PENGARUH KOMPOSISI GLUKOMANAN-TAPIOKA TERHADAP KARAKTERISTIK BIOPOLIMER SEBAGAI PLASTIK RAMAH LINGKUNGAN

Nama Mahasiswa : Faizal Maulana
NRP : 2408 100 081
Jurusan : Teknik Fisika FTI-ITS
Dosen Pembimbing : Lizda Johar Mawarani, ST, MT.
Dyah Sawitri, ST, MT.

Abstrak

Penggunaan bahan alam untuk polimer (polimer alami) merupakan salah satu solusi pencemaran tanah oleh limbah plastik, karena polimer alami dapat terurai oleh alam. Bahan yang telah dikembangkan untuk bahan dasar polimer adalah glukomanan umbi porang dan tepung singkong (tapioka). Tugas akhir ini menggunakan campuran dari glukomanan porang dan tepung tapioka untuk mengetahui pengaruh komposisi glukomanan dan tapioka terhadap karakteristik biopolimer. Variasi kadar tepung tapioka yang digunakan adalah 0%, 10%, 20%, 30%, 40%, dan 50%. Karakterisasi sampel dari semua variasi dilakukan dengan uji tarik, uji penggembungan, uji biodegradasi dengan bakteri *Pseudomonas sp,* dan FTIR. Hasil penelitian ini menunjukkan bahwa semakin besar penambahan kadar tepung tapioka, sifat kekuatan tarik cenderung menurun, elongasi cenderung meningkat dan modulus elastisitas biopolimer cenderung menurun. Kekuatan tarik dan modulus elastisitas paling besar dimiliki oleh sampel dengan komposisi glukomanan 100% yakni sebesar 666,66 kPa dan 41,72 kPa. Penambahan kadar tepung tapioka mengakibatkan derajat penggembungan biopolimer menurun hingga 33,12% yaitu pada film biopolimer glukomanan-tapioka 5:5. Dan variasi komposisi 8:2 memiliki laju degradasi tercepat yaitu 0,19 gr/hari.

Kata kunci: glukomanan porang, tapioka, karakteristik biopolimer.

Halaman ini memang dikosongkan

COMPOSITION EFFECT OF GLUCOMANNAN-TAPIOCA FLOUR TO BIOPOLYMER CHARACTERISTIC AS ECO-FRIENDLY PLASTIC

Name of Student : Faizal Maulana
NRP : 2408 100 081
Department : Engineering Physics FTI-ITS
Supervisor : Lizda Johar Mawarani, ST, MT.
Dyah Sawitri, ST, MT.

Abstract

Plastic usages are rapidly increase in recent years, it contaminates environment especially water and soil. Natural polymer that made from natural substances is one of its solutions, because it can be decomposed. Glucomannan from Amorphophallus oncophillus and tapioca flour are already used in term of biopolymer substance in previous research. This research used glucomannan from Amorphophallus oncophillus and tapioca flour to figure out composition effect of glucomannan/tapioca flour to biopolymer characteristic. Level variations of tapioca flour are 0%,10%, 20%, 30%, 40%, and 50%. Tensile test, swelling test, biodegradable test and FTIR are applied in this research. The results showed that the increase of tapioca flour affects the decrease of tensile strength and elasticity modulus, and the increase of elongation. Tensile strength and elasticity modulus reach its peak on 666.66 kPa and 41.72 kPa for composition of 100% glucomannan. The increase of tapioca flour affected the decrease of swelling degree, the lowest is 33.12% for 5:5 composition. The highest biodegradation rate is 0,19 gr/day that occured on 8:2 composition.

Key words: Amorphophallus oncophillus, glucomannan, tapioca, biopolymer characteristic

Halaman ini memang dikosongkan

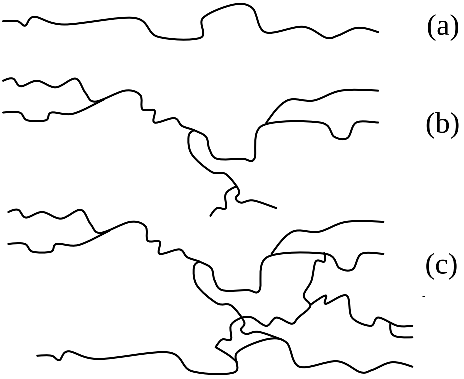
BAB II
DASAR TEORI

2.1 Polimer

Polimer adalah material yang dibentuk oleh satuan struktur secara berulang. Polimer berasal dari bahasa Yunani *poly* dan *mer*. *Poly* yang berarti banyak dan *mer* yang berarti bagian, maka polimer berarti banyak bagian. Sedangkan satuan struktur polimer disebut monomer (Stevens, 2001). Polimer mempunyai berat molekul diatas 10000 yang disebabkan oleh jumlah atom pembentuk yang besar. Karena berat molekul yang besar serta jumlah atom pembentuk yang besar pula, polimer disebut juga sebagai makromolekul. Setiap atom dari pasangan yang terikat dalam polimer diikat oleh gaya tarik-menarik yang kuat yang disebut ikatan kovalen. Gaya tarik-menarik antar molekul dalam polimer antara lain ikatan hidrogen dan gaya *Van der Waals*, namun lebih lemah daripada ikatan kovalen (Surdia, 2000).

Polimer terbentuk dari sejumlah monomer yang berulang. Jumlah total unit monomer dinyatakan dalam derajat polimerisasi (DP). Derajat polimerisasi ekivalen dengan panjang rantai dan berkaitan dengan berat molekul polimer, dimana berat molekul polimer merupakan perkalian antara DP dengan berat molekul unit strukturnya. Sedangkan polimerisasi sendiri merupakan proses pembentukan polimer dari monomer-monomer penyusunnya (Pradipta, 2012).

Polimerisasi terbagi atas polimerisasi adisi dan polimerisasi kondensasi. Polimerisasi adisi merupakan polimerisasi yang melibatkan monomer ikatan rangkap dua. Monomer tersebut akan saling berikatan dan membentuk unit berulang dengan memecah ikatan rangkapnya. Contoh dari polimer yang terbentuk dari polimerisasi adisi adalah polietilena ($CH_2{=}CH_2 \rightarrow [CH_2\text{-}CH_2]_n$) dan teflon ($CF_2{=}CF_2 \rightarrow [CF_2\text{-}CF_2]_n$). Sedangkan polimerisasi kondensasi adalah pembentukan polimer dari monomer-monomer yang berikatan dengan melepaskan suatu bentuk molekul lain seperti H_2O, NH_3, atau HCl. Contoh dari polimer yang terbentuk dari polimerisasi kondensasi adalah polietilena-glikol ($HOCH_2CH_2OH \rightarrow [OCH_2CH_2]_n + nH_2O$) (Pradipta, 2012).



Gambar 2.1 Jenis rantai pada polimer: (a) linier, (b) bercabang, dan (c) jaringan (Stevens, 2001)

Polimer dapat diklasifikasikan berdasarkan parameter tertentu, diantaranya berdasarkan respon termal dan asalnya. Berdasarkan respon termal, polimer terdiri atas polimer termoplastik dan polimer termoset. Polimer termoplastik adalah polimer yang dapat melunak atau terplastisisasi secara berulang-ulang akibat pemanasan dan pendinginan, contohnya adalah poliester, polistiren, PVC, dan sebagainya. Sedangkan polimer termoset adalah polimer yang pada awalnya berbentuk cairan kental namun akan berubah menjadi kaku ketika dikenai pemanasan lanjutan. Berbeda dengan polimer termoplastik, polimer termoset tidak dapat dikembalikan ke bentuk semula dengan perlakuan panas, contohnya adalah resin fenol, resin melamin, resin epoksi, dan sebagainya. Berdasarkan asalnya, polimer terdiri atas polimer alami, polimer semisintetik, dan polimer sintetik. Polimer alami adalah polimer yang tersedia di alam, misalnya selulosa, protein, dan pati (polisakarida). Polimer semisintetik adalah polimer alam yang dimodifikasi secara kimia, seperti ester, selulosa nitrat, dan metil selulosa. Sedangkan polimer sintetik adalah polimer buatan/sintesis manusia, seperti polietilen, polistiren, dan PVC (Pradipta, 2012).

Polimer banyak diaplikasikan pada kehidupan sehari-hari, seperti sebagai plastik pembungkus atau tas plastik. Berikut adalah beberapa sifat khas yang menjadi kelebihan bahan polimer:

- Mempunyai kemampuan cetak yang baik.
- Menghasilkan produk yang ringan dan kuat.
- Mempunyai ketahanan air dan bahan kimia yang baik.
- Dapat menghasilkan produk dengan sifat yang berbeda tergantung pada cara pembuatannya, jenis zat pemlastis (*plasticizer*) yang digunakan atau zat tambahan lain yang digunakan.
- Umumnya bahan polimer lebih murah (Surdia, 2000).

Dengan sifat tersebut maka polimer sering dimanfaatkan dalam berbagai aplikasi, salah satunya adalah sebagai kemasan plastik.

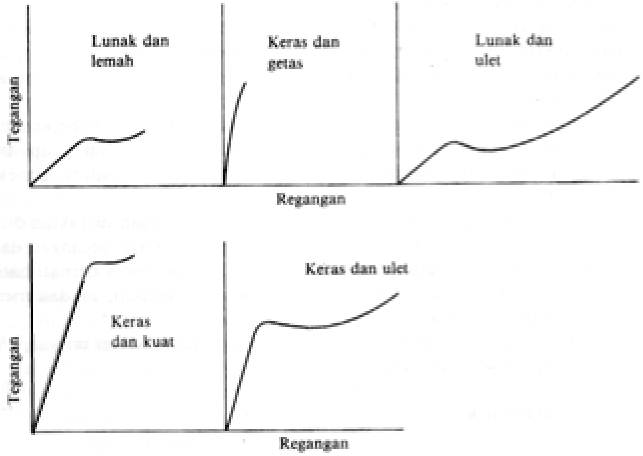
Dalam kaitannya dengan kemasan plastik, maka perlu dipertimbangkan terhadap sifat mekanik bahan polimer. Sifat-sifat mekanik bahan polimer adalah khas dengan perilaku viskoelastisitasnya. Contohnya adalah mudah terjadinya pemelaran (*creep*) dan relaksasi, serta pada pengujian tarik sifatnya sangat dipengaruhi oleh laju pengujian tarik.

Kekuatan tarik adalah salah satu sifat dasar dari bahan. Hubungan tegangan-regangan pada tarikan memberikan nilai yang cukup berubah tergantung pada laju tegangan, temperatur, serta kelembaban. Nilai kekuatan tarik diperoleh melalui persamaan (2.1),

$$\sigma = \frac{F}{A_0} \tag{2.1}$$

dengan σ adalah kuat tarik , sedangkan F adalah gaya tarik dan A_0 adalah luas penampang awal.

Pada bahan termoplastik besaran nilai kekuatan tarik berubah dengan penyearahan molekul rantai dalam bahan. Umumnya kekuatan tarik bahan polimer lebih rendah daripada bahan lain, misalnya baja. Kekuatan tarik nilon 66 adalah 6,5-8,4 kgf/mm^2, PVC adalah 3,5-6,3 kgf/mm^2, dan resin polietilen memiliki kekuatan tarik antara 0,7-8,4 kgf/mm^2, sedangkan baja memiliki kuat tarik hingga 70 kgf/mm^2 (Surdia, 2000). Gambar 2.2 menunjukkan kelakuan tarikan dari bahan polimer dalam bentuk kurva tegangan regangan menurut karakteristiknya lunak atau keras, lemah atau kuat, dan getas atau liat.



Gambar 2.2 Kelakuan bahan polimer pada pengujian tarik (Surdia, 2000)

Polimer juga memiliki daya perpanjangan (elongasi) bila dikenai gaya tarikan sesuai dengan sifat viskoelastisnya. Daya perpanjangan diperoleh melalui persamaan (2.2),

$$\varepsilon = \frac{\Delta l}{l_0} \tag{2.2}$$

dengan ε adalah daya elongasi, Δl adalah perubahan panjang dan l_0 adalah panjang mula-mula. Perbandingan antara tegangan/kuat tarik (σ) dan regangan/perpanjangan (ε) disebut modulus Young (E), seperti yang terlihat pada persamaan (2.3).

$$E = \frac{\sigma}{\varepsilon} \tag{2.3}$$

Modulus Young bahan polimer terletak di daerah 0,1-21x10^2 kgf/mm^2 yang jauh lebih rendah daripada baja sebesar 200 x10^2 kgf/mm^2 (Surdia, 2000). Deformasi oleh penarikan sampai patah berbeda-beda tergantung pada jenis dan temperatur.

Tabel 2.1 Sifat Mekanis Beberapa Film Polimer Sintesis dan Biopolimer (Darni, 2008 dan Sanjaya, 2011)

Bahan Film	Kuat tarik (MPa)	Elongasi (%)	Modulus Young (MPa)
LDPE	10	620	166
HDPE	15– 40	500	800
Plastik Pati Pisang-Gelatin	22,85	6,05	377,686
Pati Kulit Singkong-Gliserol	12,12-43,22	1,27-2,6	465,99-3412,39

Dalam kaitannya dengan kemasan plastik pula, akhir-akhir ini para pemerhati lingkungan meningkatkan perhatiannya terhadap sampah polimer yang merusak lingkungan. Oleh karena itu banyak sintesis polimer tahan lama (*durable*) yang beralih ke sintesis polimer yang dapat diurai (*degradable*) oleh lingkungan seperti sinar matahari dan mikroorganisme tanah. Polimer terdegradasi dari sinar matahari (*fotodegradable*) dapat terurai dengan menginkorporasi gugus-gugus karbonil yang menyerap radiasi *ultraviolet* (UV) sebagai energi untuk pembelahan ikatan (Stevens, 2001). Selain itu, mikroorganisme dapat menguraikan polimer-polimer dengan mengkatalisis hidrolisis (*hidro-biodgradable*) dan oksidasi (*oxo-biodegradable*), sedangkan polimer yang murni terdegradasi oleh mikroorganisme disebut *biodegradable* dimana polimer tersebut biasanya terbuat dari polimer alami.

Pengujian biodegradasi polimer alami dapat dilakukan dengan menggunakan bantuan mikroorganisme pengompos EM4 (Sanjaya, 2011). EM4 berupa larutan coklat yang memiliki pH 3,5-4,0 yang terdiri dari mikroorganisme aerob dan anaerob.

Kandungan EM4 terdiri dari bakteri fotosintetik, bakteri asam laktat, *actinomicetes*, ragi, dan jamur fermentasi. Pada polimer *biodegradable*, mikroba akan mengonsumsi bahan di dalamnya, misalnya pati, yang akan memutus rantai dan membentuk pori-pori yang merusak polimer. Semakin rendah berat molekul, maka polimer akan semakin cepat terdegradasi.

Untuk mengetahui ikatan dalam polimer, dapat dilakukan pengujian FTIR. Pada FTIR, spektrum inframerah (IR) yang dipancarkan dapat terabsorpsi oleh pita-pita absorpsi dari gugus fungsional apabila mengenai gugus tersebut. Akibatnya, spektrum yang dilewatkan bahan uji (polimer) akan mengalami perubahan. Dari nilai gelombang inframerah yang melewati bahan uji, maka dapat diketahui karakterisasi gugus fungsi dari struktur polimer yang diuji (Pradipta, 2012).

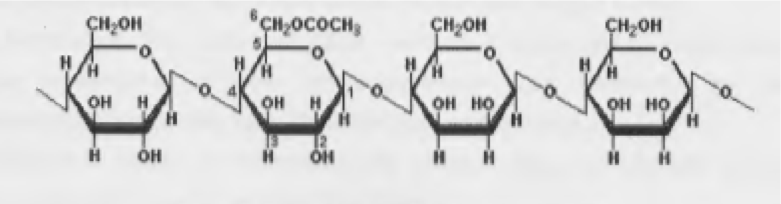
Tabel 2.2 Contoh Nilai Gelombang dan Gugus Fungsional pada Analisa FTIR (http://www.chemistry.ccsu.edu)

Wave Number (cm^{-1})	Gerak Molekul	Gugus Fungsional
2400 – 3400	O-H *stretch*	Asam karboksil
2800 – 2950	C-H *stretch*	Alkana
~2150	C=C	Alkina
1630-1690	C=C *isolated*	Alkena
1290-1430	C-H *plane bond*	Alkena
1000-1260	C-O *stretch*	Alkohol

2.2 Glukomanan

Glukomanan adalah polisakarida larut dalam air yang dianggap sebagai serat makanan. Glukomanan merupakan komponen hemiselulosa di dinding sel beberapa spesies tanaman. Glukomanan merupakan makanan aditif yang digunakan sebagai pengemulsi dan pengental (Rohimi dkk., 2013).

Glukomanan terdiri dari 40% berat kering dari akar, atau umbi tanaman konjak. Glukomanan ini juga sebuah hemiselulosa yang terdapat dalam jumlah besar di kayu dari konifer dan dalam jumlah yang lebih kecil di kayu dari *dicotyledons.* (Rohimi dkk., 2013) Di Indonesia sebenarnya juga banyak dihasilkan glukomanan yang berasal dari iles-iles kuning.



Gambar 2.3 Struktur molekul glukomanan

Glukomanan yang terdapat dalam umbi iles-iles berbentuk polisakarida yang tersusun dari satuan monosakarida mannosa dan glukosa dengan perbandingan molar 3:2, memiliki rantai linier β (1-4) satuan gula pembentuknya, dan ukuran berat molekulnya lebih besar dari 300 kD. Dalam air pada suhu ruang glukomanan akan memberikan kekentalan yang tinggi.

Tepung glukomanan yang disebut juga *konjac flour* merupakan *soluble dietary fiber* yang mirip dengan pektin dalam struktur dan fungsinya. Glukomanan tidak dapat dihidrolisis oleh enzim pencernaan di dalam tubuh manusia dan dikenal sebagai pangan tanpa kalori di Jepang dan China (Li et al. ,2006). Glukomanan sebagai serat pangan memiliki beberapa sifat fungsional antara lain menurunkan kadar kolesterol dan gula dalam darah, meningkatkan fungsi pencernaan dan sistem imun serta membantu menurunkan berat badan (Zhang et al.,2005).

Salah satu karakter istimewa dari glukomanan adalah polimer tersebut memiliki sifat-sifat antara selulosa dan galaktomanan, sehingga zat tersebut mempu mengalami proses pengkristalan serta dapat pula membentuk struktur serat-serat halus (Frey dan Peston, 1967). Menurut Sarko (1967), glukomanan Iarut dalam air dingin dan membentuk massa yang bersifat kental. Larutan kental glukomanan dengan penambahan air kapur dapat membentuk gel yang bersifat tidak mudah pecah (Sugiyama et al., 1972). Perlakuan pemanasan sampai terbentuk gel akan mengakibatkan glukomanan tidak larut kembali di air. Namun glukomanan tidak larut dalam larutan NaOH 20%. Berdasarkan hasil analisis termografik, suhu dekomposisi glukomanan adalah 280°C (Jianrong et al. dalam Nurjanah, 2010).

Glukomanan dalam air mempunyai kemampuan mengembang yang besar yaitu sekitar 138 sampai 200 persen. Larutan glukomanan di dalam air juga mempunyai sifat merekat, namun sifat rekat tersebut akan hilang apabila ditambahkan asam asetat atau asam pada umumnya. Larutan glukomanan dapat diendapkan dengan cara rekristalisasi oleh etanol dan kristal yang terbentuk dapat dilarutkan kembali dengan menggunakan asam klorida encer (Syaefullah, 1990). Glukomanan juga mempunyai sifat mencair seperti agar, sehingga dapat digunakan dalam media pertumbuhan mikroba pengganti agar (Boelhasrin et al., 1970).

Beberapa sifat glukomanan atau zat mannan yang penting adalah sebagai berikut:

- Sifat larut dalam air, yaitu larut dalam air dan tidak larut dalam NaOH 20 %. Glukomanan dalam air dapat membentuk larutan yang sangat kental.
- Sifat membentuk Gel, yaitu ketika di dalam air dapat membentuk larutan yang sangat kental maka dengan penambahan air kapur, zat glukomanan dapat membentuk gel. Gel yang terbentuk mempunyai sifat yang khas dan tidak mudah rusak.
- Sifat merekat, yaitu ketika di dalam air mempunyai sifat merekat yang kuat. Dengan penambahan asam asetat sifat merekat tersebut akan hilang.
- Sifat mengembang, yaitu ketika di dalam air mempunyai sifat mengembang yang besar. Daya mengembangnya 138 sampai 200%.
- Sifat tembus pandang, larutan glukomanan dapat membentuki lapisan tipis (film) yang mempunyai sifat tembus pandang. Film yang terbentuk dapat larut dalam air, asam lambung dan cairan usus. Jika film dari tepung glukomanan dibuat dengan penambahan NaOH atau gliserin maka akan menghasilkan film yang kedap air.
- Sifat mencair, glukomanan mempunyai sifat mencair seperti agar sehingga dapat digunakan dalam media pertumbuhan

mikroba. Sifat mencair ini dapat digunakan sebagai kriteria untuk klasifikasi *Actinomycetes* yang pertumbuhannya diperlambat dan diikuti dengan metabolisme yang lambat dibandingkan dengan bakteri dan fungi lain.

2.3 Biopolimer

Polimer adalah material yang dibentuk oleh satuan struktur berupa monomer yang berulang. Polimer dibuat berasal dari sintetis, semisintesis, dan polimer yang tersedia di alam atau alami. Polimer sintesis adalah polimer yang banyak dan umum digunakan, namun permasalahan muncul berkaitan dengan produk habis pakai (limbah) maupun dengan sumber bahan baku untuk sintesis polimer itu sendiri. Limbah polimer sintesis menimbulkan pencemaran lingkungan yang sulit diurai, sedangkan bahan baku polimer sintesis berasal dari minyak bumi yang merupakan sumber tak terbarukan yang dapat habis sewaktu-waktu. Maka dari itu, banyak aplikasi dan penelitian tentang polimer beralih pada polimer alami.

Polimer alami atau disebut juga sebagai biopolimer adalah material polimer yang berasal dari alam. Biopolimer dapat digolongkan ke dalam dua jenis, yaitu:

- Polimer yang diproduksi oleh sistem biologi seperti oleh hewan, tumbuhan, dan mikroorganisme
- Polimer yang disintesis secara kimia tetapi merupakan turunan dari senyawa alami yang diproduksi oleh sistem biologi seperti gula dan asam amino (Allan, 1993).

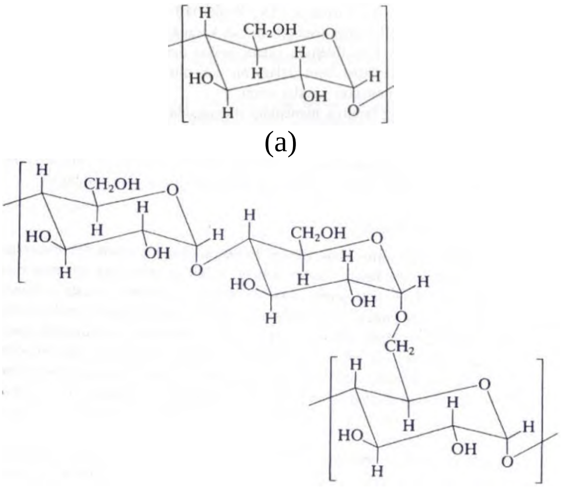
Polimer pada Tabel 2.3 merupakan beberapa contoh polimer yang diproduksi oleh sistem biologi yang terbentuk dari struktur monomer biokimia yang mempunyai fungsi untuk menjalankan fungsi kehidupan bagi makhluk hidup.

Polimer alami salah satu contohnya adalah pati, yang merupakan bentuk polimer sebagai penyimpan energi. Pati termasuk dalam jenis polisakarida dan merupakan kopolimer yang tersusun atas dua jenis unit penyusun yang berbeda, yaitu amilose dan amilopektin yang bisa dipisahkan menurut kelarutan.

Tabel 2.3 Contoh Bentuk Biopolimer (Allan, 1993)

Polimer	**Monomer**	**Bentuk dan Fungsi**
Asam nukleat	Nukleotida	RNA dan DNA (pembawa informasi genetik pada organisme)
Protein	Asam amino-alfa	Enzim (katalis biologis), rambut dan jaringan (material struktural dan faktor pertumbuhan), racun (alat pertahanan pada organisme berbisa)
Polisakarida	Gula	Selulosa dan kitin (material struktural), pati (penyimpan energi)
Polihidroksi Alkanoat	Asam lemak	Penyimpan energi

Amilosa memiliki berat molekul 30.000 sampai 1 juta yang berarti memiliki DP 295 sampai 9804, sedangkan amilopektin memiliki berat molekul diatas 1 juta yang berarti memiliki DP minimum sebesar 3610, namun tentu masih dibawah polimer sintesis. Derajat polimerisasi ini termasuk bernilai kecil, bila dibandingkan dengan polietilen. Dengan berat molekul terendah 100.000 dan tertinggi hingga 6.000.000, DP yang dimiliki polietilen mencapai 3572 hingga 214.286. Harga ini masih jauh diatas DP selulosa yang mempunyai DP yang cukup besar diantara polimer alami hingga 15.000 (Stevens, 2001). Kecilnya DP mengindikasikan bahwa polimer alami mempunyai rantai yang pendek. Pendeknya rantai ikatan ini menjadikan kelemahan bagi polimer alami dalam hal ketahan (durabilitas), namun menjadikan kebihan dalam hal mampu urai (degradabilitas), dimana semakin rendah berat molekul dan derajat polimerisasi, maka polimer akan semakin cepat terdegradasi.



(a)

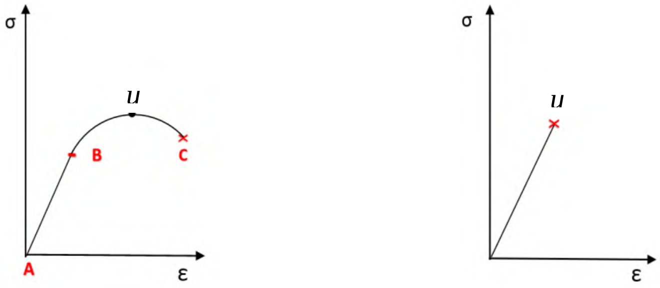
(b)

Gambar 2.4 Gugus penyusun pati: (a) amilosa, (b) amilopektin (Stevens, 2001)

Polimer alami terutama pati, memerlukan suatu proses dengan kondisi khusus untuk mengubahnya ke dalam struktur material plastik biopolimer. Proses tersebut adalah gelatinisasi. Gelatinisasi merupakan proses yang melibatkan air dan pemanasan hingga tercapai suhu tertentu, yang merupakan suhu gelatinisasi dimana suhu gelatinisasi ini biasanya berada di atas temperatur transisi gelas (T_g). Gelatinisasi bertujuan untuk mengubah struktur pati yang berupa polimer semi-kristalin menjadi amorf. Pengubahan itu diawali dengan terputusnya ikatan hidrogen pada molekul pembentuk pati (amilosa dan amilopektin), dimana pemutusan ikatan tersebut terjadi karena pemanasan. Setelah ikatan hidrogen putus, air dapat masuk ke granula pati sehingga pati mengalami penggembungan (*swelling*). Kemudian terjadi peningkatan ikatan hidrogen antara air dengan molekul penyusun pati. Pada tahap ini dapat dikatakan bahwa pati telah terplastisasi oleh air. Penambahan sejumlah *plasticizer* akan meningkatkan mobilitas segmental dan ruang bebas (*free volume*) polimer serta menurunkan atau melemahkan ikatan intermolekular (Pradipta, 2012).

2.4 Uji Tarik

Kekuatan tarik, modulus elastisitas dan daya elongasi suatu bahan dapat diketahui melalui pengujian tarik. Jika suatu bahan yang memiliki luas penampang tertentu diberi perlakuan tarik dengan gaya tertentu juga, maka akan mengalami deformasi. Secara umum, suatu bahan memiliki deformasi elastis dan plastis. Daerah A-B pada gambar 2.4a merupakan deformasi elastis dari suatu bahan. Jika bahan ditarik dengan kekuatan tarik pada daerah tersebut kemudian dilepaskan, maka bahan tersebut akan kembali ke bentuk semula. Sedangkan B-C merupakan deformasi plastisnya, sehingga jika bahan ditarik dengan kekuatan tarik pada daerah plastis kemudian dilepaskan, maka bahan tersebut tidak kembali ke bentuk semula (terdeformasi plastis). Kekuatan tarik pada gambar 2.4a berada pada titik *u*. Gambar 2.4b menunjukkan kurva tegangan-regangan bahan yang tidak memiliki deformasi plastis. Nilai kekuatan tarik dari bahan tersebut merupakan tegangan saat bahan putus (Dasuki Z.,2014).



(a) (b)

Gambar 2.5 Kurva tegangan-regangan (a) dengan deformasi plastis, (b) tanpa deformasi plastis

Sebagai polimer yang banyak diaplikasikan, *polyethylene* memiliki sifat mekanik yang cukup kuat. Kekuatan tarik LDPE sebesar 900-2.500 psi atau setara dengan 6,21-17,24 MPa dan elongasi 550%-600%. Sedangkan HDPE memiliki kekuatan tarik 2900-5400 psi (19,99-37,23 Mpa) dan elongasi 20%-120% (Smith, 1990).

Beberapa film ramah lingkungan (berbahan dasar polimer alam) memiliki sifat mekanik yang bervariasi. Plastik *biodegradable* yang berbahan pencampuran polylactide (PLA) dan *thermoplastic konjac glucomannan* (TKGM) memiliki kekuatan tarik 36,5 MPa dan elongasi 520,5% (Xu, 2009). Kekuatan tarik film glukomannan konjak sebesar 35-55 MPa (Cheng, 2006), dan film dari pati kulit singkong dengan penambahan khitosan dan gliserol memiliki kuat tarik 6269,059 psi (43,22 MPa) dengan modulus elastisitas 494925,675 psi (3412,39 MPa) dan elongasi 1,27% (Sanjaya, 2011). Namun, Plastik glukomanan dengan *plasticizer* gliserol memiliki sifat mekanik yang rendah yaitu rentang kekuatan tarik nya berkisar antara 0,0275-0,8 MPa, sedangkan elongasi yang dimiliki 5,19%-26,48%, dan modulus elastisitasnya 0,2818-15,4202 MPa (Pradipta dan Mawarani, 2012).

2.5 Uji *swelling* (Penggembungan)

Uji *swelling* digunakan untuk menentukan jumlah air yang diserap dalam kondisi tertentu. Faktor yang mempengaruhi penyerapan air meliputi: jenis plastik, aditif yang digunakan, temperatur dan lama paparan. Data menyoroti kinerja bahan dalam air atau lembab lingkungan. Penyerapan air dinyatakan sebagai peningkatan berat persen. Persen Penyerapan Air = [(berat basah - berat kering) / berat kering] x 100%.

Untuk mengetahui sifat penggembungan, maka perlu dilakukan uji *swelling* (*swelling test*). Changgang Xu (2009) juga melakukan uji *swelling* pada plastik hasil penelitiannya. Kemampuan serap air (W_m) dari film plastik dapat diperoleh dari perbedaan massa awal polimer dan massa polimer setelah menyerap air (Xu, 2009), seperti yang ditunjukkan oleh persamaan:

$$W_m = \frac{m_2 - m_1}{m_1} \; x \; 100\% \qquad (2.4)$$

dimana m_1 adalah massa sampel sebelum dilakukan pencelupan dan m_2 adalah massa sampel setelah dilakukan pencelupan. Perhitungan ini sama dengan standar ASTM D570 (Dasuki Z.,2014).

Plastik *biodegradable* yang terbuat dari pencampuran poli-asam laktat (PLA) dan *thermoplastic konjac glucomannan* (TKGM) memliliki daya serap air 3,8% (Xu, 2009). Angka tersebut jauh lebih kecil dibanding penggembungan film dari pati kulit singkong dengan penambahan khitosan dan gliserol, yaitu 66%-77% (Sanjaya, 2011). Plastik glukomanan dengan *plasticizer* gliserol juga memiliki sifat ketahanan terhadap air berkisar antara 61,6%-391,42% (Pradipta dan Mawarani, 2012).

2.6 Degradasi Polimer

Perubahan senyawa kimia menjadi molekul yang lebih sederhana melalui bantuan mikroorganisme disebut biodegradasi. Biodegradasi dibagi menjadi dua, yaitu *primary biodegradation* dan *ultimate biodegradation*. *Primary biodegradation* atau biodegradasi tahap pertama merupakan perubahan sebagian molekul kimia menjadi komponen lain yang lebih sederhana. Sedangkan *ultimate biodegradation* atau biodegradasi tuntas merupakan perubahan molekul kimia secara lengkap sampai terbentuk CO_2, H_2O dan senyawa organik lain (Gledhill dalam Al Ummah, 2013).

Polimer terdegradasi dari sinar matahari (*fotodegradable*) dapat terurai dengan menginkorporasi gugus-gugus karbonil yang menyerap radiasi *ultraviolet* (UV) sebagai energi untuk pembelahan ikatan (Stevens dalam Pradipta dan Mawarani, 2012). Selain menggunakan UV, sifat biodegradabilitas film plastik dapat diketahui dengan biodegradasi. Bakteri *Pseudomonas sp.* merupakan bakteri pengurai yang memiliki kemampuan yang baik. Bakteri ini memiliki kemampuan biodegradasi sebesar 40.5% untuk menguraikan polietilena (Nanda *et al*, 2010). Film dari pati kulit singkong dengan penambahan khitosan dan gliserol mampu terdegradasi selama 10 hari (Sanjaya, 2011) dan plastik glukomanan dengan *plasticizer* gliserol membutuhkan waktu 9 hari (Pradipta dan Mawarani, 2012).

2.7 *Fourier Transform Infrared Spectrometry* (FTIR)

Fourier Transform Infrared Spectrometry merupakan metode yang digunakan untuk mengetahui jenis ikatan yang terdapat dalam suatu bahan.

Tabel 2.4 Jenis Gugus Fungsi Hasil FTIR. Sumber : Coates dalam Merisianto dan Mawarani (2013)

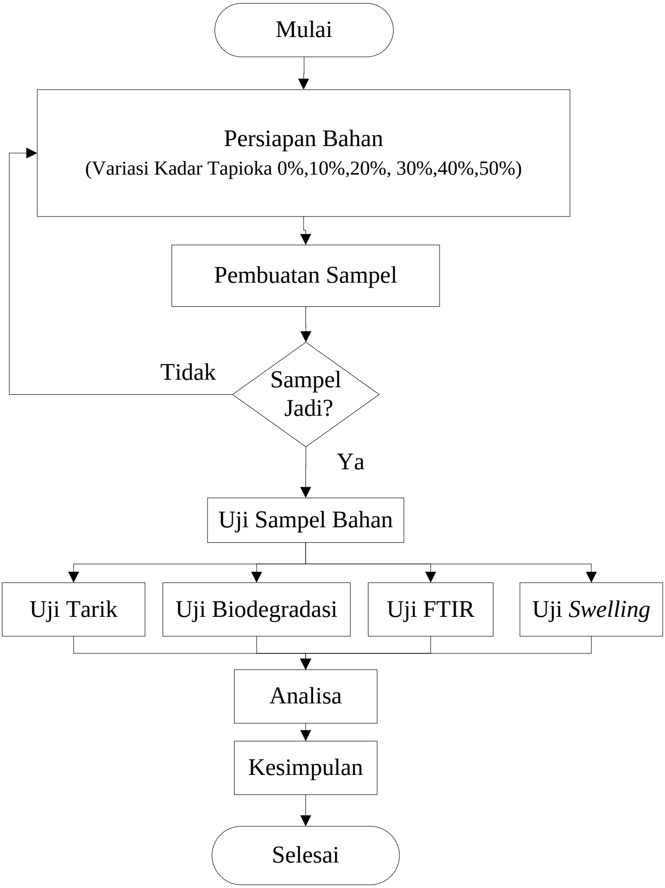
Rentang Bilangan gelombang	Jenis Gugus Fungsi
3650 – 3200	-OH
3000 - 2500	Alkyl C-H
1680 - 1620	Ulul C=C
1420-1410	C-H Vinil
1410 - 1310	Bengkok –OH
1150 - 1050	Ulur C-O
1140 - 1070	Ulur C-O
1150-1000	C-F
1300-700	C-C
1225 - 950	Bengkok C-H
1650 – 1550	N-H bengkok

Jika seberkas sinar inframerah dilewatkan pada suatu sampel polimer, maka beberapa frekuensinya diabsorpsi oleh molekul sedangkan frekuensi lainnya ditransmisikan. Transisi yang terlibat pada absorpsi IR berhubungan dengan perubahan vibrasi yang terjadi pada molekul. Jenis ikatan yang ada dalam molekul polimer (C-C, C=C, C-O, C=O) memiliki frekuensi vibrasi yang berbeda. Adanya ikatan tersebut dalam molekul polimer dapat diketahui melalui identifikasi frekuensi karakteristik sebagai puncak absorpsi dalam spektrum IR. (Eli Rohaeti, 2009)

Halaman ini memang dikosongkan

BAB III
METODOLOGI PENELITIAN

Secara runtut, penelitian ini dilakukan dengan tahapan-tahapan yang digambarkan sesuai dengan alur metodologi penelitian. Metodologi dalam penelitian ini antara lain:



Gambar 3.1 *Flowchart* pelaksanaan penelitian

3.1 Persiapan Bahan

Bahan yang digunakan dalam penelitian ini adalah glukomanan porang yang diproduksi oleh CV. Alif Jaya dan tepung tapioka *Rose Brand* yang diproduksi oleh PT. Budi Starch and Sweetener Tbk. Serta NaOH yang diperoleh dari Toko SUK dan Gliserin dari PT. Brataco. Secara lengkap peralatan dan bahan yang digunakan dalam melakukan penelitian tugas akhir ini adalah:

- Peralatan
  - Gelas *beaker*
  - *Magnetic Stirrer*
  - Timbangan digital
  - Kaca dan lakban (Cetakan)
  - *Autograph* (uji tarik)
  - Alat uji FTIR
  - Pipet
  - Cawan
- Bahan
  - Tepung tapioka
  - Tepung glukomanan porang
  - NaOH
  - Gliserin
  - Bakteri *Pseudomonas sp.*
  - Akuades
  - Minyak goreng (pelumas)

Adapun komposisi antara glukomanan porang dan tapioka dalam penelitian ini yaitu tertera dalam Tabel 3.1.

Tabel 3.1 Komposisi Glukomanan-Tapioka

Komposisi	Glukomanan (gr)	Tapioka (gr)
10:0	10	0
9:1	9	1
8:2	8	2
7:3	7	3
6:4	6	4
5:5	5	5

3.2 Pembuatan Film Biopolimer

Proses pertama yang dilakukan dalam penelitian kali ini adalah proses pencampuran bahan untuk membuat biopolimer berbentuk *film*. Bahan yang dicampur adalah glukomanan, tepung tapioka, NaOH, gliserin dan akuades. Campuran ini akan diaduk menggunakan *magnetic stirrer* dan *hot plate* selama kurang lebih 5-7 menit. Dan dicetak dengan cetakan tipis yang kemudian dikeringkan dengan menggunakan lampu bohlam.

Digunakan timbangan digital untuk mengukur massa dari tepung tapioka dan glukomanan dalam satu adonan. Glukomanan dan tapioka dituang bersama ke dalam gelas *beaker*, dan kemudian ditambahkan 5ml NaOH, 10ml gliserin dan 100ml akuades.

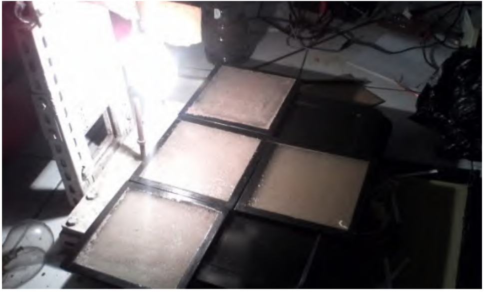
Gambar 3.2 Pencampuran bahan

Setelah semua bahan dimasukkan ke dalam gelas *beaker* , berikutnya adalah proses pencampuran atau pengadukan. Semua bahan dalam gelas *beaker* diaduk secara manual untuk memastikan bahan tercampur. Selanjutnya, gelas *beaker* ditaruh di atas *hot plate* dan diberi *magnetic stirrer*. Suhu *hot plate* diatur menjadi 80^{o}C dengan kecepatan 2. Proses pengadukan berlangsung 5-7 menit hingga adonan cukup kental dan *magnetic stirrer* tidak bisa berputar lagi. Adonan yang telah mengental ditaruh di atas cetakan yang telah disediakan.

Gambar 3.3 Pengadukan sampel

Cetakan terbuat dari kaca yang dilapisi lakban yang dibagi menjadi 6 bagian, sesuai dengan jumlah variasi. Cetakan diolesi dengan minyak goreng, agar adonan tidak lengket dengan cetakan. Sehingga pada saat adonan kering, adonan mudah dilepas dari cetakan.

Adonan yang terdapat di cetakan akan diletakkan di bawah lampu bohlam Philips 60 watt dengan jarak 30 cm selama 4-6 jam. Adonan yang telah kering akan menjadi biopolimer yang akan siap diuji mekanik, *swelling*, *biodegradable* dan FTIR.



Gambar 3.4 Pengeringan sampel menggunakan lampu bohlam

3.3 Uji Sampel

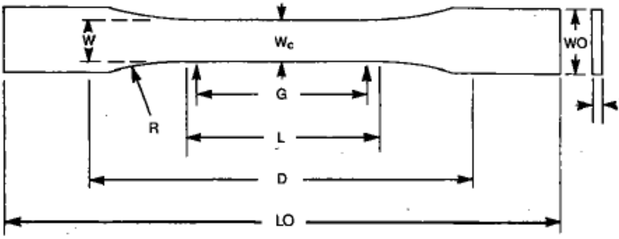
Biopolimer atau sampel yang telah dibuat akan diuji kekuatannya (tarik) dengan menggunakan alat uji tarik (*autograph*). Kemudian sampel akan direndam dengan air untuk menguji kadar air yang diserap oleh sampel. Untuk kemampuan *biodegradable*, sampel akan direndam dengan bakteri

Pseudomonas sp. Dan untuk mengetahui jenis ikatan, sampel akan diuji dengan metode FTIR.

3.3.1 Uji tarik

Sampel akan diuji kekuatan tariknya dengan menggunakan *autograph*. Pada uji kali ini diketahui nilai kekuatan tarik, daya elongasi dan modulus elastisitas dari sampel. Dalam penelitian ini, sampel akan dipotong sesuai dengan tipe V dari ASTM D 638 dengan panjang total (L_0) 6 cm dan lebar 1 cm. (ASTM International, 2003)

Data yang didapatkan dari uji ini adalah gaya (F) dan pertambahan panjang (Δl), dari data ini akan diperoleh nilai *tensile strength* melalui persamaan (2.1) dan elongasi dengan persamaan (2.2). Melalui besar *tensile strength* dan elongasi, maka dapat diketahui sifat elastisitasnya. Perbandingan antara tegangan/kuat tarik (σ) dan regangan/perpanjangan (ε) disebut modulus elastisitas (E) yang didapat melalui persamaan (2.3)



Gambar 3.5 Bentuk dan ukuran sampel uji

3.3.2 Uji *swelling*

Uji *swelling* digunakan untuk menentukan jumlah air yang diserap dalam kondisi tertentu. Derajat penggembungan dinyatakan sebagai peningkatan berat (W_m). Massa awal sampel kering ditimbang terlebih dahulu (m_1).

(a) (b)

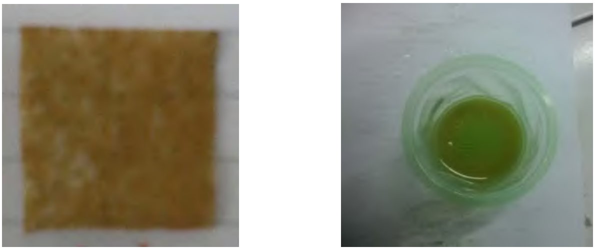
Gambar 3.6 Proses uji *swelling* (a) pencelupan sampel (b) pengukuran berat sampel

Sampel kering dicelupkan dalam air selama 10 detik. Setelah itu sampel diangkat dan ditiriskan pada tisu lalu ditimbang. Sampel dicelupkan kembali dalam air, lalu diangkat setelah 10 detik dan ditimbang lagi. Cara yang sama dilakukan hingga diperoleh berat akhir sampel yang konstan (m_2) (Al Ummah, 2013). Derajat penggembungan (W_m) dari film plastik dapat diperoleh dari perbedaan massa awal polimer dan massa polimer setelah menyerap air (Xu, 2009) yang ditunjukkan dengan persamaan (2.4).

3.3.3 Uji biodegradasi

Kemampuan film biopolimer untuk terurai secara biologis dilakukan dengan cara merendam film biopolimer ke dalam bakteri. Bakteri yang digunakan dalam penelitian ini adalah *Pseudomonas sp.* Bakteri tersebut dimasukkan ke dalam wadah kecil dengan jaring sebagai alas. Film biopolimer dicelupkan ke dalam bakteri tersebut dan diamati setiap 24 jam.

Pengamatan dilakukan dengan melihat perubahan dimensi dan massa film biopolimer. Setiap 24 jam (1 hari), film akan diangkat dari cairan bakteri, ditiriskan dan diamati perubahan dimensinya dan dibandingkan dengan bentuk semula. Setelah itu, massa film biopolimer akan ditimbang menggunakan timbangan digital untuk mengetahui perubahan massa film biopolimer akibat terurai oleh bakteri. Pengamatan dilakukan hingga film biopolimer benar-benar habis terurai oleh bakteri.


(a) (b)

Gambar 3.7 Pengujian biodegradasi (a) sampel uji (b) bakteri *Pseudomonas sp.* dalam wadah

Dari uji ini didapatkan data massa sampel per hari, data tersebut kemudian dimasukkan ke dalam grafik dan dihitung kemiringan (gradien) dari grafik tersebut. Gradien grafik menunjukkan besar laju degradasi sampel. Gradien dari semua variasi sampel akan dimasukkan ke dalam satu grafik sehingga dapat terlihat pengaruh komposisi glukomanan dan tapioka terhadap laju degradasi.

3.3.4 Uji FTIR

Pengujian FTIR akan menunjukkan bagaimana serapan gugus polimer pada sampel berdasarkan grafik yang muncul pada layar komputer sebagai piranti yang terhubung dengan FTIR. Pengujian ini dilakukan terhadap semua variasi sampel sehinggan akan diketahui gugus ikatan yang terkandung dalam tiap variasi. Alat yang digunakan dalam uji ini adalah *Fourier Transform Infrared Spectrometry* di Jurusan Teknik Material dan Metalurgi ITS.

3.4 Pengolahan dan Analisa Data

Pada bagian ini, akan dilakukan analisa data dari uji eksperimen. Dari analisis tersebut akan dilakukan pembahasan untuk mengulas dan menjelaskan dari hasil penelitian ini. Berdasarkan hasil semua uji, dapat terlihat kecenderungan hasil yang paling optimal di antara semua variasi. Hal ini dilakukan dengan membandingkan data dari semua hasil uji dalam satu tabel dan dalam satu grafik. Hasil penelitian akan ditulis ke dalam laporan tugas akhir. Yang berisi tentang proses penelitian serta hasil yang diperoleh.

BAB IV
HASIL DAN PEMBAHASAN

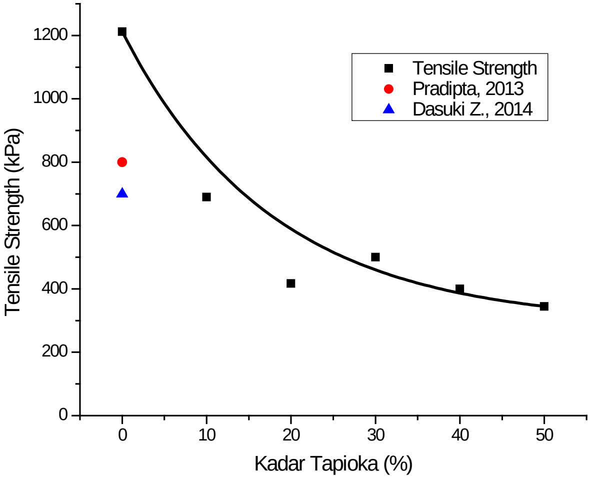
4.1 Sifat Mekanik

Penentuan sifat mekanik pada penelitian ini yaitu dengan mengukur kekuatan tarik dari bahan. Uji tarik dilakukan dengan menggunakan *Autograph.* Data yang diperoleh pada uji tersebut adalah nilai gaya tarik dari mesin (F) dan pertambahan panjang dari bahan yang diuji (Δl). Data tersebut diolah dengan menggunakan persamaan (2.1), (2.2) dan (2.3) sehingga didapatkan nilai *tensile strength* (σ), elongasi (ε) dan modulus elastisitas (E). Hasil olahan data tersebut tertera pada Tabel 4.1 dan digambarkan dalam grafik *tensile strength* pada Gambar 4.1 serta grafik elongasi pada Gambar 4.2 dari setiap variasi kadar tapioka.

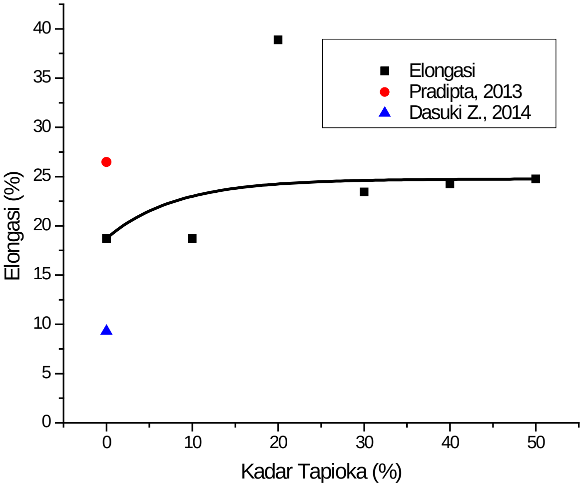
Tabel 4.1 Sifat Mekanik Film Biopolimer Glukomanan-Tepung Tapioka

Kadar Tapioka (%)	**σ (kPa)**	**ε (%)**	**E (kPa)**
0	1212,12	15,45	78,45
10	689,66	18,73	36,83
20	416,67	38,88	10,72
30	454,55	27,38	16,60
40	400	24,25	16,49
50	344,83	24,75	13,93

Dari tabel di atas, dapat dilihat bahwa terjadi perubahan di setiap variasi film biopolimer. Namun perubahan signifikan terlihat pada variasi 20%, nilai elongasi dan modulus elastistas memiliki tren yang berbeda dari variasi lainnya. Data pada tabel tersebut digambarkan dalam bentuk grafik pada Gambar 4.1 dan 4.2.

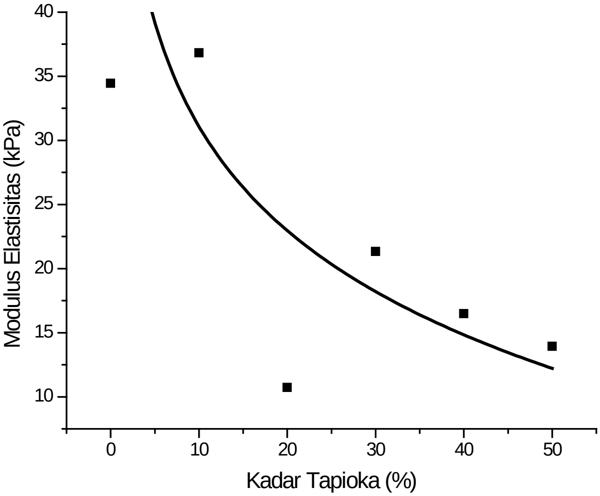


Gambar 4.1 Grafik *tensile strength* dari setiap variasi sampel



Gambar 4.2 Grafik elongasi dari setiap variasi sampel

Dari Gambar 4.1, dapat terlihat bahwa kekuatan tarik cenderung menurun dengan pertambahan kadar tapioka. Kekuatan tarik tertinggi dihasilkan oleh film biopolimer dengan kadar tapioka 0% yaitu sebesar 1212,12 kPa, nilai terendah berada pada titik kadar tapioka 50%. Grafik di atas memiliki *trendline* eksponensial yang ditunjukkan dengan garis hitam. Namun terdapat penurunan yang cukup signifikan pada kadar tapioka 20%, hal ini terlihat dari titik tersebut yang melenceng cukup jauh dari garis *trendline*. Pada Gambar 4.2, bentuk grafik cenderung meningkat dengan *trendline* eksponensial. Dapat terlihat bahwa pada kadar tapioka 20%, elongasi meningkat secara drastis sebesar 38,88 dan terletak jauh di atas garis *trendline*. Secara umum, grafik tersebut menggambarkan bahwa penambahan tapioka pada sampel dapat meningkatkan nilai elongasi dari film biopolimer.



Gambar 4.3 Kurva modulus elastisitas terhadap penambahan kadar tapioka

Modulus elastisitas merupakan derajat kekakuan dari suatu bahan elastis, semakin besar modulus elastisitas maka semakin kaku bahan tersebut, begitu juga sebaliknya. Dari Gambar 4.3, nilai modulus elastisitas menurun seiring bertambahnya kadar tapioka. Hal ini menunjukkan bahwa semakin banyak tapioka yang ditambahkan maka bahan akan semakin elastis. Namun terdapat *error* yang cukup besar yang ditunjukkan pada titik 20%, dimana nilai modulus elastisitas menurun secara drastis hingga 10,72 kPa.

4.2 Derajat Penggembungan

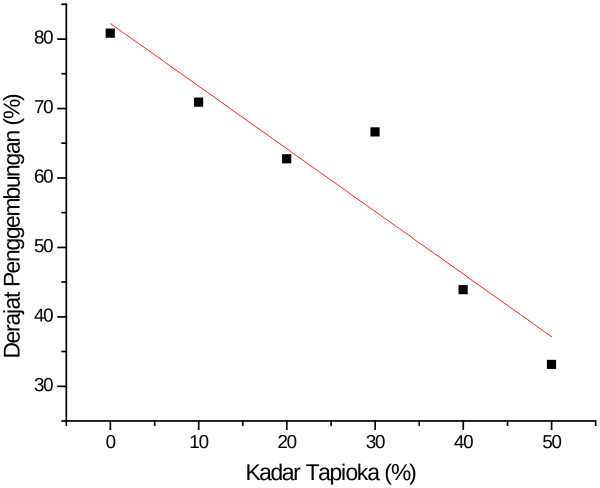
Uji *swelling* (derajat penggembungan) dilakukan dengan menggunakan *aquades* dan timbangan digital untuk mengukur perubahan massa sebelum dan sesudah dicelup dengan *aquades*. Data yang diperoleh dari uji *swelling* adalah perubahan massa (Δm) dan besar derajat penggembungan (*Wm*) seperti yang ditunjukkan pada Tabel 4.2.

Tabel 4.2 Perubahan Massa dan Derajat Penggembungan Film Biopolimer Tepung Tapioka-Glukomanan

Kadar Tapioka (%)	**Δm (gr)**	***Wm* (%)**
0	0,1516	80,8280
10	0,1108	70,8893
20	0,1185	62,7493
30	0,0980	66,5987
40	0,1020	43,8944
50	0,1180	33,1184

Tabel 4.2 menunjukkan data dari uji penggembungan. Dari data tersebut dapat terlihat bahwa derajat penggembungan dari film biopolimer berbahan dasar glukomanan dan tepung tapioka adalah sebesar 33,12% - 80,83%. Gambar 4.5 merupakan grafik dari derajat penggembungan. Dari gambar tersebut dapat terlihat bahwa nilai derajat penggembungan menurun secara linier seiring pertambahan tapioka. Dari grafik tersebut terlihat bahwa kadar

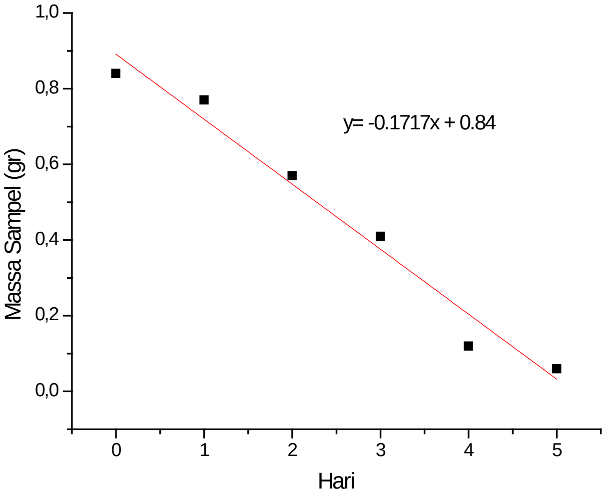
tapioka dan glukomanan mempengaruhi nilai derajat penggembungan, semakin banyak kadar tapioka maka derajat penggembungan semakin menurun.



Gambar 4.4 Derajat penggembungan film biopolimer

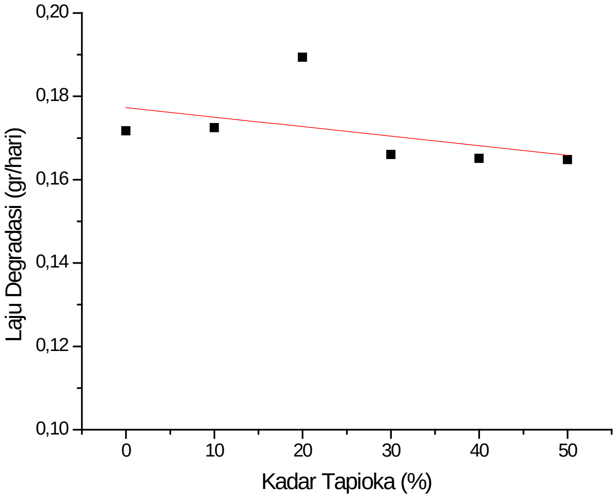
4.3 Hasil Uji Biodegradasi

Hasil uji biodegradasi menggunakan bakteri *Pseudomonas sp.* menunjukkan bahwa terjadi perubahan bentuk (dimensi) penurunan massa dari film biopolimer. Pengamatan dilakukan selama 5 hari hingga semua film biopolimer habis terurai oleh bakteri. Penurunan massa akan diplot dan dicari laju degradasinya. Dalam bentuk grafik, laju degradasi ditunjukkan dengan derajat kemiringan (*slope*). Dari Gambar 4.5, massa biopolimer semakin berkurang dari hari ke hari. Grafik menunjukkan bahwa kemiringan ditentukan dari besar gradien (m) dari persamaan linear dari garis *trendline* yaitu $y = mx + c$. Pada Gambar 4.5, gradiennya (m) sebesar 0,1717, artinya laju degradasinya adalah 0,1717 gr/hari.

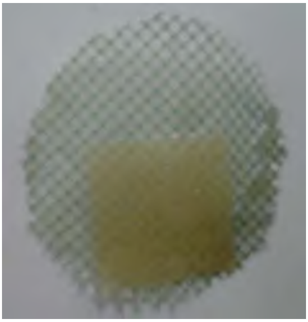


Gambar 4.5 *Plotting* grafik penurunan massa untuk sampel kadar tapioka 0%

Dari semua *plotting* grafik penurunan massa sampel dari seluruh variasi komposisi terlihat laju biodegradasi dari gradien (*m*) masing-masing grafik. *Plotting* semua gradien dari seluruh variasi komposisi dijadikan dalam satu grafik yang ditampilkan pada Gambar 4.6. Dari Gambar 4.6 terlihat penurunan laju degradasi seiring bertambahnya kadar tapioka. Hal ini menunjukkan bahwa semakin banyak kadar glukomanan, maka laju degradasi semakin tinggi. Dari data menunjukkan bahwa laju degradasi tertinggi terjadi pada film biopolimer dengan kadar tapioka 20% yaitu sebesar 0,19 gram/hari.

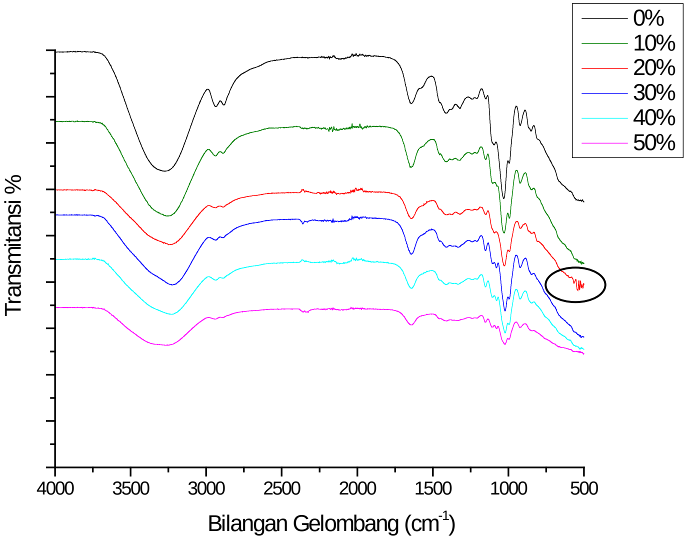


Gambar 4.6 Laju biodegradasi film biopolimer terhadap kadar tapioka



4.4 Hasil Uji FTIR

Pengaruh komposisi dari tapioka dan glukomanan dapat dilihat melalui uji FTIR. Dari uji tersebut, akan dapat terlihat gugus fungsi dari masing-masing variasi sampel. Dari uji FTIR didapatkan data berupa transmitansi terhadap bilangan gelombang.



Gambar 4.8 Transmitansi gugus fungsi pada film biopolimer glukomanan-tapioka

Pada Gambar 4.8, terdapat grafik FTIR dari berbagai variasi kadar tapioka pada film biopolimer. Dari grafik tersebut tidak terdapat perbedaan yang mencolok antara satu dengan yang lain. Secara umum terdapat beberapa puncak yang terlihat, yaitu pada rentang 3226,27-3257,54 cm^{-1} yang menunjukkan terdapat gugus O-H, kemudian pada rentang 2800-3000 cm^{-1} terdapat dua puncak yang menunjukkan adanya gugus C-H. Film tersebut juga menyerap infra merah pada bilangan gelombang 1640,05 cm^{-1} yang menunjukkan gugus C=O ulur dari golongan amida. Ikatan hidrokarbon C-H vinyl ditemukan yang ditandai dengan diserapnya infra merah pada 1416,85 cm^{-1}. Beberapa gugus fungsi yang lain pada film tepung glukomanan porang ini yaitu O-H bengkok (1334,04 cm^{-1}), C-O ulur (1235,88 cm^{-1}), C-N ulur (1201,06 cm^{-1} dan 1150,62 cm^{-1}), C-O ulur eter aromatik (1106,07 cm^{-1} dan 1071,24 cm^{-1}), dan C-C (995,62 cm^{-1}, 922,94 cm^{-1}, dan 853,57 cm^{-1})(Coates, 2000)

Namun pada variasi kadar tapioka 20%, grafik FTIR menunjukkan adanya beberapa puncak pada rentang 500-600 cm^{-1} (bagian yang dilingkari). Rentang tersebut menggambarkan adanya gugus C-I yaitu Alphatic iodo compounds (Coates, 2000). Gugus ini muncul hanya di variasi kadar tapioka 20% dan tidak muncul di variasi yang lain.

4.5 Interpretasi Hasil

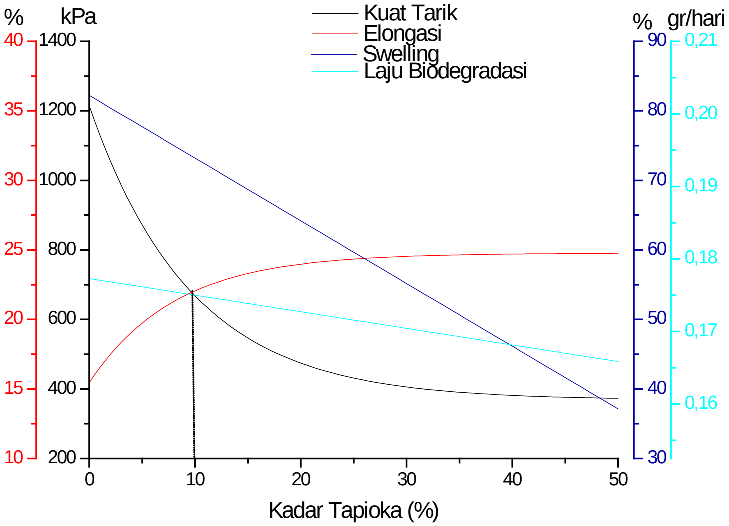
Pada penelitian ini didapatkan data uji tarik (kuat tarik, elongasi, modulus elastisitas), uji *swelling* (derajat penggembungan), uji biodegradasi (laju degradasi) dari film biopolimer berbahan dasar glukomanan porang dan tepung tapioka. Dari data tersebut dapat kita rangkum dalam tabel 4.3

Tabel 4.3 Data Hasil Penelitian Terhadap Film Biopolimer Berbahan Dasar Glukomanan dan Tepung Tapioka

Kadar Tapioka (%)	**σ (kPa)**	**ε (%)**	**E (kPa)**	***Wm* (%)**	**Laju Biodegradasi (gr/hari)**
0	1212,12	15,45	78,45	80,8280	0,1717
10	689,66	18,73	36,83	70,8893	0,1725
20	416,67	38,88	10,72	62,7493	0,1894
30	454,55	27,38	16,60	66,5987	0,1660
40	400	24,25	16,49	43,8944	0,1651
50	344,83	24,75	13,93	33,1184	0,1648

Berdasarkan tabel 4.3, dapat terlihat bahwa untuk kuat tarik nilai tertinggi terdapat pada sampel dengan kadar tapioka 0% sebesar 1212,12 kPa. Nilai elongasi, modulus elastisitas dan laju biodegradasi terbaik terdapat pada sampel dengan kadar tapioka 20%. Sementara sampel dengan kadar tapioka 50% memiliki derajat penggembungan paling baik yaitu 33,1184%.

Dari hasil di atas dapat terlihat bahwa sampel dengan kadar tapioka 20% memiliki keunggulan daripada sampel yang lain. Hal ini disebabkan adanya kandungan yang berbeda pada variasi tersebut yang dapat terlihat melalui analisa FTIR. Dari Gambar 4.8, grafik FTIR di atas terdapat puncak pada rentang 566,34-506,48 yang menggambarkan gugus *Aliphatic iodo*. Senyawa alifatik memiliki atom karbon yang berikatan secara terbuka dalam bentuk garis lurus yang panjang. Hal ini memberikan sifat elongasi pada sampel sehingga menyebabkan nilai elongasi yang besar dibandingkan dengan yang lain. Nilai elongasi ini secara langsung akan berpengaruh kepada nilai modulus elastisitas melalui persamaan (2.3). Sementara adanya gugus ini tidak terlalu mempengaruhi laju biodegradasi, hal ini terlihat dari selisih antar variasi yang cukup dekat yaitu 0,01gr/hari.



Gambar 4.9 Plot grafik hasil uji tarik, uji *swelling* dan uji biodegradasi

Jika dibandingkan dengan penelitian sebelumnya dapat terlihat bahwa kuat tarik dalam penelitian ini masih tergolong rendah. Kuat tarik yang dimiliki HDPE sebesar 37,23 MPa (Smith,1990), bioplastik glukomanan dengan *plasticizer* gliserol sebesar 0,8 MPa (Pradipta, 2013) dan bioplastik glukomanan dengan penambahan sebesar NaOH sebesar 0,8 MPa (Dasuki Z., 2014). Namun penelitian ini unggul dalam hal laju biodegradasi jika dibandingkan dengan sebelumya. HDPE membutuhkan waktu sekitar 2 bulan untuk terdegradasi (Nanda et al, 2010), sementara untuk penelitian bioplastik glukomanan dengan gliserol membutuhkan 9 hari (Pradipta, 2013) dan bioplastik dengan penambahan NaOH membutuhkan waktu 7 hari dengan laju 36mg/hari.

Dari semua uji yang dilakukan, karakteristik yang dibutuhkan dalam biopolimer sebagai kemasan adalah sifat kuat tarik, elongasi, *swelling* dan laju biodegradasi yang tinggi. Sampel dengan kadar tepung tapioka 10% menunjukkan nilai kombinasi kuat tarik dan laju degradasi yang optimum. Hal ini menunjukkan bahwa pada komposisi tersebut paling optimal untuk dijadikan plastik kemasan.

Dari gambar pada Lampiran D, foto mikroskop optik menunjukkan adanya perubahan morfologi permukaan dari sampel seiring dengan penambahan kadar tapioka. Pada sampel dengan kadar tapioka 0% hingga 20%, terlihat bahwa permukaannya berwarna kuning dikarenakan jumlah glukomanan lebih banyak daripada tapioka. Permukaan terlihat tidak rata dan bergelombang karena ukuran glukomanan cenderung besar dan tidak terlalu rapat susunannya. Hal ini berbeda dengan sampel dengan kadar tapioka 30% sampai 50%, sampel-sampel tersebut warna kuning bercampur dengan warna putih dikarenakan jumlah tapioka semakin banyak. Seiring bertambahnya kadar tapioka hingga 50%, permukaan sampel lebih halus dan merata.

Namun dari seluruh gambar tersebut, terlihat bahwa sampel dengan kadar tapioka 10% memiliki bentuk permukaan yang lebih teratur. Hal ini dapat dilihat dari bentuk glukomanan yang bulat serta jarak yang lebih teratur. Celah di antara glukomanan diiisi oleh tapioka sehingga membuat glukomanan-glukomanan semakin merekat satu sama lain. Faktor ini akan berpengaruh pada kuat tarik dan elongasi dari sampel, yaitu semakin rekat dan teratur jarak antar komponen penyusun maka nilai kuat tarik dan elongasi akan semakin baik. Hal ini sesuai dengan hasil uji yang menunjukkan bahwa sampel dengan kadar tapioka 10 % memiliki kombinasi kuat tarik yang optimum.

BAB V
KESIMPULAN

Dalam tugas akhir ini, telah berhasil dibuat biopolimer dan dilakukan karakterisasi terhadap biopolimer tersebut. Dari pengujian dan pembahasan, dapat disimpulkan bahwa:

- Semakin besar kadar tepung tapioka, sifat kekuatan tarik dan modulus elastisitas dan derajat penggembungan biopolimer cenderung menurun. Namun elongasi cenderung meningkat.
- Sampel dengan kadar tapioka 10% merupakan sampel dengan performansi yang optimal dengan nilai kuat tarik sebesar 689,66 kPa, elongasi sebesar 18,73%, modulus elastisitas 36,83 kPa, derajat penggembungan sebesar 70,8893% dan laju biodegradasi 0,1725 gr/hari.

Halaman ini memang dikosongkan

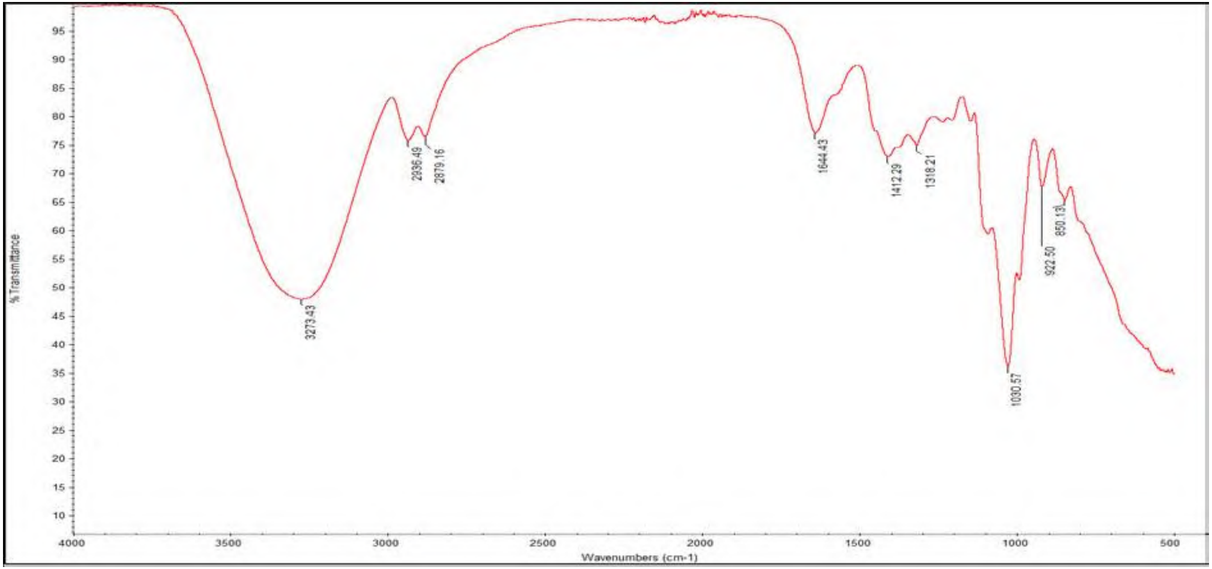
LAMPIRAN A
DATA UJI TARIK

Kadar Tapioka (%)		Tebal sampel (mm)	A_0 (mm^2)	F (kN)	Δl (mm)	σ_{max} (kPa)	ε (%)	E (kPa)
0	Percobaan 1	0,31	1,55	0,001	7,49	645,16	18,73	34,45
	Percobaan 2	0,33	1,65	0,002	6,18	1212,12	15,45	78,45
	Percobaan 3	0,29	1,45	0,0015	5,72	1034,48	14,30	72,34
	Rata-Rata			0,0015	6,46	963,92	16,16	61,75
10	Percobaan 1	0,29	1,45	0,001	7,49	689,66	18,73	36,83
	Percobaan 2	0,31	1,55	0,0005	6,18	322,58	15,45	20,88
	Percobaan 3	0,34	1,7	0,001	5,72	588,24	14,30	41,14
	Rata-Rata			0,0008	6,46	533,49	16,16	32,95
20	Percobaan 1	0,29	1,45	0,0005	5,78	344,83	14,45	23,86
	Percobaan 2	0,28	1,4	0,0005	10,25	357,14	25,63	13,94
	Percobaan 3	0,24	1,2	0,0005	15,55	416,67	38,88	10,72
	Rata-Rata			0,0005	10,53	372,88	26,32	16,17

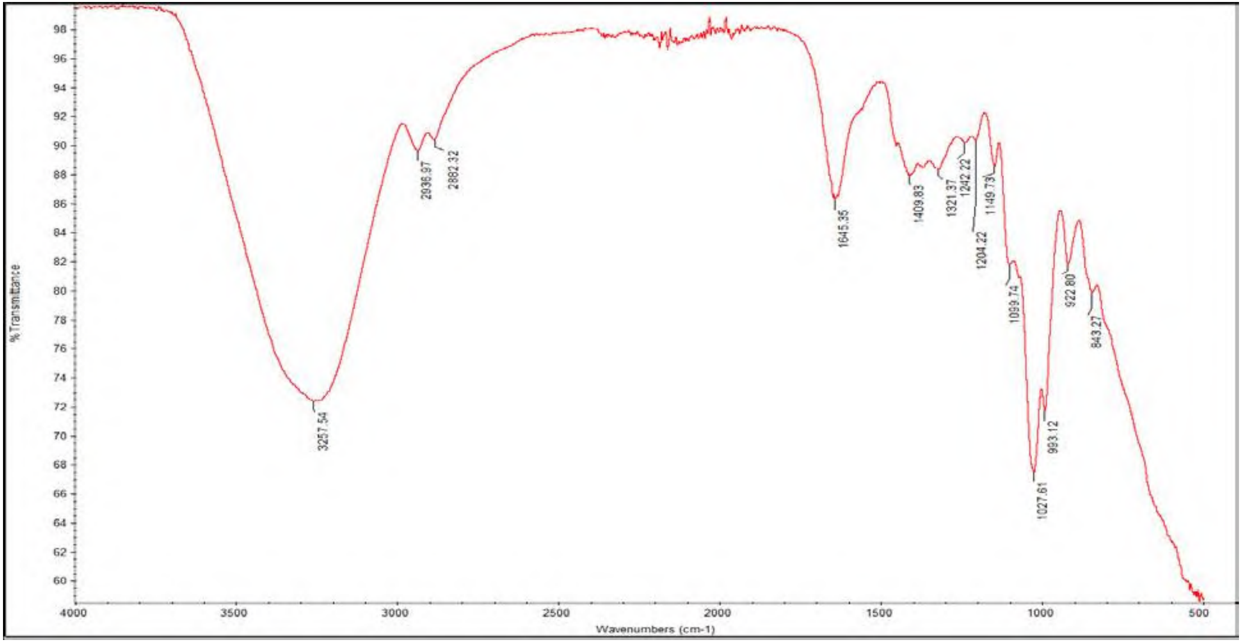
DATA UJI TARIK (Lanjutan)

Kadar Tapioka (%)	Tebal sampel (mm)	A_0 (mm^2)	F (kN)	Δl (mm)	σ_{max} (kPa)	ε (%)	E (kPa)	Kadar Tapioka (%)
30	Percobaan 1	0,21	1,05	0,0005	6,97	476,19	17,43	27,33
	Percobaan 2	0,2	1	0,0005	9,37	500,00	23,43	21,34
	Percobaan 3	0,22	1,1	0,0005	10,95	454,55	27,38	16,60
	Rata-Rata			0,0005	9,10	476,91	22,74	21,76
40	Percobaan 1	0,28	1,4	0,0005	9,31	357,14	23,28	15,34
	Percobaan 2	0,29	1,45	0,0005	7,69	344,83	19,23	17,94
	Percobaan 3	0,25	1,25	0,0005	9,7	400,00	24,25	16,49
	Rata-Rata			0,0005	8,90	367,32	22,25	16,59
50	Percobaan 1	0,29	1,45	0,0005	9,9	344,83	24,75	13,93
	Percobaan 2	0,31	1,55	0,0005	8,78	322,58	21,95	14,70
	Percobaan 3	0,34	1,7	0,0005	10,76	294,12	26,90	10,93
	Rata-Rata			0,0005	9,81	320,51	24,53	13,19

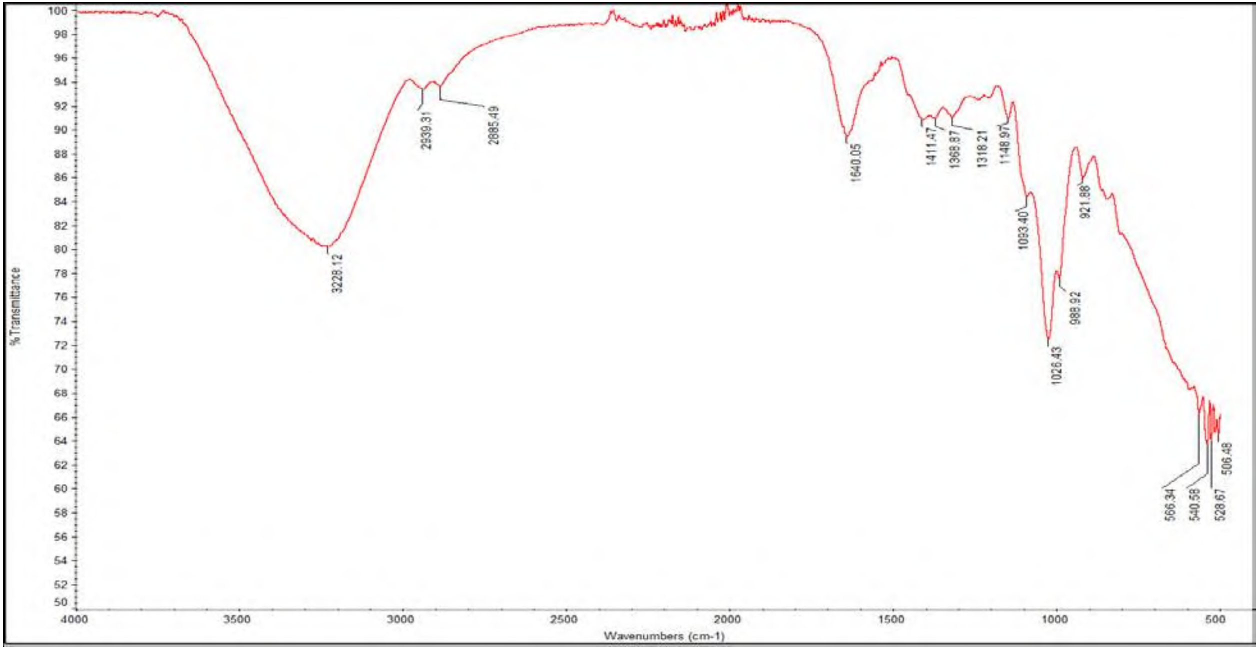
LAMPIRAN B
HASIL UJI FTIR



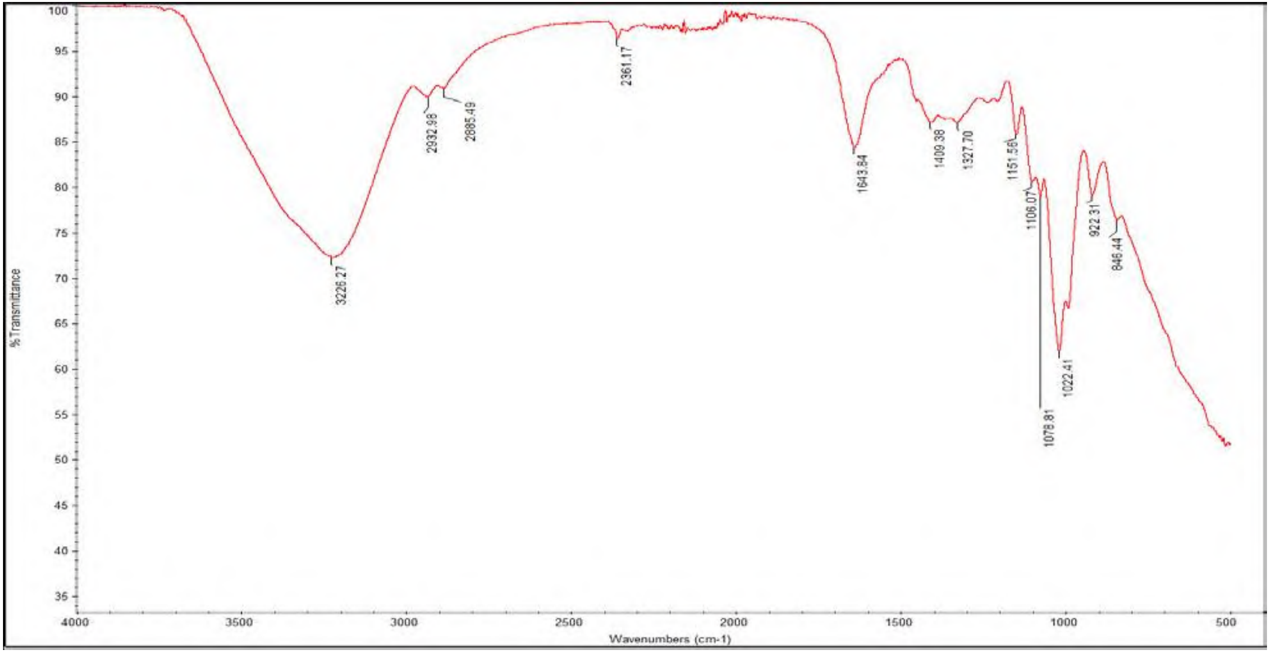
Gambar B.1 Hasil uji FTIR untuk sampel dengan kadar tapioka 0%



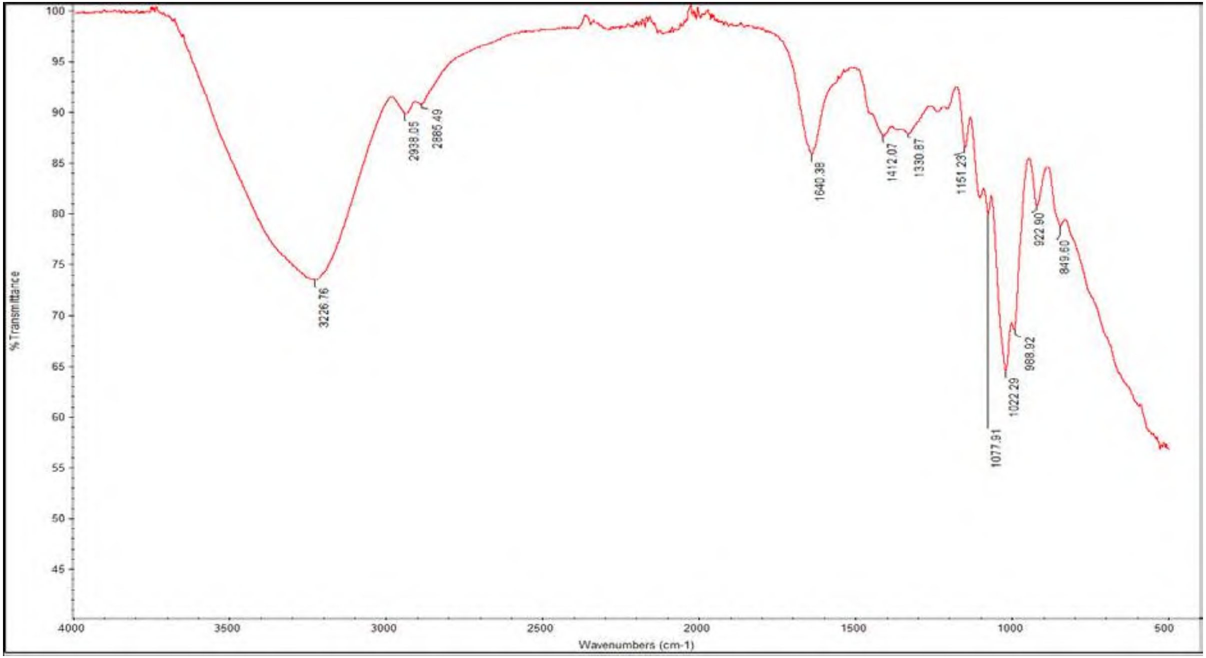
Gambar B.2 Hasil uji FTIR untuk sampel dengan kadar tapioka 10%



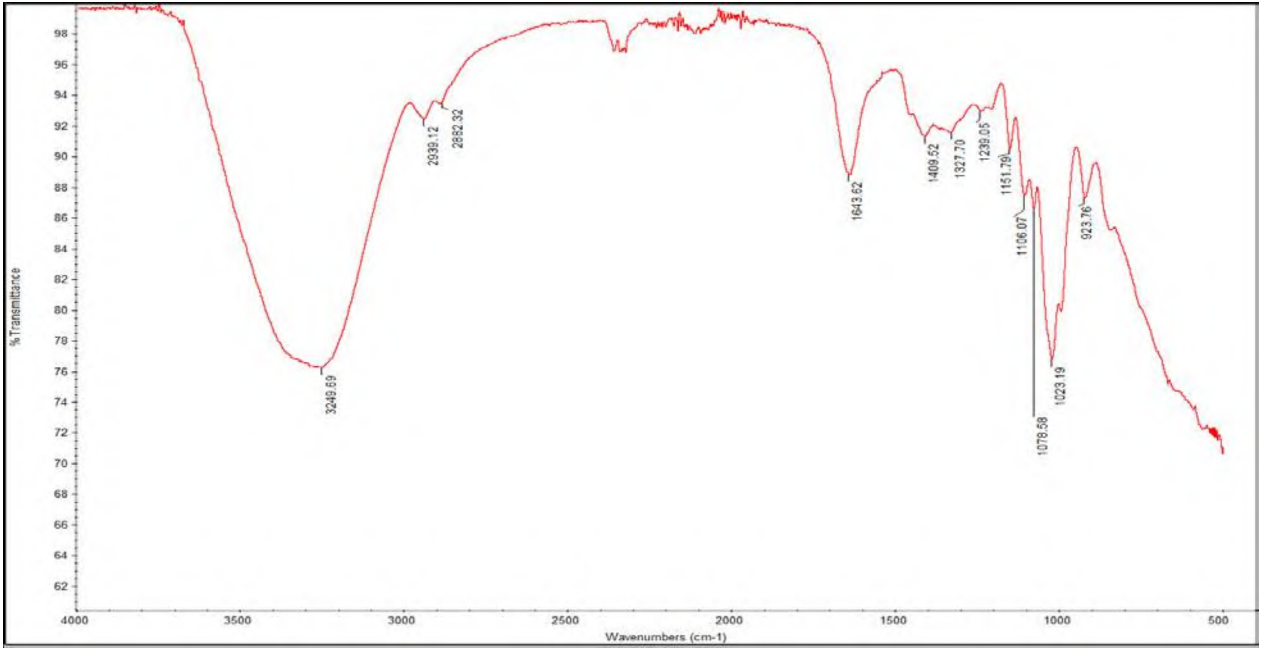
Gambar B.3 Hasil uji FTIR untuk sampel dengan kadar tapioka 20%



Gambar B.4 Hasil uji FTIR untuk sampel dengan kadar tapioka 30%

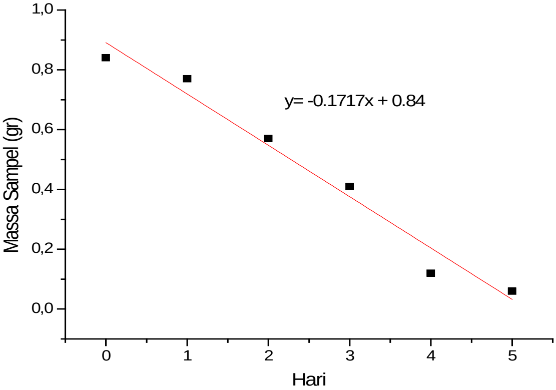


Gambar B.5 Hasil uji FTIR untuk sampel dengan kadar tapioka 40%

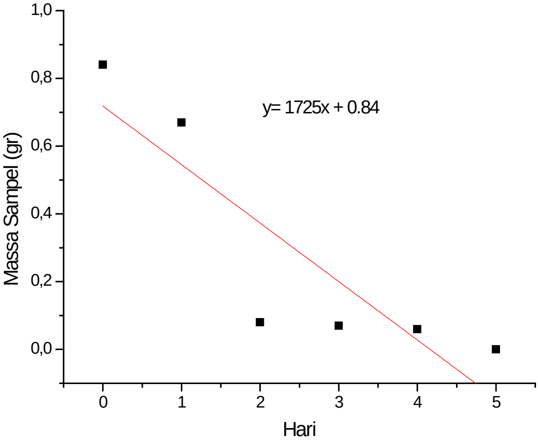


Gambar B.6 Hasil uji FTIR untuk sampel dengan kadar tapioka 50%

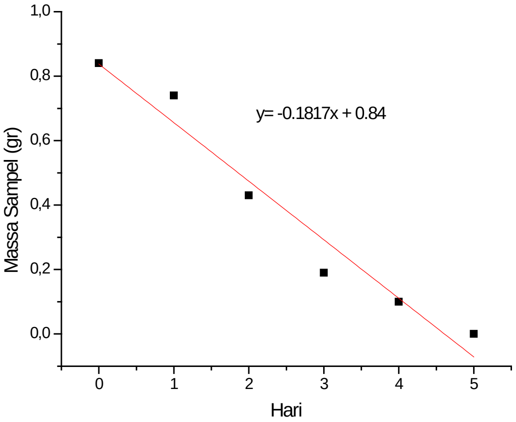
LAMPIRAN C
PLOT HASIL UJI BIODEGRADASI



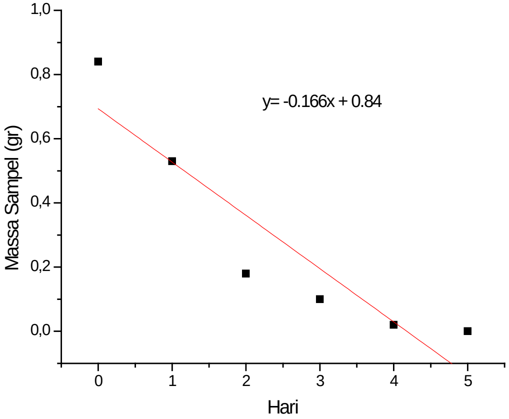
Gambar C.1 Hasil uji biodegradasi untuk sampel dengan tapioka 0%



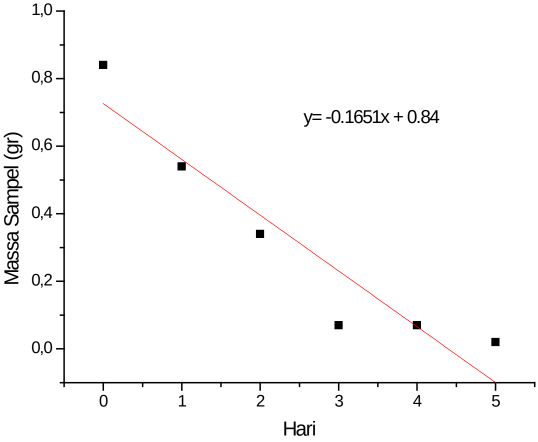
Gambar C.2 Hasil uji biodegradasi untuk sampel dengan tapioka 10%



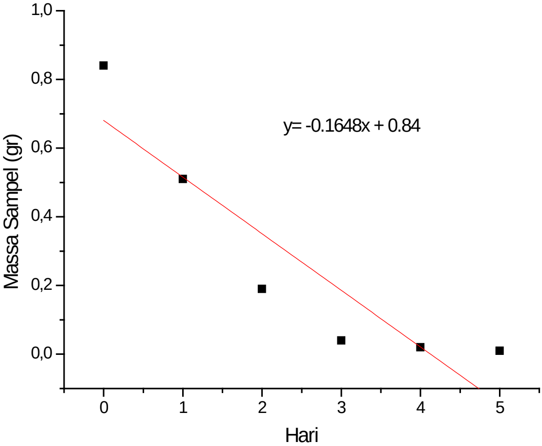
Gambar C.3 Hasil uji biodegradasi untuk sampel dengan tapioka 20%



Gambar C.4 Hasil uji biodegradasi untuk sampel dengan tapioka 30%

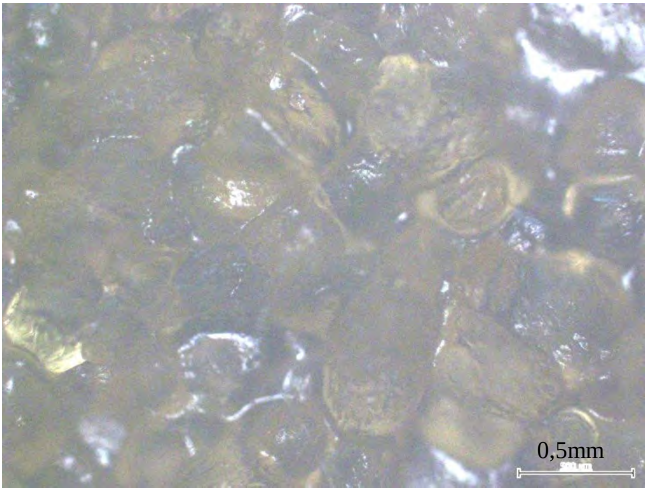


Gambar C.5 Hasil uji biodegradasi untuk sampel dengan tapioka 40%

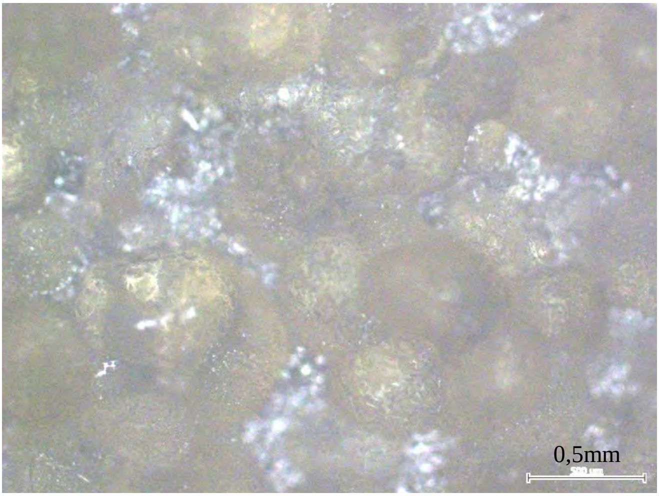


Gambar C.6 Hasil uji biodegradasi untuk sampel dengan tapioka 50%

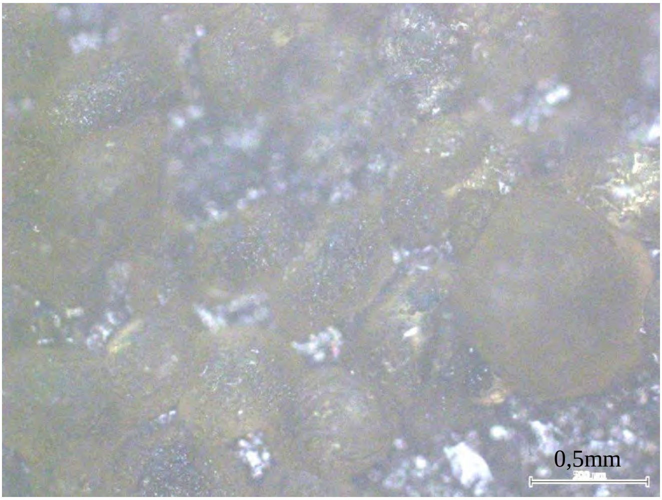
LAMPIRAN D
HASIL FOTO MIKROSKOP OPTIK



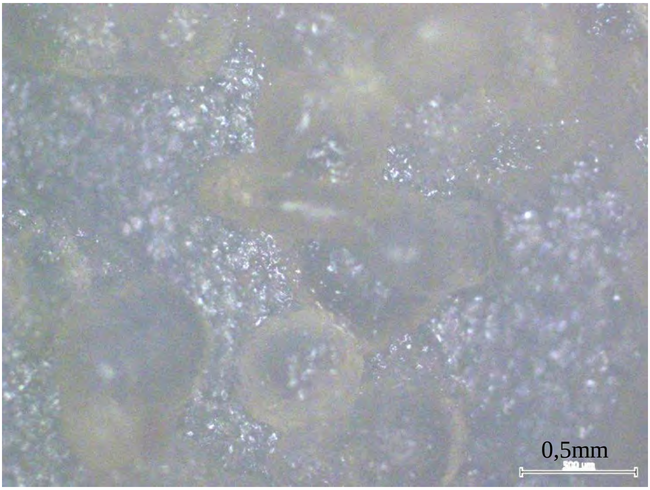
Gambar D.1 Hasil foto mikroskop optik untuk sampel dengan tapioka 0%



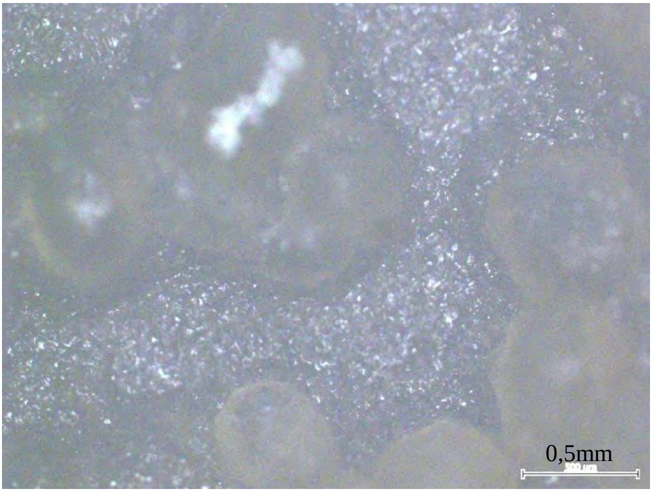
Gambar D.2 Hasil foto mikroskop optik untuk sampel dengan tapioka 10%



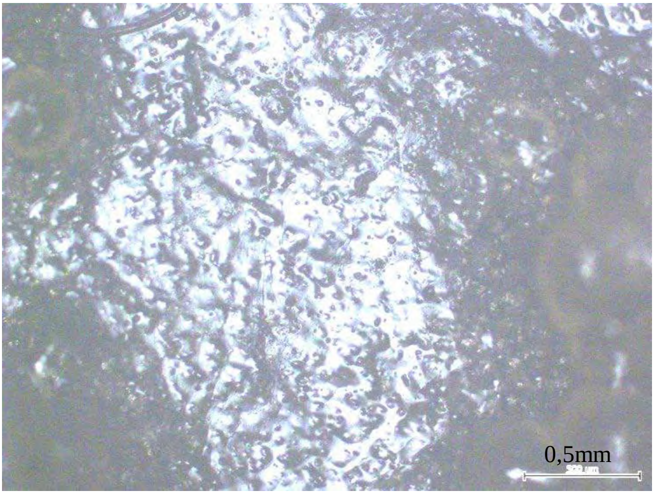
Gambar D.3 Hasil foto mikroskop optik untuk sampel dengan tapioka 20%



Gambar D.4 Hasil foto mikroskop optik untuk sampel dengan tapioka 30%



Gambar D.5 Hasil foto mikroskop optik untuk sampel dengan tapioka 40%



Gambar D.6 Hasil foto mikroskop optik untuk sampel dengan tapioka 50%

LAMPIRAN E
STANDAR UJI TARIK

Designation: D 638 – 02a

Standard Test Method for Tensile Properties of Plastics[1]

This standard is issued under the fixed designation D 638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Methods D 882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

1.3 This test method includes the option of determining Poisson's ratio at room temperature.

NOTE 1—This test method and ISO 527-1 are technically equivalent.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant rate of crosshead movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with Test Methods D 229 and Test Method D 651.

NOTE 4—For tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus >20-GPa ($>3.0 \times 10^6$-psi) fibers, tests shall be made in accordance with Test Method D 3039/D 3039M.

1.4 Test data obtained by this test method are relevant and appropriate for use in engineering design.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation[2]
D 412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension[3]
D 618 Practice for Conditioning Plastics for Testing[4]
D 651 Test Method for Tensile Strength of Molded Electrical Insulating Materials[5]
D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[4]
D 883 Terminology Relating to Plastics[4]
D 1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials[4]
D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials[6]
D 4000 Classification System for Specifying Plastic Materials[7]
D 4066 Classification System for Nylon Injection and Extrusion Materials[7]
D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[8]
E 4 Practices for Force Verification of Testing Machines[9]
E 83 Practice for Verification and Classification of Extensometer[9]
E 132 Test Method for Poisson's Ratio at Room Temperature[9]
E 691 Practice for Conducting an Interlaboratory Study to

---

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved November 10, 2002. Published January 2003. Originally approved in 1941. Last previous edition approved in 2002 as D 638 – 02.

[2] *Annual Book of ASTM Standards*, Vol 10.01.
[3] *Annual Book of ASTM Standards*, Vol 09.01.
[4] *Annual Book of ASTM Standards*, Vol 08.01.
[5] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 10.01.
[6] *Annual Book of ASTM Standards*, Vol 15.03.
[7] *Annual Book of ASTM Standards*, Vol 08.02.
[8] *Annual Book of ASTM Standards*, Vol 08.03.
[9] *Annual Book of ASTM Standards*, Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

Determine the Precision of a Test Method[10]

2.2 *ISO Standard:*

ISO 527-1 Determination of Tensile Properties[11]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D 883 and Annex A2.

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development. For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D 4000 lists the ASTM materials standards that currently exist.

4.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

4.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

4.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 5—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted, generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

4.4 *Poisson's Ratio*—When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions lateral to the applied force. If the solid is homogeneous and isotropic, and the material remains elastic under the action of the applied force, the lateral strain bears a constant relationship to the axial strain. This constant, called Poisson's ratio, is defined as the negative ratio of the transverse (negative) to axial strain under uniaxial stress.

4.4.1 Poisson's ratio is used for the design of structures in which all dimensional changes resulting from the application of force need to be taken into account and in the application of the generalized theory of elasticity to structural analysis.

NOTE 6—The accuracy of the determination of Poisson's ratio is usually limited by the accuracy of the transverse strain measurements because the percentage errors in these measurements are usually greater than in the axial strain measurements. Since a ratio rather than an absolute quantity is measured, it is only necessary to know accurately the relative value of the calibration factors of the extensometers. Also, in general, the value of the applied loads need not be known accurately.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member of the testing machine can be either the fixed or self-aligning type.

5.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. When this type of grip is used extreme care should be taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the center line of the grip assembly.

5.1.3.2 Self-aligning grips are attached to the fixed and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.3 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (0.09 in.) apart and about 1.6 mm (0.06 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations

---

[10] *Annual Book of ASTM Standards*, Vol 14.02.

[11] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic, or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Section 8.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

NOTE 7—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Practices E 4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.1.7 *Crosshead Extension Indicator*—A suitable extension indicating mechanism capable of showing the amount of change in the separation of the grips, that is, crosshead movement. This mechanism shall be essentially free of inertial lag at the specified rate of testing and shall indicate the crosshead movement with an accuracy of ±10 % of the indicated value.

5.2 *Extension Indicator* (extensometer)—A suitable instrument shall be used for determining the distance between two designated points within the gage length of the test specimen as the specimen is stretched. For referee purposes, the extensometer must be set at the full gage length of the specimen, as shown in Fig. 1. It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia at the specified speed of testing. Extensometers shall be classified and their calibration periodically verified in accordance with Practice E 83.

5.2.1 *Modulus-of-Elasticity Measurements*—For modulus-of-elasticity measurements, an extensometer with a maximum strain error of 0.0002 mm/mm (in./in.) that automatically and continuously records shall be used. An extensometer classified by Practice E 83 as fulfilling the requirements of a B-2 classification within the range of use for modulus measurements meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E 83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

5.2.3 *High-Extension Measurements*—For making measurements at elongations greater than 20 %, measuring techniques with error no greater than ±10 % of the measured value are acceptable.

5.2.4 *Poisson's Ratio*—Bi-axial extensometer or axial and transverse extensometers capable of recording axial strain and transverse strain simultaneously. The extensometers shall be capable of measuring the change in strains with an accuracy of 1 % of the relevant value or better.

NOTE 8—Strain gages can be used as an alternative method to measure axial and transverse strain; however, proper techniques for mounting strain gages are crucial to obtaining accurate data. Consult strain gage suppliers for instruction and training in these special techniques.

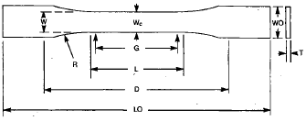
5.3 *Micrometers*—Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: *(1)* a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), *(2)* a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter, and *(3)* a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.0002 in.) over the entire foot area. Flatness of the foot and anvil shall conform to Test Method D 5947.

5.3.1 An optional instrument equipped with a circular contact foot 15.88 ± 0.08 mm (0.625 ± 0.003 in.) in diameter is recommended for thickness measuring of process samples or larger specimens at least 15.88 mm in minimum width.

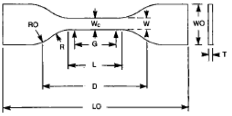
6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics*:

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of



TYPES I, II, III & V



TYPE IV

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1:30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

[A] Thickness, *T*, shall be 3.2± 0.4 mm (0.13 ± 0.02 in.) for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm (0.55 in.) the specimens shall be machined to 14 ± 0.4 mm (0.55 ± 0.02 in.) in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm (0.55 and 2 in.) approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined, and the location of the specimen with reference to the original thickness of the sheet shall be noted. Tolerances on thickness less than 14 mm (0.55 in.) shall be those standard for the grade of material tested.

[B] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm (0.250± 0.002 in.). The dimensions are essentially those of Die C in Test Methods D 412.

[C] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:

$W = 3.18 \pm 0.03$ mm (0.125 ± 0.001 in.),
$L = 9.53 \pm 0.08$ mm (0.375 ± 0.003 in.),
$G = 7.62 \pm 0.02$ mm (0.300 ± 0.001 in.), and
$R = 12.7 \pm 0.08$ mm (0.500 ± 0.003 in.).

The other tolerances are those in the table.

[D] Supporting data on the introduction of the L specimen of Test Method D 1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1038.

[E] The width at the center W_c shall be +0.00 mm, –0.10 mm (+0.000 in., –0.004 in.) compared with width *W* at other parts of the reduced section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[F] For molded specimens, a draft of not over 0.13 mm (0.005 in.) may be allowed for either Type I or II specimens 3.2 mm (0.13 in.) in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:

[G] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

[H] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[I] Test marks or initial extensometer span.

[J] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

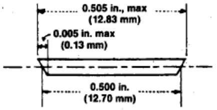


FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.3 *Reinforced Composites*—The test specimen for reinforced composites, including highly orthotropic laminates, shall conform to the dimensions of the Type I specimen shown in Fig. 1.

6.1.4 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

NOTE 9—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by 7.3.

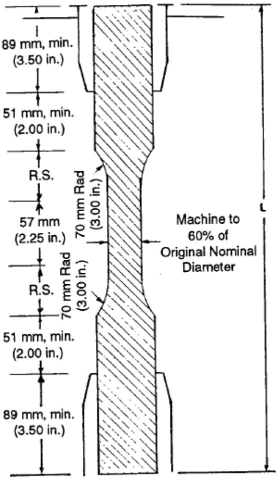
NOTE 10—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement. The reinforcement will be significantly weakened by cutting on a bias, resulting in lower laminate properties, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE 11—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 *Rigid Tubes*—The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

6.3 *Rigid Rods*—The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

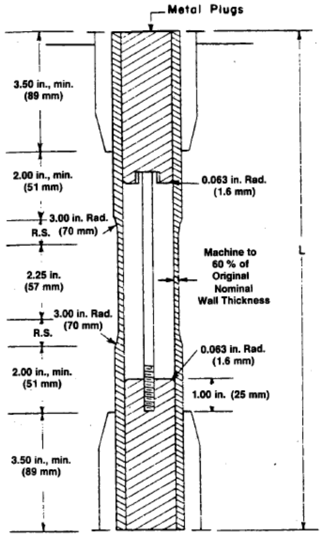


DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3½-in.) Jaws[A]
		mm (in.)	
3.2 (⅛)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (3⁄16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (¼)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (⅜)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (½)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (⅝)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (¾)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (⅞)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine



DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
		mm (in.)	
0.79 (1⁄32)	13.9 (0.547)	350 (13.80)	381 (15)
1.2 (3⁄64)	17.0 (0.670)	354 (13.92)	381 (15)
1.6 (1⁄16)	19.6 (0.773)	356 (14.02)	381 (15)
2.4 (3⁄32)	24.0 (0.946)	361 (14.20)	381 (15)
3.2 (1⁄8)	27.7 (1.091)	364 (14.34)	381 (15)
4.8 (3⁄16)	33.9 (1.333)	370 (14.58)	381 (15)
6.4 (1⁄4)	39.0 (1.536)	376 (14.79)	400 (15.75)
7.9 (5⁄16)	43.5 (1.714)	380 (14.96)	400 (15.75)
9.5 (3⁄8)	47.6 (1.873)	384 (15.12)	400 (15.75)
11.1 (7⁄16)	51.3 (2.019)	388 (15.27)	400 (15.75)
12.7 (1⁄2)	54.7 (2.154)	391 (15.40)	419 (16.5)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens in Testing Machine

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

7. Number of Test Specimens

7.1 Test at least five specimens for each sample in the case of isotropic materials.

7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

7.3 Discard specimens that break at some flaw, or that break outside of the narrow cross-sectional test section (Fig. 1, dimension "L"), and make retests, unless such flaws constitute a variable to be studied.

NOTE 12—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5-min testing time.

8.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min (in./min)	Nominal Strain[C] Rate at Start of Test, mm/mm· min (in./in.·min)
Rigid and Semirigid	I, II, III rods and tubes	5 (0.2) ± 25 %	0.1
		50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	5 (0.2) ± 25 %	0.15
		50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15
	V	1 (0.05) ± 25 %	0.1
		10 (0.5) ± 25 %	1
		100 (5)± 25 %	10
Nonrigid	III	50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 8.2).

[B] See Terminology D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

8.4 Poisson's ratio determinations shall be made at the same speed selected for modulus determinations.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618, unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

10. Procedure

10.1 Measure the width and thickness of rigid flat specimens (Fig. 1) with a suitable micrometer to the nearest 0.025 mm (0.001 in.) at several points along their narrow sections. Measure the thickness of nonrigid specimens (produced by a Type IV die) in the same manner with the required dial micrometer. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

TABLE 2 Modulus, 10^6 psi, for Eight Laboratories, Five Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	0.210	0.0089	0.071	0.025	0.201
Cellulose acetate butyrate	0.246	0.0179	0.035	0.051	0.144
Acrylic	0.481	0.0179	0.063	0.051	0.144
Glass-reinforced nylon	1.17	0.0537	0.217	0.152	0.614
Glass-reinforced polyester	1.39	0.0894	0.266	0.253	0.753

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Fig. 2 and Fig. 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extension indicator. When modulus is being determined, a Class B-2 or better extensometer is required (see 5.2.1).

NOTE 13—Modulus of materials is determined from the slope of the linear portion of the stress-strain curve. For most plastics, this linear portion is very small, occurs very rapidly, and must be recorded automatically. The change in jaw separation is never to be used for calculating modulus or elongation.

10.3.1 *Poisson's Ratio Determination:*

10.3.1.1 When Poisson's ratio is determined, the speed of testing and the load range at which it is determined shall be the same as those used for modulus of elasticity.

10.3.1.2 Attach the transverse strain measuring device. The transverse strain measuring device must continuously measure the strain simultaneously with the axial strain measuring device.

TABLE 3 Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.63	0.022	0.161	0.062	0.456
Cellulose acetate butyrate	5.01	0.058	0.227	0.164	0.642
Acrylic	10.4	0.067	0.317	0.190	0.897

TABLE 4 Elongation at Yield, %, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Cellulose acetate butyrate	3.65	0.27	0.62	0.76	1.75
Acrylic	4.89	0.21	0.55	0.59	1.56
Polypropylene	8.79	0.45	5.86	1.27	16.5

10.3.1.3 Make simultaneous measurements of load and strain and record the data. The precision of the value of Poisson's ratio will depend on the number of data points of axial and transverse strain taken.

10.4 Set the speed of testing at the proper rate as required in Section 8, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 14—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials, to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand-rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 Toe compensation shall be made in accordance with Annex A1, unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

11.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (or pounds-force) by the original minimum cross-sectional area of the specimen in square metres (or square inches). Express the result in pascals (or pounds-force per square inch) and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A2.8).

11.3 Elongation values are valid and are reported in cases where uniformity of deformation within the specimen gage length is present. Elongation values are quantitatively relevant and appropriate for engineering design. When non-uniform deformation (such as necking) occurs within the specimen gage length nominal strain values are reported. Nominal strain values are of qualitative utility only.

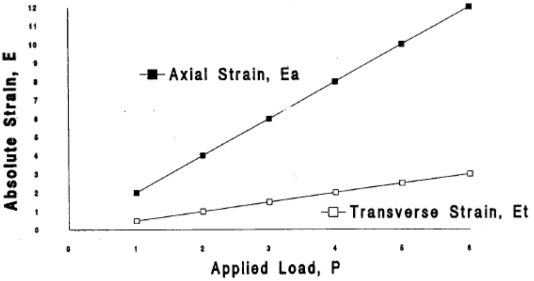


FIG. 4 Plot of Strains Versus Load for Determination of Poisson's Ratio

11.3.1 *Percent Elongation*—Percent elongation is the change in gage length relative to the original specimen gage length, expressed as a percent. Percent elongation is calculated using the apparatus described in 5.2.

11.3.1.1 *Percent Elongation at Yield*—Calculate the percent elongation at yield by reading the extension (change in gage length) at the yield point. Divide that extension by the original gage length and multiply by 100.

11.3.1.2 *Percent Elongation at Break*—Calculate the percent elongation at break by reading the extension (change in gage length) at the point of specimen rupture. Divide that extension by the original gage length and multiply by 100.

11.3.2 *Nominal Strain*—Nominal strain is the change in grip separation relative to the original grip separation expressed as a percent. Nominal strain is calculated using the apparatus described in 5.1.7.

11.3.2.1 *Nominal strain at break*—Calculate the nominal strain at break by reading the extension (change in grip separation) at the point of rupture. Divide that extension by the original grip separation and multiply by 100.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average initial cross-sectional area of the test specimens in the calculations. The result shall be expressed in pascals (pounds-force per square inch) and reported to three significant figures.

11.5 *Secant Modulus*—At a designated strain, this shall be calculated by dividing the corresponding stress (nominal) by the designated strain. Elastic modulus values are preferable and shall be calculated whenever possible. However, for materials where no proportionality is evident, the secant value shall be calculated. Draw the tangent as directed in A1.3 and Fig. A1.2, and mark off the designated strain from the yield point where the tangent line goes through zero stress. The stress to be used in the calculation is then determined by dividing the load-extension curve by the original average cross-sectional area of the specimen.

11.6 *Poisson's Ratio*—The axial strain, ϵ_a, indicated by the axial extensometer, and the transverse strain, ϵ, indicated by the transverse extensometers, are plotted against the applied load, P, as shown in Fig. 4. A straight line is drawn through each set of points, and the slopes, $d\epsilon_a / dP$ and $d\epsilon_t / dP$, of these lines are determined. Poisson's ratio, μ, is then calculated as follows:

$$\mu = -(d\epsilon_t / dP)/(d\epsilon_a / dP) \qquad (1)$$

where:

$d\epsilon_t$ = change in transverse strain,
$d\epsilon_a$ = change in axial strain, and
dP = change in applied load;

or

$$\mu = -(d\epsilon_t) / (d\epsilon_a) \qquad (2)$$

11.6.1 The errors that may be introduced by drawing a straight line through the points can be reduced by applying the method of least squares.

11.7 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.8 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2) / (n - 1)} \qquad (3)$$

where:

s = estimated standard deviation,
X = value of single observation,

n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.9 See Annex A1 for information on toe compensation.

TABLE 5 Tensile Strength at Break, 10^3 psi, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Polypropylene	2.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	9.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.233	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.698	0.784	1.98

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 6 Elongation at Break, %, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.283	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 7 Tensile Yield Strength, for Ten Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1544	52.4	64.0	146.6	179.3
LDPE	20	1894	53.1	61.2	148.7	171.3
LLDPE	20	1879	74.2	99.9	207.8	279.7
LLDPE	20	1791	49.2	75.8	137.9	212.3
LLDPE	20	2900	55.5	87.9	155.4	246.1
LLDPE	20	1730	63.9	96.0	178.9	268.7
HDPE	2	4101	196.1	371.9	549.1	1041.3
HDPE	2	3523	175.9	478.0	492.4	1338.5

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Classification of extensometers used. A description of measuring technique and calculations employed instead of a minimum Class-C extensometer system,

12.1.9 Tensile strength at yield or break, average value, and standard deviation,

12.1.10 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.11 Percent elongation at yield, or break, or nominal strain at break, or all three, as applicable, average value, and standard deviation,

12.1.12 Modulus of elasticity, average value, and standard deviation,

12.1.13 Date of test, and

12.1.14 Revision date of Test Method D 638.

13. Precision and Bias [12]

13.1 *Precision*—Tables 2-6 are based on a round-robin test conducted in 1984, involving five materials tested by eight laboratories using the Type I specimen, all of nominal 0.125-in. thickness. Each test result was based on five individual determinations. Each laboratory obtained two test results for each material.

TABLE 8 Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	17.0	1.26	3.16	3.52	8.84
LDPE	20	14.6	1.02	2.38	2.86	6.67
LLDPE	20	15.7	1.37	2.85	3.85	7.97
LLDPE	20	16.6	1.59	3.30	4.46	9.24
LLDPE	20	11.7	1.27	2.88	3.56	8.08
LLDPE	20	15.2	1.27	2.59	3.55	7.25
HDPE	2	9.27	1.40	2.84	3.91	7.94
HDPE	2	9.63	1.23	2.75	3.45	7.71

TABLE 9 Tensile Break Strength, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.3	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2840	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2660	119.1	166.3	333.6	465.6

13.1.1 Tables 7-10 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving eight polyethylene materials tested in ten laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

13.1.2 In Tables 2-10, for the materials indicated, and for test results that derived from testing five specimens:

---

[12] Supporting data are available from ASTM Headquarters. Request RR:D20-1125 for the 1984 round robin and RR:D20-1170 for the 1988 round robin.

TABLE 10 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	890	25.7	113.8	71.9	318.7
LLDPE	20	64.4	6.68	11.7	18.7	32.6
LLDPE	20	803	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

13.1.2.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.2.3 for application of I_r.)

13.1.2.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.2.4 for application of I_R.)

13.1.2.3 *Repeatability*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, those test results should be judged not equivalent if they differ by more than the I_r value for that material and condition.

13.1.2.4 *Reproducibility*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, those test results should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

13.1.2.5 Any judgment in accordance with 13.1.2.3 and 13.1.2.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.2.6 Other formulations may give somewhat different results.

13.1.2.7 For further information on the methodology used in this section, see Practice E 691.

13.1.2.8 The precision of this test method is very dependent upon the uniformity of specimen preparation, standard practices for which are covered in other documents.

13.2 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

14. Keywords

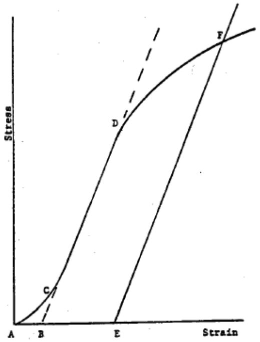
14.1 modulus of elasticity; percent elongation; plastics; tensile properties; tensile strength

ANNEXES

(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

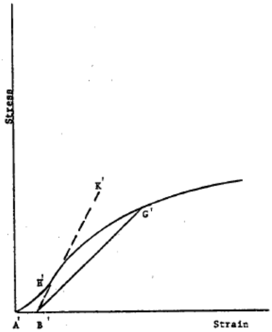


NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H'*). This is extended to intersect the strain axis at Point *B'*, the corrected zero-strain point. Using Point *B'* as zero strain, the stress at any point (*G'*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B' G'*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.2 Material with No Hookean Region

A2. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A2.1 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress. It is expressed in force per unit area, usually pounds-force per square inch (megapascals).

NOTE A2.1—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A2.2 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually inches (millimetres). (Also known as *extension.*)

NOTE A2.2—Elongation and strain values are valid only in cases where uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting necking phenomena, such values are only of qualitative utility after attainment of yield point. This is due to inability to ensure that necking will encompass the entire length between the gage marks prior to specimen failure.

A2.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A2.4 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (pounds-force per square inch). (Also known as *elastic modulus* or *Young's modulus*).

NOTE A2.3—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A2.5 *necking*—the localized reduction in cross section which may occur in a material under tensile stress.

A2.6 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.4—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A2.1):

On the strain axis lay off *OM* equal to the specified offset.

Draw *OA* tangent to the initial straight-line portion of the stress-strain curve.

Through *M* draw a line *MN* parallel to *OA* and locate the intersection of *MN* with the stress-strain curve.

The stress at the point of intersection *r* is the "offset yield strength." The specified value of the offset must be stated as a percent of the original gage length in conjunction with the strength value. *Example:* 0.1 % offset yield strength = ... MPa (psi), or yield strength at 0.1 % offset ... MPa (psi).

A2.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A2.8 *percent elongation at break and yield:*

A2.8.1 *percent elongation at break*—the percent elongation at the moment of rupture of the test specimen.

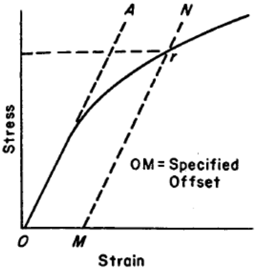


FIG. A2.1 Offset Yield Strength

A2.8.2 *percent elongation at yield*—the percent elongation at the moment the yield point (A2.21) is attained in the test specimen.

A2.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A2.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A2.11 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

A2.12 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A2.13 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre (inches per inch) per minute, or percent elongation per unit time, usually percent elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain versus time diagram.

NOTE A2.5—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant rate of crosshead movement and when the specimen has a uniform original cross section, does not "neck down," and does not slip in the jaws.

A2.14 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals (pounds-force per square inch) per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A2.6—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A2.15 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch), and reported together with the specified stress or strain.

NOTE A2.7—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A2.16 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A2.16.1 *nominal strain at break*—the strain at the moment of rupture relative to the original grip separation.

A2.17 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A2.21), it shall be designated tensile strength at yield. When the maximum stress occurs at break, it shall be designated tensile strength at break.

A2.18 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.8—The expression of tensile properties in terms of the minimum original cross section is almost universally used in practice. In the case of materials exhibiting high extensibility or necking, or both (A2.15), nominal stress calculations may not be meaningful beyond the yield point (A2.21) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross section. These properties are called true tensile properties (that is, true tensile stress, etc.).

A2.19 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A2.20 *true strain* (see Fig. A2.2) is defined by the following equation for ϵ_T:

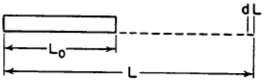


FIG. A2.2 Illustration of True Strain Equation

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o \qquad \text{(A2.1)}$$

where:

dL = increment of elongation when the distance between the gage marks is L,

L_o = original distance between gage marks, and

L = distance between gage marks at any time.

A2.21 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A2.2).

NOTE A2.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A2.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A2.22 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required in A2.17 (Fig. A2.3). (See *offset yield strength.*)

A2.23 *Symbols*—The following symbols may be used for the above terms:

Symbol	Term
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_U	Tensile strength at break (nominal)
σ_{UT}	Tensile strength at break (true)
ϵ	Strain
$\Delta\epsilon$	Increment of strain
ϵ_U	Total strain, at break
ϵ_T	True strain
$\%El$	Percentage elongation
Y.P.	Yield point
E	Modulus of elasticity

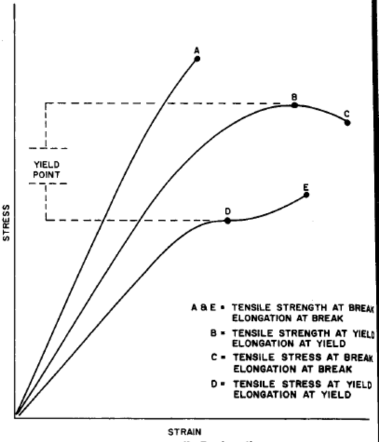


FIG. A2.3 Tensile Designations

A2.24 Relations between these various terms may be defined as follows:

$\sigma = W/A_o$

$\sigma_T = W/A$

$\sigma_U = W/A_o$(where W is breaking load)

$\sigma_{UT} = W/A_T$(where W is breaking load)

$\epsilon = \Delta L/L_o = (L - L_o)/L_o$

$\epsilon_U = (L_u - L_o)/L_o$

$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$

$\%El = [(L - L_o)/L_o] \times 100 = \epsilon \times 100$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$

Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$

Rate of loading = $\Delta W/\Delta t$

Rate of stressing (nominal) = $\Delta\sigma/\Delta = (\Delta W]/A_o)/\Delta t$

Rate of straining = $\Delta\epsilon/\Delta t = (\Delta L/L_o)\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \epsilon) = \sigma L/L_o \qquad \text{(A2.2)}$$

$$\sigma_{UT} = \sigma_U(1 + \epsilon_U) = \sigma_U L_u/L_o$$

$$A = A_o/(1 + \epsilon)$$

LAMPIRAN F
STANDAR UJI *SWELLING*

Designation: D 570 – 98

Standard Test Method for Water Absorption of Plastics[1]

This standard is issued under the fixed designation D 570; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the relative rate of absorption of water by plastics when immersed. This test method is intended to apply to the testing of all types of plastics, including cast, hot-molded, and cold-molded resinous products, and both homogeneous and laminated plastics in rod and tube form and in sheets 0.13 mm (0.005 in.) or greater in thickness.

1.2 The values given in SI units are to be regarded as the standard. The values stated in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—ISO 62 is technically equivalent to this test method.

2. Referenced Documents

2.1 *ASTM Standards:*

D 647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials[2]

2.2 *ISO Standard:*

ISO 62 Plastics—Determination of Water Absorption[3]

3. Significance and Use

3.1 This test method for rate of water absorption has two chief functions: first, as a guide to the proportion of water absorbed by a material and consequently, in those cases where the relationships between moisture and electrical or mechanical properties, dimensions, or appearance have been determined, as a guide to the effects of exposure to water or humid conditions on such properties; and second, as a control test on the uniformity of a product. This second function is particularly applicable to sheet, rod, and tube arms when the test is made on the finished product.

3.2 Comparison of water absorption values of various plastics can be made on the basis of values obtained in accordance with 7.1 and 7.4.

3.3 Ideal diffusion of liquids[4] into polymers is a function of the square root of immersion time. Time to saturation is strongly dependent on specimen thickness. For example, Table 1 shows the time to approximate time saturation for various thickness of nylon-6.

3.4 The moisture content of a plastic is very intimately related to such properties as electrical insulation resistance, dielectric losses, mechanical strength, appearance, and dimensions. The effect upon these properties of change in moisture content due to water absorption depends largely on the type of exposure (by immersion in water or by exposure to high humidity), shape of the part, and inherent properties of the plastic. With nonhomogeneous materials, such as laminated forms, the rate of water absorption may be widely different through each edge and surface. Even for otherwise homogeneous materials, it may be slightly greater through cut edges than through molded surfaces. Consequently, attempts to correlate water absorption with the surface area must generally be limited to closely related materials and to similarly shaped specimens: For materials of widely varying density, relation between water-absorption values on a volume as well as a weight basis may need to be considered.

4. Apparatus

4.1 *Balance*—An analytical balance capable of reading 0.0001 g.

4.2 *Oven*, capable of maintaining uniform temperatures of 50 ± 3°C (122 ± 5.4°F) and of 105 to 110°C (221 to 230°F).

5. Test Specimen

5.1 The test specimen for molded plastics shall be in the form of a disk 50.8 mm (2 in.) in diameter and 3.2 mm (⅛ in.) in thickness (see Note 2). Permissible variations in thickness are ±0.18 mm (±0.007 in.) for hot-molded and ±0.30 mm (±0.012 in.) for cold-molded or cast materials.

---

[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D 20.50 on Permanence Properties.

Current edition approved July 10, 1998. Published January 1999. Originally published as D 570 – 40 T. Last previous edition D 570 – 95.

[2] Discontinued 1994; replaced by D 1896, D 3419, D 3641, D 4703, and D 5227. See 1994 *Annual Book of ASTM Standards*, Vol 08.01.

[3] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[4] Additional information regarding diffusion of liquids in polymers can be found in the following references: (*1*) *Diffusion, Mass Transfer in Fluid Systems,* E. L. Cussler, Cambridge University Press, 1985, ISBN 0-521-29846-6, (*2*) *Diffusion in Polymers,* J. Crank and G. S. Park, Academic Press, 1968, and (*3*) "Permeation, Diffusion, and Sorption of Gases and Vapors," R. M. Felder and G. S. Huvard, in *Methods of Experimental Physics,* Vol 16C, 1980, Academic Press.

TABLE 1 Time to Saturation for Various Thickness of Nylon-6

Thickness, mm	Typical Time to 95 % Saturation, h
1	100
2	400
3.2	1 000
10	10 000
25	62 000

NOTE 2—The disk mold prescribed in the Molds for Disk Test Specimens Section of Practice D 647 is suitable for molding disk test specimens of thermosetting materials but not thermoplastic materials.

5.2 *ISO Standard Specimen*—The test specimen for homogeneous plastics shall be 60 by 60 by 1 mm. Tolerance for the 60-mm dimension is ±2 mm and ±0.05 mm for the 1-mm thickness. This test method and ISO 62 are technically equivalent when the test specimen described in 5.2 is used.

5.3 The test specimen for sheets shall be in the form of a bar 76.2 mm (3 in.) long by 25.4 mm (1 in.) wide by the thickness of the material. When comparison of absorption values with molded plastics is desired, specimens 3.2 mm (⅛ in.) thick should be used. Permissible variations in thickness shall be 0.20 mm (±0.008 in.) except for asbestos-fabric-base phenolic laminated materials or other materials which have greater standard commercial tolerances.

5.4 The test specimen for rods shall be 25.4 mm (1 in.) long for rods 25.4 mm in diameter or under and 12.7 mm (½ in.) long for larger-diameter rods. The diameter of the specimen shall be the diameter of the finished rod.

5.5 The test specimen for tubes less than 76 mm (3 in.) in inside diameter shall be the full section of the tube and 25.4 mm (1 in.) long. For tubes 76 mm (3 in.) or more in inside diameter, a rectangular specimen shall be cut 76 mm in length in the circumferential direction of the tube and 25.4 mm in width lengthwise of the tube.

5.6 The test specimens for sheets, rods, and tubes shall be machined, sawed, or sheared from the sample so as to have smooth edges free from cracks. The cut edges shall be made smooth by finishing with No. 0 or finer sandpaper or emery cloth. Sawing, machining, and sandpapering operations shall be slow enough so that the material is not heated appreciably.

NOTE 3—If there is any oil on the surface of the specimen when received or as a result of machining operations, wash the specimen with a cloth wet with gasoline to remove oil, wipe with a dry cloth, and allow to stand in air for 2 h to permit evaporation of the gasoline. If gasoline attacks the plastic, use some suitable solvent or detergent that will evaporate within the 2-h period.

5.7 The dimensions listed in the following table for the various specimens shall be measured to the nearest 0.025 mm (0.001 in.). Dimensions not listed shall be measured within 0.8 mm (±1⁄32 in.).

Type of Specimen	Dimensions to Be Measured to the Nearest 0.025 mm (0.001 in.)
Molded disk	thickness
Sheet	thickness
Rod	length and diameter
Tube	inside and outside diameter, and wall thickness

6. Conditioning

6.1 Three specimens shall be conditioned as follows:

6.1.1 Specimens of materials whose water-absorption value would be appreciably affected by temperatures in the neighborhood of 110°C (230°F), shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

NOTE 4—If a static charge interferes with the weighing, lightly rub the surface of the specimens with a grounded conductor.

6.1.2 Specimens of materials, such as phenolic laminated plastics and other products whose water-absorption value has been shown not to be appreciably affected by temperatures up to 110°C (230°F), shall be dried in an oven for 1 h at 105 to 110°C (221 to 230°F).

6.1.3 When data for comparison with absorption values for other plastics are desired, the specimens shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

7. Procedure

7.1 *Twenty-Four Hour Immersion*—The conditioned specimens shall be placed in a container of distilled water maintained at a temperature of 23 ± 1°C (73.4 ± 1.8°F), and shall rest on edge and be entirely immersed. At the end of 24, +½, −0 h, the specimens shall be removed from the water one at a time, all surface water wiped off with a dry cloth, and weighed to the nearest 0.001 g immediately. If the specimen is 1⁄16 in. or less in thickness, it shall be put in a weighing bottle immediately after wiping and weighed in the bottle.

7.2 *Two-Hour Immersion*—For all thicknesses of materials having a relatively high rate of absorption, and for thin specimens of other materials which may show a significant weight increase in 2 h, the specimens shall be tested as described in 7.1 except that the time of immersion shall be reduced to 120 ± 4 min.

7.3 *Repeated Immersion*—A specimen may be weighed to the nearest 0.001 g after 2-h immersion, replaced in the water, and weighed again after 24 h.

NOTE 5—In using this test method the amount of water absorbed in 24 h may be less than it would have been had the immersion not been interrupted.

7.4 *Long-Term Immersion*—To determine the total water absorbed when substantially saturated, the conditioned specimens shall be tested as described in 7.1 except that at the end of 24 h they shall be removed from the water, wiped free of surface moisture with a dry cloth, weighed to the nearest 0.001 g immediately, and then replaced in the water. The weighings shall be repeated at the end of the first week and every two weeks thereafter until the increase in weight per two-week period, as shown by three consecutive weighings, averages less than 1 % of the total increase in weight or 5 mg, whichever is greater; the specimen shall then be considered substantially saturated. The difference between the substantially saturated weight and the dry weight shall be considered as the water absorbed when substantially saturated.

7.5 *Two-Hour Boiling Water Immersion*—The conditioned specimens shall be placed in a container of boiling distilled water, and shall be supported on edge and be entirely immersed. At the end of 120 ± 4 min, the specimens shall be removed from the water and cooled in distilled water maintained at room temperature. After 15 ± 1 min, the specimens shall be removed from the water, one at a time, all surface water removed with a dry cloth, and the specimens weighed to the nearest 0.001 g immediately. If the specimen is $\frac{1}{16}$ in. or less in thickness, it shall be weighed in a weighing bottle.

7.6 *One-Half-Hour Boiling Water Immersion*—For all thicknesses of materials having a relatively high rate of absorption and for thin specimens of other materials which may show a significant weight increase in ½ h, the specimens shall be tested as described in 7.5, except that the time of immersion shall be reduced to 30 ± 1 min.

7.7 *Immersion at 50°C*—The conditioned specimens shall be tested as described in 7.5, except that the time and temperature of immersion shall be 48 ± 1 h and 50 ± 1°C (122.0 ± 1.8°F), respectively, and cooling in water before weighing shall be omitted.

7.8 When data for comparison with absorption values for other plastics are desired, the 24-h immersion procedure described in 7.1 and the equilibrium value determined in 7.4 shall be used.

8. Reconditioning

8.1 When materials are known or suspected to contain any appreciable amount of water-soluble ingredients, the specimens, after immersion, shall be weighed, and then reconditioned for the same time and temperature as used in the original drying period. They shall then be cooled in a desiccator and immediately reweighed. If the reconditioned weight is lower than the conditioned weight, the difference shall be considered as water-soluble matter lost during the immersion test. For such materials, the water-absorption value shall be taken as the sum of the increase in weight on immersion and of the weight of the water-soluble matter.

9. Calculation and Report

9.1 The report shall include the values for each specimen and the average for the three specimens as follows:

9.1.1 Dimensions of the specimens before test, measured in accordance with 5.6, and reported to the nearest 0.025 mm (0.001 in.),

9.1.2 Conditioning time and temperature,

9.1.3 Immersion procedure used,

9.1.4 Time of immersion (long-term immersion procedure only),

9.1.5 Percentage increase in weight during immersion, calculated to the nearest 0.01 % as follows:

$$\text{Increase in weight, \%} = \frac{\text{wet weight} - \text{conditioned weight}}{\text{conditioned weight}} \times 100$$

9.1.6 Percentage of soluble matter lost during immersion, if determined, calculated to the nearest 0.01 % as follows (see Note 6):

$$\text{Soluble matter lost, \%} = \frac{\text{conditioned weight} - \text{reconditioned weight}}{\text{conditioned weight}} \times 100$$

NOTE 6—When the weight on reconditioning the specimen after immersion in water exceeds the conditioned weight prior to immersion, report "none" under 9.1.6.

9.1.7 For long-term immersion procedure only, prepare a graph of the increase in weight as a function of the square root of each immersion time. The initial slope of this graph is proportional to the diffusion constant of water in the plastic. The plateau region with little or no change in weight as a function of the square root of immersion time represents the saturation water content of the plastic.

NOTE 7—Deviation from the initial slope and plateau model indicates that simple diffusion may be a poor model for determining water content. In such cases, additional studies are suggested to determine a better model for water absorption.

9.1.8 The percentage of water absorbed, which is the sum of the values in 9.1.5 and 9.1.6, and

9.1.9 Any observations as to warping, cracking, or change in appearance of the specimens.

10. Precision and Bias [5]

10.1 *Precision*—An interlaboratory test program was carried out using the procedure outlined in 7.1, involving three laboratories and three materials. Analysis of this data yields the following coefficients of variation (average of three replicates).

	Within Laboratories	Between Laboratories
Average absorption above 1 % (2 materials)	2.33 %	4.89 %
Average absorption below 0.2 % (1 material)	9.01 %	16.63 %

NOTE 8—A round robin is currently under way to more completely determine repeatability and reproducibility of this test method.

10.2 *Bias*—No justifiable statement on the bias of this test method can be made, since the true value of the property cannot be established by an accepted referee method.

11. Keywords

11.1 absorption; immersion; plastics; water

---

[5] Supporting data are available from ASTM Headquarters. Request RR: D-20-1064.

BIODATA PENULIS

Penulis yang memiliki nama lengkap Faisal Maulana lahir pada 30 Desember 1989 di Kota Probolinggo. Penulis menempuh pendidikan formal di SDN Bangselok III, SMP Negeri 1 Sumenep, SMA Negeri 3 Kota Probolinggo, dan pada tahun 2008 Penulis diterima menjadi mahasiswa Teknik Fisika ITS. Di kampus penulis aktif di beberapa organisasi seperti HMTF, BEM ITS dan PCMI Jawa Timur. Selama kuliah penulis mendapat beasiswa dari PPA-BBM, beasiswa kepemimpinan dari PPSDMS Nurul Fikri. Penulis juga pernah mengikuti Program Pertukaran Pemuda Indonesia-Kanada pada tahun 2012-2013 selama 7 bulan di Kota Halifax, Nova Scotia, Kanada dan Garut, Jawa Barat, Indonesia.

faisal.maulana.lana@gmail.com