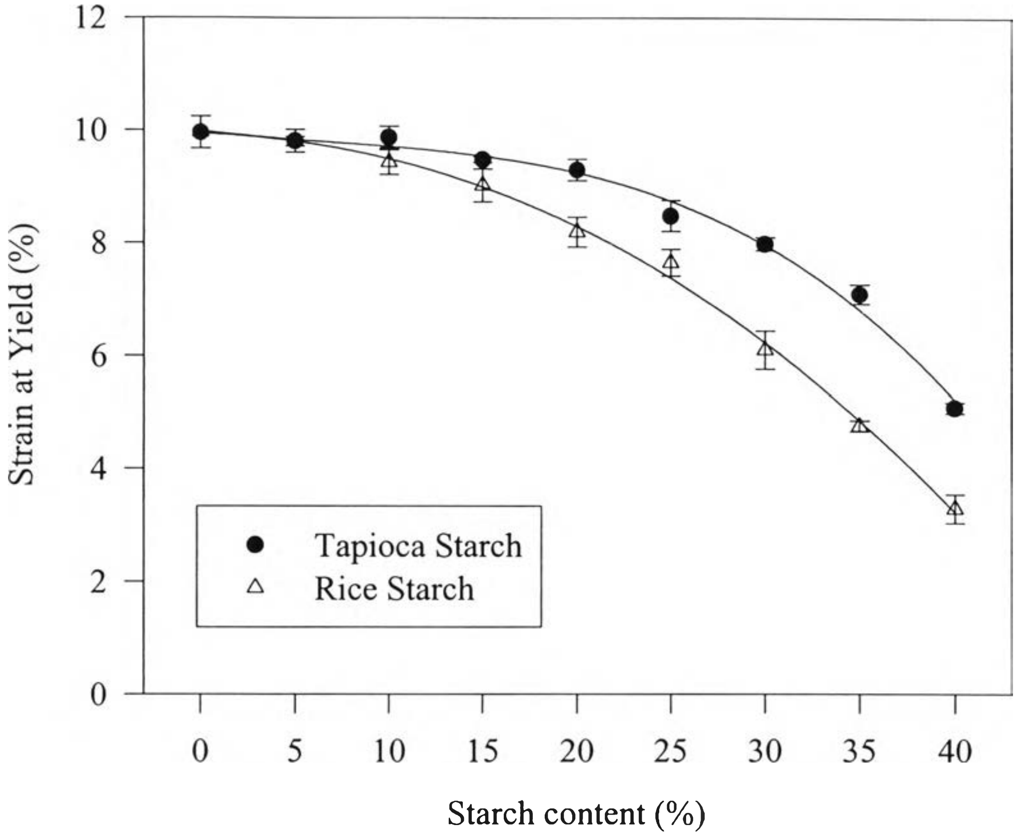
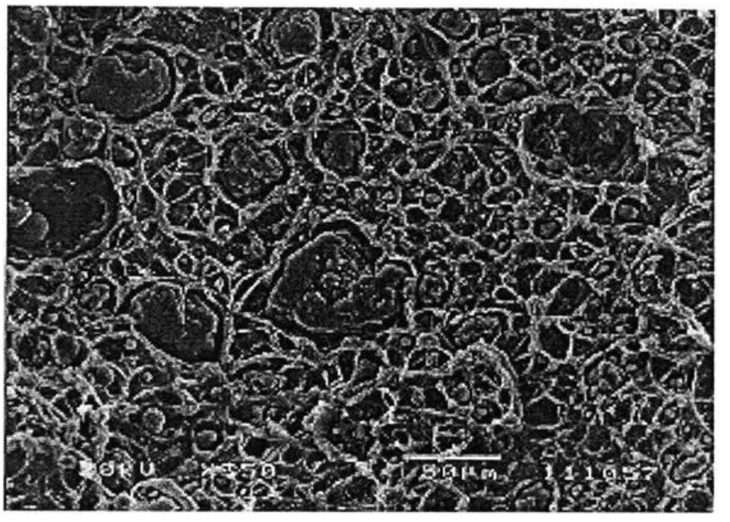
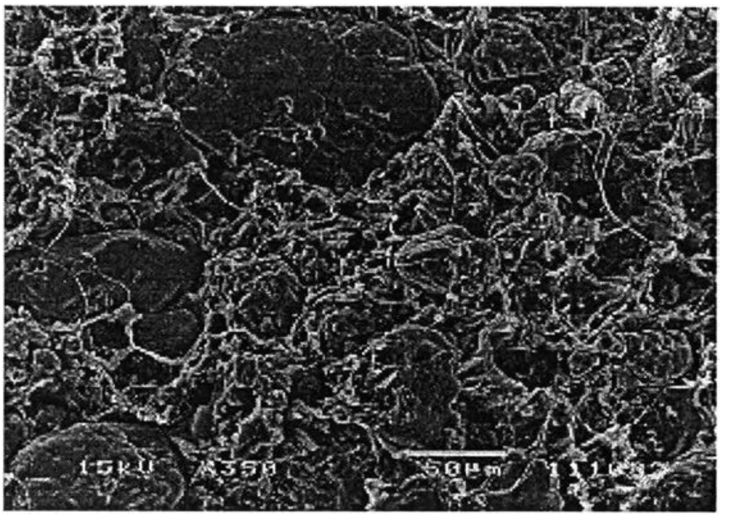


Figure 3.6 Percent strain at yield of starch-based HDPE blends.

Furthermore, it was found that the percent strain at yield of rice starch-based HDPE was lower than that of tapioca starch-based HDPE blends. This was because of the agglomeration of the rice starch particles and the absence of adhesion between the starch particles and the HDPE matrix. In addition, the degree of agglomeration increased as the starch content increased, as shown in Figure 3.7. The rice starch agglomerates, which occupy effectively larger voids in the HDPE matrix than the 'individual' tapioca starch particles, will therefore result in lower elongation at yield.



(a) 10% starch content



(b) 40% starch content

Figure 3.7 Scanning electron micrographs of rice starch-based HDPE blends containing (a) 10% starch content (b) 40% starch content.

3.1.3 Tensile Modulus

Tensile moduli of starch-based HDPE blends are shown in Figure 3.8. An increase in tensile modulus was observed as the starch content increased. The increase in tensile modulus was due to the stiffening effect of the starch particles. The particles restrict the mobility and deformability of the matrix by introducing a mechanical restraint. The restriction in polymer mobility in the presence of solid particles occurs due to an effective attraction potential between segments of the chain and the repulsive potential that the polymer is subjected to when it is close to the solid particles.

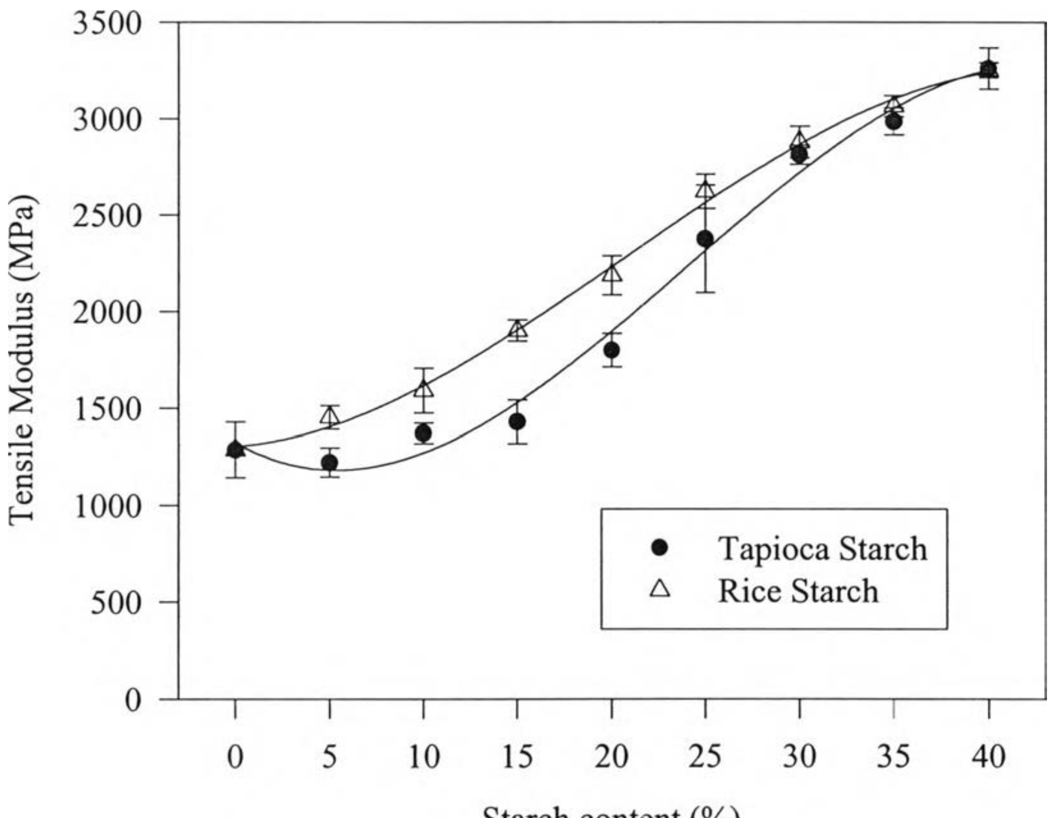


Figure 3.8 Tensile modulus of starch-based HDPE blends.

The degree of particle restriction depends on the properties of the particles and the matrix. It is also noted that the modulus increment is greater at higher filler loadings than lower filler loadings. This is probably due to particle-particle interaction, which becomes significant at higher filler loadings.

The tensile modulus of rice starch-based HDPE was found to be higher than that of tapioca starch-based HDPE blends because of the agglomeration of rice starch particles. Agglomerate particles are stiffer than primary particles and so lead to higher tensile modulus.

3.2 Flexural Testing

The flexural properties that have been studied were flexural strength at yield and flexural modulus.

3.2.1 Flexural Strength at Yield

The flexural strength at yield of starch-based HDPE blends are shown in Figure 3.9. The flexural strength at yield decreased with increasing starch content. This result agrees with tensile strength at yield. Discontinuity is created in the structure because of nonadherence of the filler to the polymer which may give rise to dewetting. The filler cannot carry any load, which then acts as a weak body. Stress concentrations will be created around the particle and thereby reduce the strength of the material.

It was observed that the rice starch-based HDPE blends had lower flexural strength at yield than that of the tapioca starch-based HDPE blends. This is due to the agglomeration of rice starch particles. The agglomerates break fairly easily when stress is applied. The broken agglomerates then behave as strong stress concentrators, resulting in lower strength than for well-dispersed tapioca starch particles.

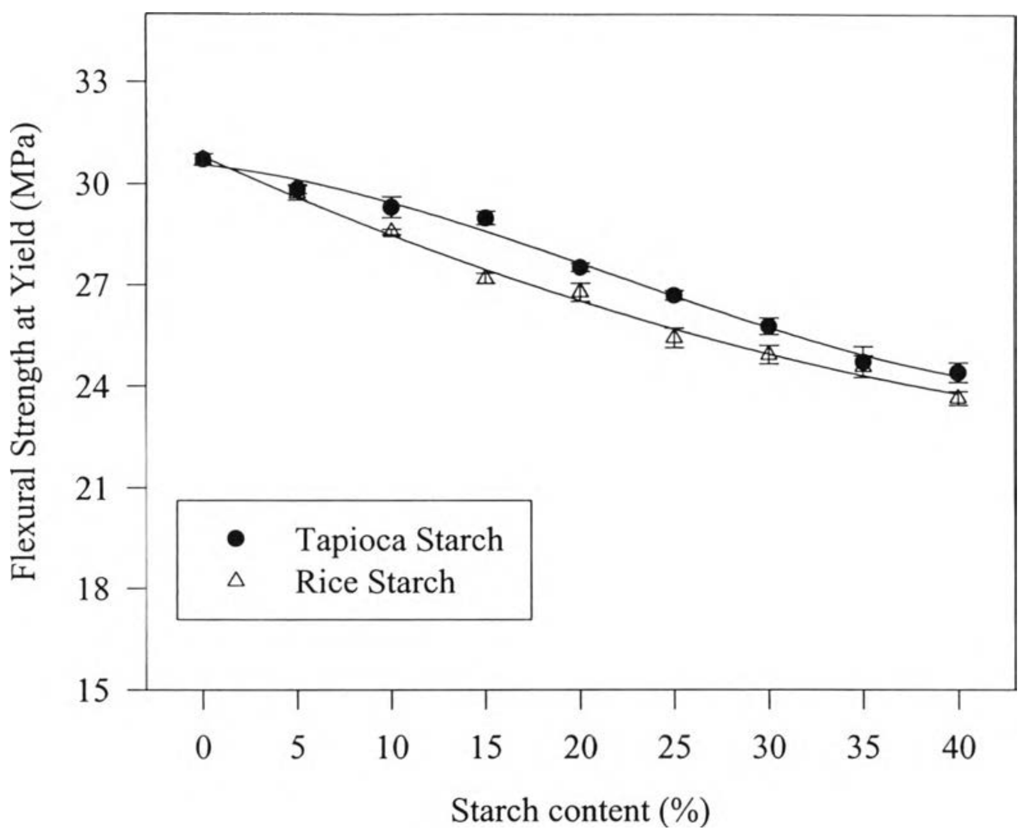


Figure 3.9 Flexural strength at yield of starch-based HDPE blends.

3.2.2 Flexural Modulus

Figure 3.10 shows a plot of flexural modulus of starch-based HDPE blends as a function of starch content. Because starch is stiffer than HDPE, an increase in flexural modulus of both tapioca starch-based HDPE and rice starch-based HDPE blends were observed with increasing starch content.

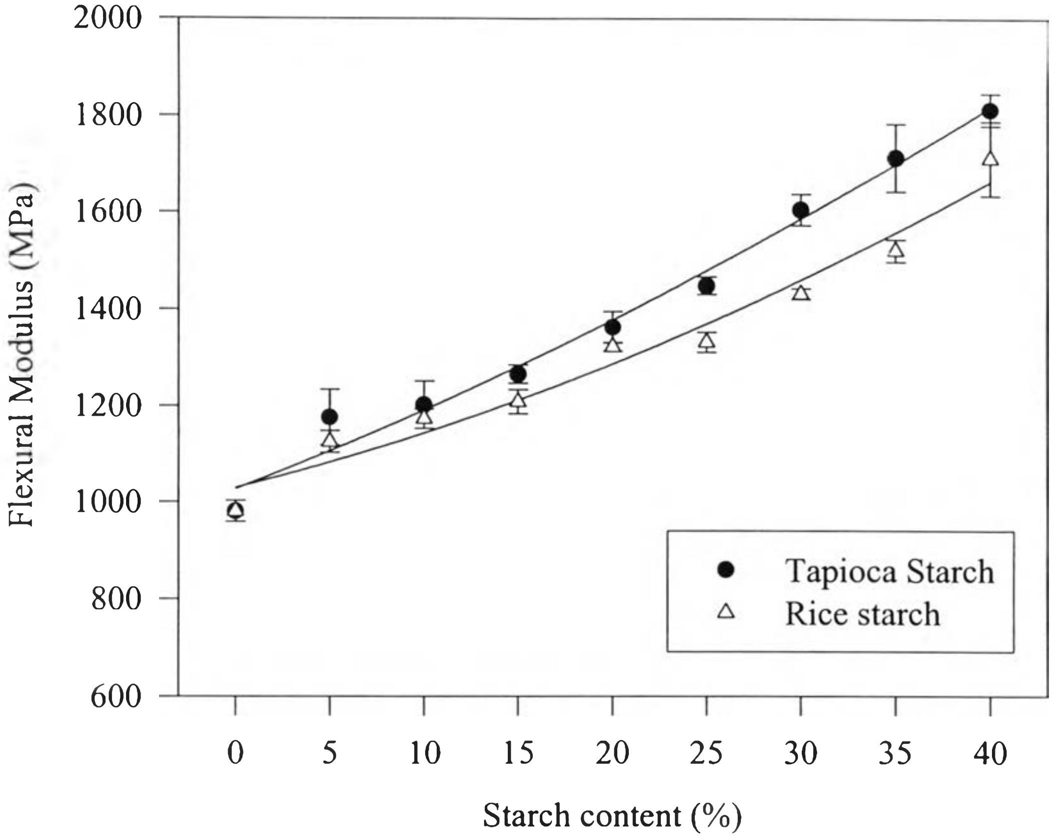


Figure 3.10 Flexural modulus of starch-based HDPE blends.

In contrast to tensile modulus, the flexural modulus of rice starch-based HDPE was found to be lower than that of tapioca starch-based HDPE blends.

3.3 Izod Impact Testing

Izod impact strengths of the starch-based HDPE blends are shown in Figure 3.11 as a function of starch content. The drastic decrease in the impact strength between 0–5 % starch content was observed in both tapioca starch-based HDPE and rice starch-based HDPE blends.

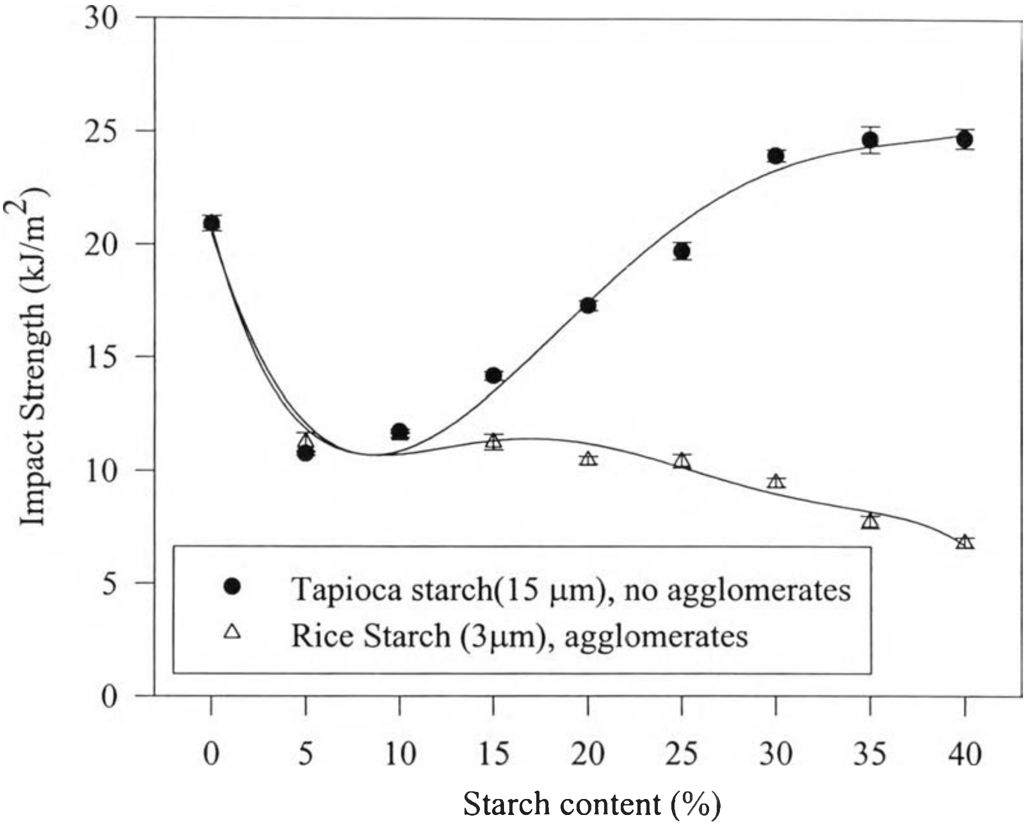
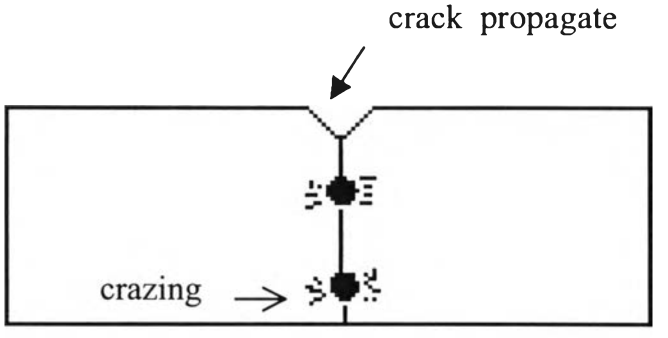
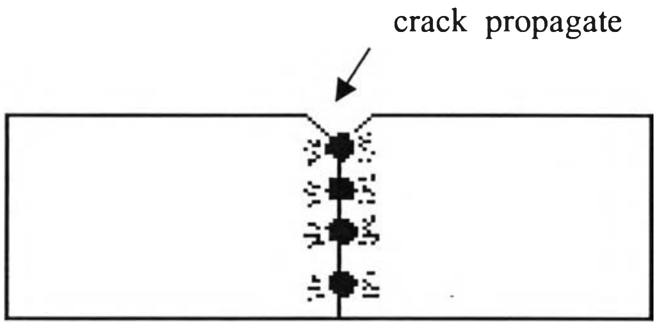


Figure 3.11 Impact strength of starch-based HDPE blends.

Above 8% starch content, the tapioca starch-based HDPE blends showed a sharp increase in impact strength. This can be explained by crazing phenomena. Tough, rigid polymers can be further toughened by the addition of rigid particles. Here, crazing of the matrix is enhanced and occurs throughout the specimen, thus dissipating more energy and therefore increasing the toughness. Figure 3.12 shows the effect of fillers on impact strength.



(a) 5% starch content



(b) As starch content increase

Figure 3.12 The effect of fillers on impact strength.

When a crack propagates, each particle causes crazing in the matrix as the crack enters it. For 5 % starch content, there is very little crazing along the crack propagation path. The rigid particle, having a lower strength than HDPE, will lower the impact strength of the specimen. As the starch content increases, the crack will propagate through many particles. Each particle causes crazing in the matrix and the crazing will dissipate the energy to break. Thus many particles will increase the impact strength.

For rice starch-based HDPE blends, the impact strength decreased as the starch content increased. This is probably due to the agglomeration effect of rice starch particles as shown in Figure 3.13. In the agglomerates, the particles are held together by weak forces. A crack can propagate through an agglomerate more easily than through a single particle leading to a decrease in impact strength.

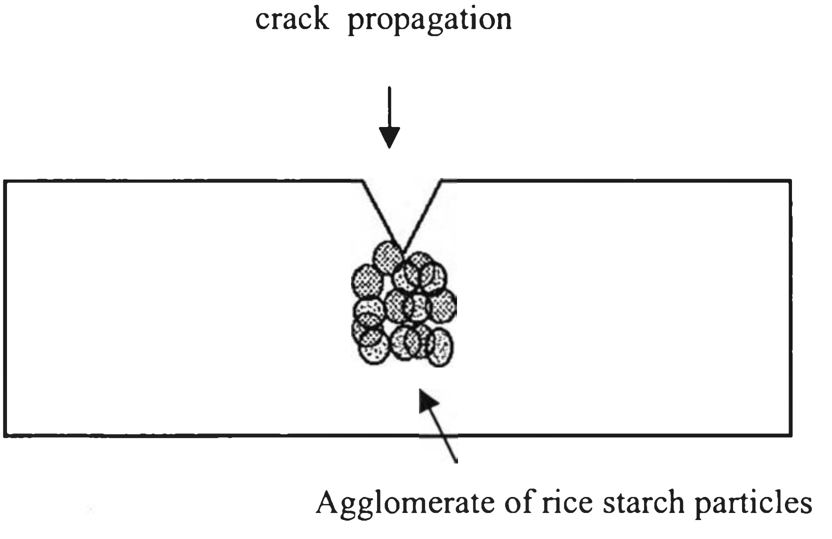


Figure 3.13 The effect of agglomeration on impact strength.