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5.3 Solvent Cast Cellulose Diacetate Film

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Summary: A review of the historical development, manufacture, properties and applications of solvent-cast cellulose diacetate film.

Keywords: Cellulose diacetate film, acetate, film moisture permeability, low birefringence, optical, biodegradable, lamination, window cartons, tape, photonegative sleeves, labels.

5.3.1 Background to diacetate film production

5.3.1.1. The Start

The earliest patent describing the solvent casting of cellulose nitrate onto glass plates for 'transparent film pellicles' was applied for on 2nd May 1887, by the Reverend Hannibal Goodwin. This was granted in September 1898 [1], though Goodwin admitted that it was not smooth or hard enough for photographic use.
By 1891, George Eastman had begun commercial production of cellulose nitrate film on jointed glass plates, resulting in a surface 200 feet long by 42 inches wide [2].

Although the first patent for solvent casting onto a continuously moving wheel was applied for by Stevens and Lefferts of the Celluloid Company in 1891 [3], the glass plate route continued until the early part of the twentieth century. By 1908, Eastman had introduced a new 'safety' film for amateur use, based on cellulose acetate to replace the flammable cellulose nitrate. By this time sufficient progress had been

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made on the quality of film produced on the continuously moving wheel (or drum) for it to have taken over as the major production method on both sides of the Atlantic.

Meanwhile, the Swiss brothers, Henri and Camille Dreyfus were producing cellulose diacetate products at the Cellonite Company in Basle.At the onset of the First World War, they were asked by the various governments to install plants in France, Italy and the UK [4]. Later still, they installed a plant in USA. The latter two subsequently became known as British Cellulose and Chemical Manufacturing Company and American Cellulose and Chemical Manufacturing Company, later to become British and American Celanese. In the late 20s, the British Cellulose and Chemical Manufacturing Company at Spondon, UK developed the ‘Celastoid’ block process, from which sheets were sliced and plate polished, but this was only suitable for thicker sheet products, such as watchglass faces, spectacle frames, etc.

During the 1930s, the British and American Cellulose and Manufacturing Companies began a collaboration on a continuously moving nickel plated band to produce solvent cast cellulose diacetate film [5 & 6]. This culminated in a pilot line being commissioned in 1937, in Building 44 at Spondon, UK, capable of producing a few hundred kilogrammes/month. Meanwhile, Lonza were experimenting with casting onto a copper band. Work immediately began to develop applications for this new high gloss and highly transparent, stable film. Unfortunately, the Second World War and the need to produce military products for the war effort put a hold on this development until 1946.

A second pilot line, at Courtaulds in Coventry, UK was commissioned in 1947, followed quickly by full-scale lines in 1948 at both Coventry and Spondon. After the war, British and American Celanese at Newark, New Jersey, continued the collaboration, resulting in the latter converting some of the ‘wheel’ lines over to cellulose diacetate film production.

Over the next few years, great effort was put into developing applications for the diacetate film, including print lamination, adhesive tape, graphic arts and photonegative sleeves. From a British perspective, the drive was on export. In these halcyon days, pre-polyester, polypropylene, etc. diacetate became the plastic film of choice.

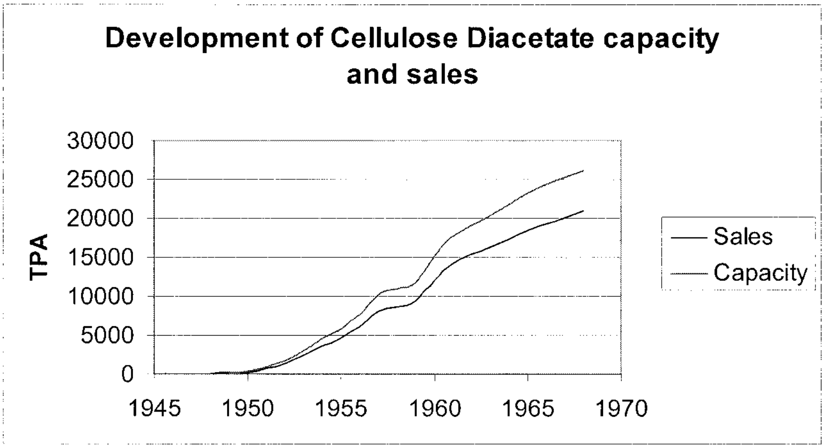
5.3.1.2 Growth of Volume and Manufacturers

During the 1950s and 1960s, sales and hence the need for production grew rapidly. By the mid-60s there were no less than 7 companies in America and Europe supplying over 20,000 tpa of solvent cast cellulose diacetate film.

Table 1 – Companies supplying cellulose diacetate film in the mid-60s

	TPA
American Celanese	12,000
Courtaulds	6,000
Rhone Poulenc	2,000
Lonza	1,000
Others	1,000

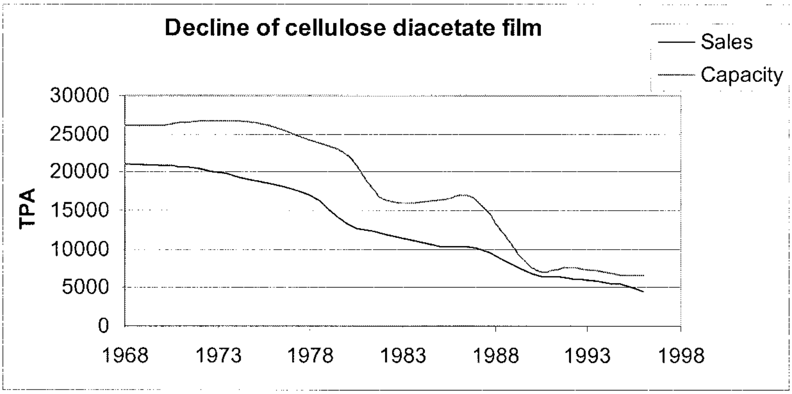
Figure 1 – Development of capacity and sales of cellulose diacetate film



The introduction of a range of new thermoplastic polymer films in the early ’60s saw a progressive decline in the demand for cellulose diacetate film. This was perhaps exacerbated by the lack of effort to improve the physical properties of the films.

Furthermore, the ability to thermally extrude polyester, polypropylene, polyvinyl chloride, etc. resulted in large volume processes with much lower prices, which continued to fall over the next 20 years. The ability to orientate these films resulted in flexible films with high tensile strength. Although diacetate film continued to be used in the traditional applications, it failed to grow with the development of new applications and was progressively replaced even in the traditional applications.

Figure 2 – Decline of capacity and sales of cellulose diacetate film



Courtaulds purchased British Celanese in 1957, combining the two major UK businesses. Both plants ran until the mid ’70s, after which the combined business was focussed in Spondon. The output of the American Celanese Belvedere plant was combined with and focussed on the Newark plant. The company went through a succession of owners and name changes, including Excel (ex-Celanese managers) and latterly Georgia Pacific prior to being purchased by Courtaulds in 1985. The late ’70s saw the demise of Rhône Poulenc’s acetate film business. Other European producers also went out of business in the late ’60s and mid ’70s. The final restructuring took place in 1996/7 when Kleerkast in the USA went out of business and Courtaulds bought the Lonza cellulose diacetate film business. At this point the Courtaulds’ trade name became the company name, Clari*f*oil. Interestingly, the original pilot line from Coventry, albeit no longer used, now resides in Building 44, in Spondon, the home of one of the earliest pilot lines in the world.

Clari*f*oil is now the sole solvent cast cellulose diacetate film producer. By a re-examination of the unique properties of cellulose diacetate film and their application to new end uses, Clari*f*oil has successfully halted the 30 year decline. Once again, cellulose diacetate is fast becoming the plastic film of choice.

5.3.2 Manufacturing routes

5.3.2.1 Introduction

Cast cellulose diacetate film is produced by the dissolution of diacetate flake in acetone, to form a dope. Various additives are combined to improve the processibility of the dope and the performance of the resultant film. These include the plasticiser, anti-block agents, band release agents, colorants, etc. The dope is filtered, de-aerated and cast through a die (the box) onto a continuously moving, highly polished, stainless steel band. Drying takes place in both the band tunnel and a drying cab, using a counter-current of hot air. The acetone in the solvent laden air is recovered and re-used. The gauge is controlled by the box gap, the band speed and the dope pump rate. The film is wound and subsequently slit to customer specification, with off-cuts being recycled.

5.3.2.2 Cellulose diacetate Flake

The choice of cotton linter or woodpulp is usually dictated by the clarity requirements of the film. Linter based diacetate flake tends to dissolve more readily, leaving less fibre and hence giving higher clarity. Colour may also be generated by the presence of resins, etc. in woodpulp. This is lessened by the use of linter grade flake, which is, however, relatively expensive.

The quality of woodpulp has progressively improved over the years, with tighter control of molecular weight, higher alpha content, lower resin and optimised choice of tree type. Thus, dissolving pulps that result in reduced band sticking and improved clarity films with higher tensile strength are available from a number of suppliers.

The viscosity of the dope is controlled by the inherent viscosity of the flake, a function of its molecular weight, the concentration and control of temperature. Further modification to the viscosity is brought about by the plasticiser and water contents.

5.3.2.3 Plasticisers

Although a range of plasticisers is possible, diethyl phthalate (DEP) has become the one of choice, due to its hydrophobic nature, favourable environmental and health credentials. The film, containing DEP, results in excellent gloss and clarity, optimal physical properties, such as softness and strength whilst being food contact approved. The second commonly used plasticiser is triacetin, though this gives a softer film.

Although known as "plasticisers", they are really bound softening agents, the properties of the film being the result of the blend of acetate and the "plasticiser". Consequently, the film performance is a result of the percentage of plasticiser present. This commonly ranges from ~10–25%.

Many plasticisers have been evaluated over the years, some of which are listed in Table 2.

Table 2 – Alternative Plasticisers

Plasticiser	Properties
Acetophenone	Strong, flexible, brilliant film.
Amyl benzoate	White pigmented film without the need of extra plasticiser.
Amyl borate	High adhesivity with metals. FR film (AB easily hydrolysed to give boric acid).
Amyl stearate	Use with triacetin to give water repellent, high polish film.
Diacetin	Soft film. Good with dyes.
Triacetin	Excessively soft film
Benzyl benzoate	Strong, hard film.

Butyl oleate	Water resistant, high polishing film. Less stable than amyl stearate. Use with another plasticiser, e.g. triacetine.

Plasticiser	**Properties**
Butyl stearate	Use with triacetin or amyl tartrate to give a high polish, water repellent film.
Diethyl phthalate	Strong, elastic film.
Dimethyl phthalate	Film with good adhesion and light stability.
Dibutyl tartrate	Stable, weatherproof film.
Diamyl tartrate	Brilliant, stable, weatherproof film
Glyceryl tribenzoate	Elastic films.
Monocresyl glyceryl ether di-acetate	More resistant to moisture than triacetin. Flexible film.
p.Toluene sulphanilide	Brittle film.
Triphenyl phosphate	Mix with triacetin, benzyl alcohol or amyl tartrate to give FR film.

5.3.2.4 Other additives

Standard film routinely includes an anti-block agent, to prevent glass bonding and to promote the desired slip characteristics during processing of cartons. However, this impacts on the very high optical clarity demanded for optoelectronic applications. For these, knurled edges provide the preferred means for the prevention of glass bonding. Solvent soluble and dispersible additives, ranging from dyes and pigments to pearlescent and metallic particles, may be added to the dope at mixing or by late injection, prior to casting.

5.3.2.5 Filtration and de-aeration

Once formed, it is important that undissolved fibres and particles, gels and dissolved air are removed from the dope. The fibres, particles and gels are removed by filtration, usually using plate and frame filter presses, lined with polyester needle felt that has been coated with filter aid. Other filter types, such as sand filtration, have also been used. The dissolved air is removed using a weir system. The dope is heated to just below the boiling point of the solvent and passed slowly over a series of baffles. Continuous evaporation and condensation brought about by the movement of the dope results in de-aeration. Prior to passage through the casting box, the dope undergoes a final stage of filtration through a candle filter to remove any debris that has been picked up along the way. The result is a bright, clear, highly transparent and glossy film free of particulate matter and bubbles.

5.3.2.6 Pros & cons of different processes

5.3.2.6.1 Gravity v pressure feed.

The dope may be fed to the band, via the box, under pressure or by gravity feeding making use of a reservoir. The advantage of the latter is the ability to cast the film using wider jaw gaps in the casting box, thus creating less drag with its resultant effect on morphology. The disadvantages, however, include reduced throughput due to both speed and lower concentration; the need for a reservoir; poor control of contour and greater demands on solvent recovery. Cellulose diacetate is currently cast via pressure feed.

5.3.2.6.2 Wheel v band

It is generally recognised that the first continuous production machine was the wheel patented by Stevens and Leffert, in 1896, five years after its introduction [3]. The patent referred to the band surface being nickel-plated copper.

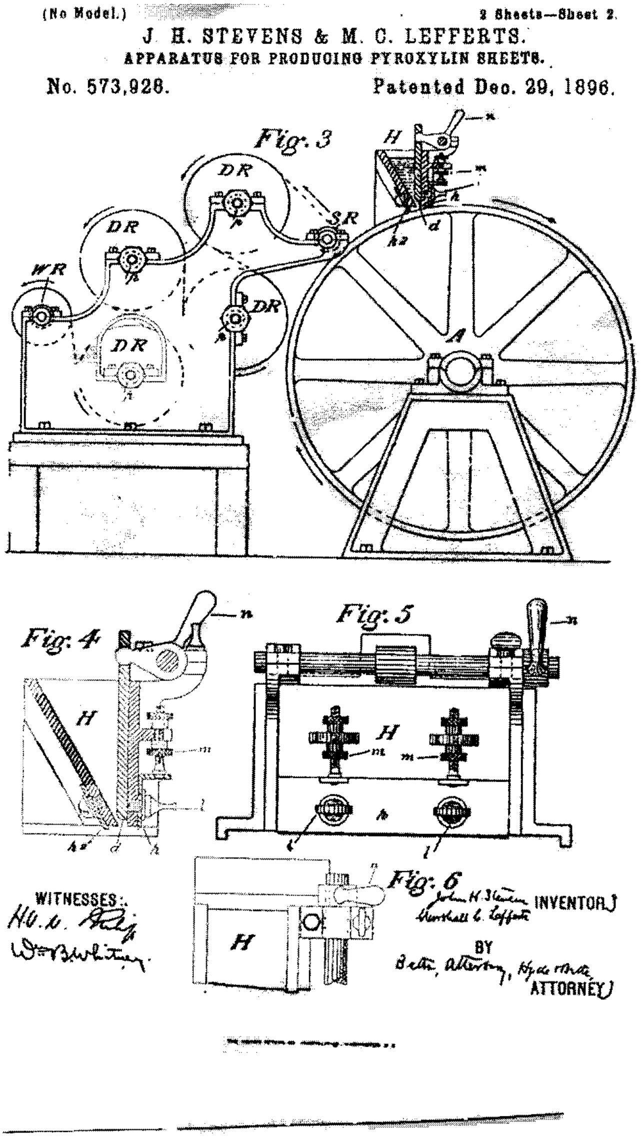


Figure 3 Early Wheel Casting

By the early part of the twentieth century, these wheels (sometimes known as drums) were being used routinely by Eastman, the Celluloid Company and others, now coated with silver [7]. By 1930, the surface was formed by the electrolytic deposition of chromium [8].

Although Stevens and Leffert had referred to an endless belt of German silver or nickel-plated copper, this was not developed until much later. During the 1920's, a range of short, narrow bands were evaluated and used mainly by German producers [2]. The only patent, subsequent to those of Stevens and Lefferts and van Derhoef, was attributed to Kinsella [5] of the Celanese Corporation of America. Much more is written on the development of these processes in an excellent historical treatise by E. G. Couzens, entitled 'A Short History of the Film Casting Process and its Products' [2].

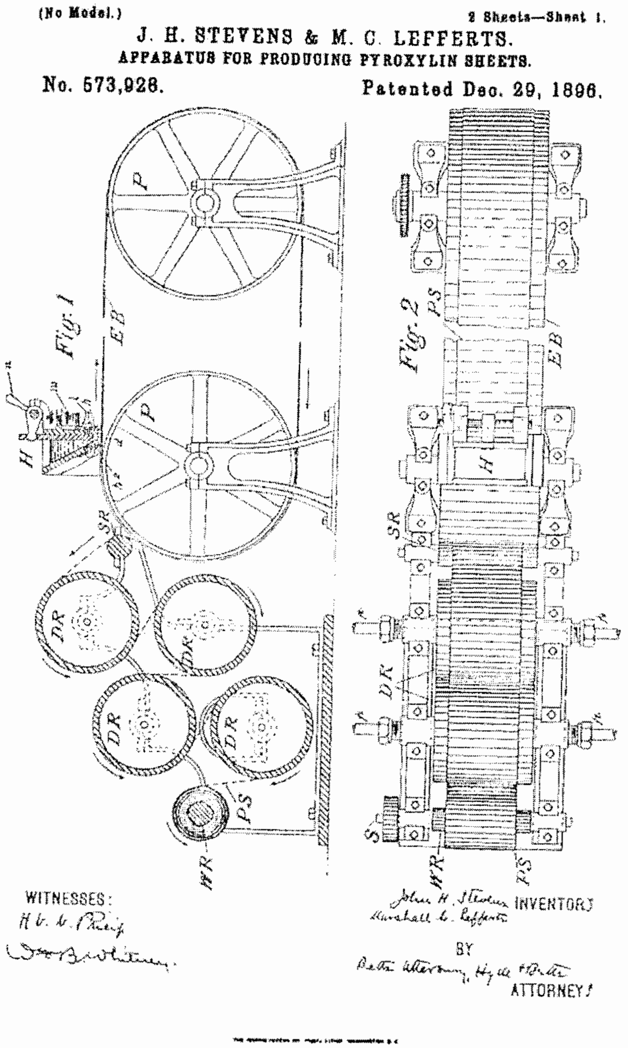
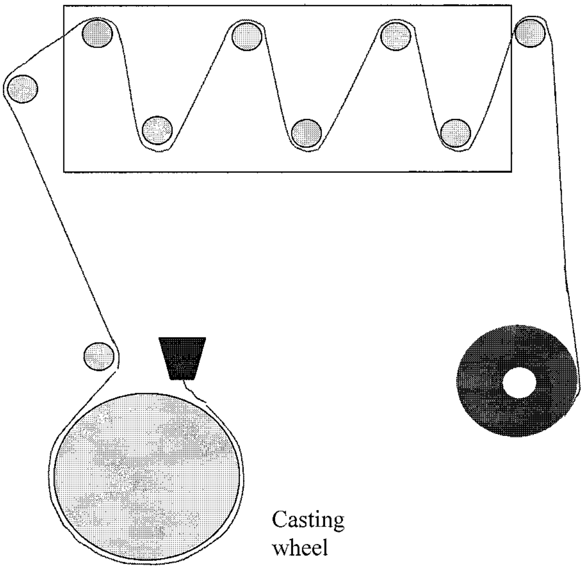


Figure 4 Early Band Casting

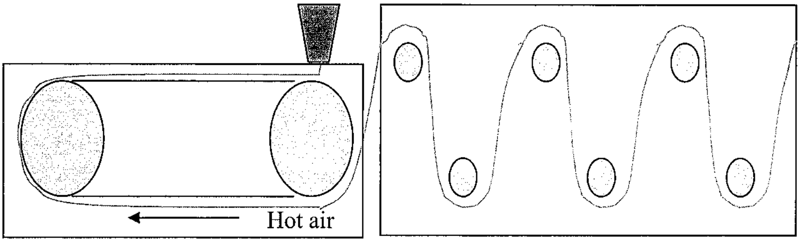
Commercial production of cellulose diacetate film was first carried out by the Celanese Corporation of America on the heated wheels, formerly used for cellulose nitrate production. Sufficient solvent was removed during the rotation of the 4-5 metre diameter wheel to give integrity to the film. The majority of the drying then took place in a festoon dryer. The major disadvantage of this system was that the localised heat on the wheel resulted in bubble formation in thin film. The use of a continuously moving stainless steel band overcame this problem, whilst giving greater contour uniformity to thin film, down to 14µ. Initially, this would have been carried out on a highly polished nickel band described by Kinsella or with gelatin coating providing the high gloss.

Figure 5 – Casting on a wheel, with festoon drying.



By the 1950s, the continuously moving stainless steel band soon took over as the workhorse for solvent cast film production. A counter-current of hot air enabled the majority of the solvent to be removed in the band tunnel, without bubble formation. This in turn enabled thinner films to be produced, down to as low as 14 µ. The final stage of drying continues to be carried out in a horizontal festoon dryer.

Figure 6 – Casting on a band, with festoon drying.



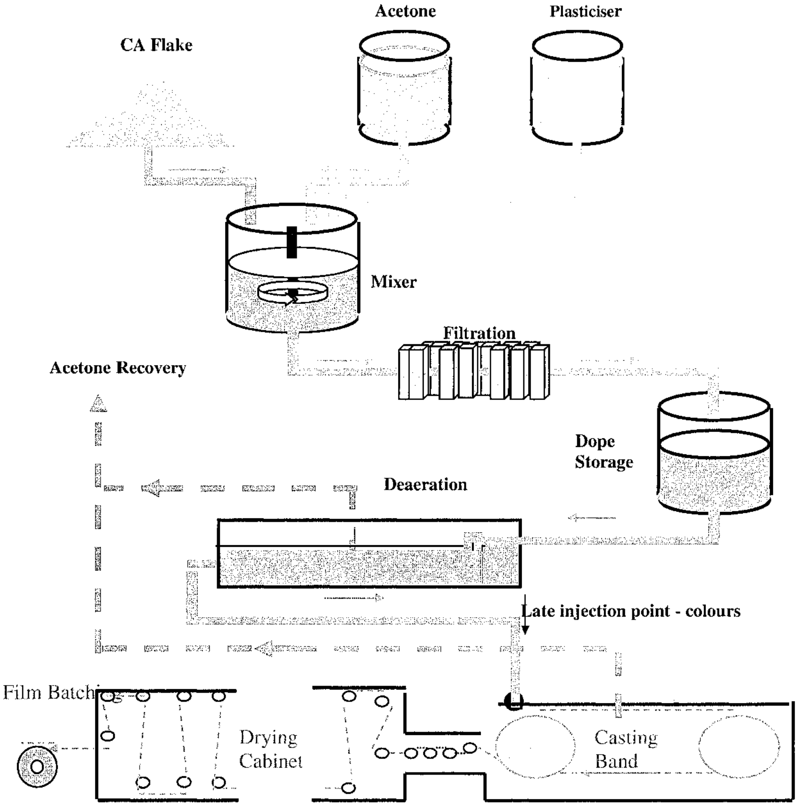
Other advantages have been realised by using a band. The rear drum is steered, to maintain tracking of the film preventing wander of the web towards the edges of the band, preventing damage to the film. The use of the band also gives the flexibility required to produce matt film.

Other drying systems are also available, including flat-bed and infra-red dryers. However, to gain maximum drying efficiency, long path lengths are required, which proves to be very expensive with all but the festoon dryers.

5.3.2.7 Current Clari*f*oil Production Process

Figure 7 is a schematic diagram of the overall Clari*f*oil process, and shows the various stages of dope mixing, filtration, de-aeration, casting, film drying, and final winding.

Figure 7 Schematic of the Clari*f*oil Process.



5.3.3 Properties of cast cellulose diacetate films

5.3.3.1 General

The properties of cast diacetate films are determined to a large extent by the film composition, and by the distinctive characteristics of the solvent casting process.
The cellulose diacetate polymer chain consists of anhydroglucose rings linked by 1,4 ß-glycosidic bonds. There are three free hydroxyl groups available on each ring, and for cellulose diacetate an average of approximately 2.5 of these hydroxyl groups are esterified with acetic anhydride. The residual hydroxyl groups mean that the polymer retains a degree of moisture sensitivity, which strongly influences film properties. Hydrogen bonding is also a significant factor influencing polymer behaviour.

The use of additives in general, and plasticisers in particular, gives a wide range of options for modifying the properties of cast cellulose diacetate films, and commercially the polymer is usually found in combination with one or more plasticisers, and often other additives, to provide the required film attributes.

5.3.3.2 Physical Properties

5.3.3.3 Mechanical Properties

Table 3 summarises some basic mechanical data for a 50µ cast cellulose diacetate film, containing approximately 16% by weight of DEP plasticiser. This represents a typical commercial formulation, where plasticiser levels typically vary from around 10% up to 25% by weight in the cast film. Properties quoted have been measured in the machine direction (MD). Transverse direction mechanical properties (TD) are typically similar: the casting process is a low pressure /low shear process which imparts little or no orientation to the polymer structure. Most properties are therefore approximately isotropic within the plane of the film.

Table 3 Typical Mechanical Properties of Cast Cellulose Diacetate Film[1]

Property	Test Method	Value
Elastic Modulus, E GPa (kNmm^{-2})	ASTM D882	2.8
Tensile Strength at Break MPa (Nmm^{-2})	ASTM D882	90
Elongation at Break (%)	ASTM D882	20 – 40
Yield Strength MPa (Nmm^{-2})	ASTM D882	57
Extension at Yield (%)	ASTM D882	4.5
Tear Initiation Resistance (N)	ASTM D1938	0.106
Tear Propagation Resistance (N)	ASTM D1938	0.078
Burst Strength (Mullens) (KPa)	BS 47688	500
Density (gcm^{-3})	ASTM D1505	1.31

Properties based on a spinning grade diacetate flake with a DS of 2.45.

Cellulose diacetate films generally demonstrate fairly high stiffness and tensile strength. Elongation at break and toughness are, however, only moderate. The films show relatively low tear resistance, a property that is used to advantage in pressure sensitive tapes, tamper evident labels, and in tear-off strips. Cast films of cellulose diacetate are relatively hard, and this imparts good scuff and scratch resistance, a useful characteristic in packaging film applications.

Overall cellulose diacetate offers a good balance of processability and acceptable strength, making it well suited for a wide range of end uses, including tapes, labels, decorative print lamination, and general packaging. Where necessary mechanical properties can be modified across a wide range by varying plasticiser type and loading. Suitable plasticisers include diethyl phthalate, glycerol triacetate (triacetin), triphenyl phosphate (TPP) as well as many others, as shown in Table 2.

Fig 8 Typical Load-Extension Curve for 50μ Cellulose Diacetate Film (23 C, 50% RH)

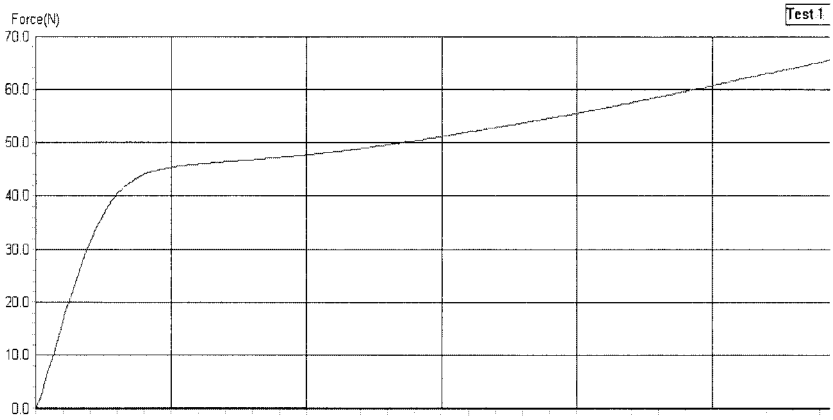


Figure 8 shows the load-extension curve for 50μ film in tension. The film initially shows good stiffness and recovery up to about 4.5% extension. At this stage a sharp yield point occurs and thereafter the polymer shows irrecoverable plastic flow, with a reduced secondary modulus. The film finally breaks at relatively low extensibilities (25 – 40%). As plasticiser levels are increased the load extension curve changes, and yield point reduces and elongation at break gradually increases, making for a tougher film. Note that care needs to be exercised in cutting tensile test specimens, especially for very thin cellulose diacetate films. Their low tear strength makes them very "notch" sensitive, and spuriously low results may be recorded without careful sample preparation, especially when determining elongation at break.

As noted above, the moisture sensitivity of the polymer also influences mechanical performance in a similar way to plasticiser. As moisture levels in film rise (e.g. due to increasing ambient humidity) extensibility and toughness tend to increase, and the film shows greater plasticity.

5.3.3.4 Optical Properties

Table 4 Typical Optical Properties of 50μ Cast Cellulose Diacete Films Containing ~ 16% Plasticiser. [9,10,11].

Property	Test Method	Value
Transparency (%)	ASTM D1746	91
Gloss (%)	ASTM D523 20°	140
	60°	146
	85°	120
Haze (%)	ASTM D1003	0.8
Refractive Index	ASTM D542	1.485
Birefringence Optical path difference (nm)	Polarizing Microscopy/Senarmont Compensator	0 - 20

Cast cellulose diacetate films have long been recognised as providing excellent transparency and very high gloss levels. The latter in part stems from the casting process, where the polymer solution is poured onto highly polished, mirror-like casting bands. On peeling from the band the very flat film surface provides high specular reflectance. This high gloss level leads to cellulose diacetate being the film of choice for lamination to high quality printed material.

As well as high transparency and gloss levels, cast acetate films generally show low haze levels. In part this is caused by small loadings of inorganic anti-block additives. For very demanding optical applications such additives can be omitted, producing very low levels of haze. As a result of the manufacturing process cast acetate films also demonstrate extremely low levels of orientation, showing near-zero birefringence. The latter makes the film very well suited to demanding optoelectronic applications, and is an inherent advantage of solvent cast over melt extruded films.

As well as producing very high gloss films, the casting process also allows the production of matt surfaced films, by casting onto bands with roughened surfaces. Using this approach films with a deep physical surface matt can be cast, as well as semi-matt films with intermediate or indeed localised surface roughness.

The solution casting process also facilitates the introduction of solvent soluble dyes, or the dispersion of insoluble pigments into the polymer solution before casting. This makes solvent cast films perhaps uniquely versatile in their ability to permit a very wide range of coloured films in both translucent and opaque forms.

5.3.3.5 Electrical Properties

Table 5 Typical Electrical Properties of Cast Cellulose Diacetate Film containing 16.7% plasticiser [9,10,12].

Property	Test Method	Value
Dielectric Constant	ASTM D149 1KHz	3.6
	1MHz	3.2
	1GHz	3.5
Dissipation Factor	ASTM D149 1KHz	0.013
	1MHz	0.038
	1GHz	-
Dielectric Strength (V/mil)	ASTM D149	3200
Volume Resistivity (Ω. Cm)	ASTM D257	$7x10^{13}$
Surface Resistivity (Ω)		$1.6x10^{13}$
Dielectric Breakdown ($KVmm^{-1}$)		150

Table 5 gives some typical electrical data for a cast cellulose diacetate film plasticised at 16% w/w with diethyl phthalate. Under normal atmospheric conditions thicker diacetate films offer reasonable insulation properties, which previously led to their use in motors and transformers. Their moisture sensitivity, however, and lower temperature performance have led to polyester films largely supplanting them in this type of application.

Given the solution manufacturing process there is scope for producing heavily loaded films which may give relatively high levels of conductivity.

5.3.3.6 Gas Permeability Properties

The permeabilities of diacetate films to moisture vapour, oxygen, nitrogen and carbon dioxide are detailed in Table 6.

Table 6 Gas Permeability of Cellulose Diacetate Film [9].

Property	Test Method	Value
Moisture vapour transmission rate, gm^{-2}24 hours^{-1}	25°C/100% RH Mocon Test Method	1800 - 200
O Permeability (ccmil/100 sq.in/24 hrs % 25°C)	ASTM D1434	150
N Permeability (ccmil/100 sq.in/24 hrs @ 25°C)	ASTM D1434	30
CO$_2$ Permeability (ccmil/100 sq.in/24 hrs @ 25°C)	ASTM D1434	860

A key characteristic of diacetate film in many end uses is its ‘breathability’ to moisture vapour. It provides a good balance between moisture resistance and the ability to transmit moisture vapour, and this makes it an ideal film for use in “hot-fill” foodstuff window cartons (e.g. bakery products). This property also helps prevent the misting of window cartons in chilled display cabinets, especially where moist confectionery and cakes are being displayed.

To some extent, moisture (and gas) permeability can be varied by changing the type and level of plasticiser, or other additives, used in the film. Surface coating can also be used to modify barrier characteristics.

5.3.3.7 Thermal Properties

Table 7 details some typical thermal properties of cellulose diacetate, again in a commercial formulation, plasticised with around 16% of diethyl phthalate.

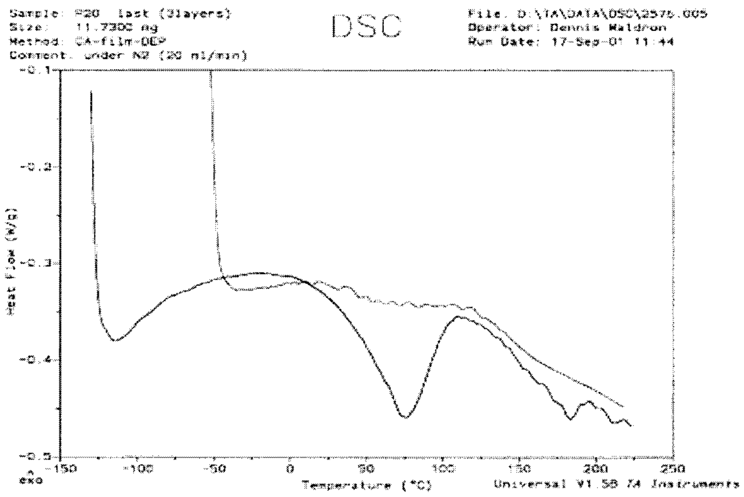
Table 7 Typical Thermal Properties of Cast Cellulose Diacetate Film with 16.7% plasticiser. [9,10,13,14].

Property	Test Method	Value
Glass transition temperature, Tg	DSC	120C
Softening point (HDT)		137C
Decomposition temperature		~260C
Thermal coefficient of expansion	ASTM D-1637	$\sim 6 \times 10^{-5}$
Heat capacity		$\sim 1.5\ kJkg^{-1} K^{-1}$
Calorific value	Bomb calorimetry	$19.6 MJkg^{-1}$

The glass transition temperature Tg for unplasticised film is around 195C. The polymer does not show a true melting point, thermally decomposing at around 260C. Typically, however, cast acetate films are produced in plasticised forms, and in this case the Tg shows a steady decrease as plasticiser levels increase: at around 16% loading by weight of diethyl phthalate the Tg has fallen to 120C. Figure 9 shows a typical DSC trace for such a film. Gradual loss of plasticiser above 120C during the temperature sweep is evident, and makes clear identification of the T_g more difficult.

The Tg is a relatively weak second order transition, and film softening does not really develop until 15-20 degrees above the Tg. However, significant shrinkage will occur around the Tg. Indeed at temperatures above 90C shrinkage will start to develop, associated with the loss of volatiles from the film (water and any residual solvent).

Figure 9: DSC Trace for Cellulose Diacetate Film, Plasticized with 16% DEP



5.3.3.8 Dimensional Stability and Moisture Effects

Table 8 lists data relating to moisture content and dimensional stability, again for a film plasticized with ~16% of DEP.

The dimensional stability of cellulose diacetate films are dominated by their sensitivity to moisture. The residual hydroxyl groups on the anhydroglucose rings, on average ~0.5 per ring, mean that cellulose diacetate has a relatively high moisture absorption. Increasing moisture levels lead to increases in film dimensions, and vice versa. The presence of plasticiser tends to reduce moisture sensitivity, but the trends remain the same unless accompanied by exposure to high temperatures. Dimensional changes with increasing or decreasing moisture levels are generally reversible, although there is an hysteresis effect.

Table 8 Properties Relating to Dimensional Stability for Cellulose Diacetate Film

Property	Test Method	Value
Moisture content (23C, 50% RH)		1.8%
Liquid Moisture Absorption (24 hr)	ASTM D-570	5-8%
Moisture Coefficient of Expansion (23C)		$25\text{x}10^{-3}$/%RH
Thermal Shrinkage (115C/15 mins)		<1.5%

In many commercial applications the moisture sensitivity of acetate film does not pose any problem. Indeed, for end uses where the film is bonded to cellulosic materials such as paper and board the moisture sensitivity can be an advantage: the moisture expansion and contraction characteristics better match those of paper and board in comparison with other film types, minimising the effects of moisture induced curl.

Thermally induced dimensional changes are generally lower in impact than moisture induced effects, at least up to the Tg. However, as already noted at higher temperatures the loss of volatiles, including plasticisers, also contributes to irreversible shrinkage.

5.3.3.9 Weathering of Cellulose Diacetate Films

Cellulose esters give good UV resistance, significantly better than cellulose itself. The addition of appropriate plasticisers and UV absorbers/light stabilising systems can provide further significant improvements in the UV resistance of cellulose diacetate films, especially under dry conditions. In the presence of moisture degradation rates tend to increase, but the polymer still offers a fair degree of stability.

5.3.3.10 Surface Properties

5.3.3.10.1 Surface Energy

As noted above cast cellulose diacetate films have remarkably flat surfaces, as a result of the highly polished bands on which they are cast. The surface energy of cellulose diacetate is typically around 40 mNm^{-1} and this is not much affected by the use of low to moderate loadings of plasticisers. This is a relatively high surface energy that remains stable and usually ensures good wet-out with inks, lacquers and adhesive systems. In particular water based inks wet out well on the hydrophilic film surface, as do water borne adhesives. In general acetate film will print satisfactorily using all the major traditional techniques of offset-litho, letterpress, silk screen, and gravure. UV inks often present a challenge when printing onto filmic substrates, with their low liquid absorption capability compared with paper. Whilst diacetate film offers some improvement, the use of primers and/or overvarnishes is recommended. Acetate films have also proved receptive to thermal transfer and other VIP techniques.

It is the chemistry of the polymer formulation which confers acetate's high and stable surface energy. Polymers such as polyolefins are usually treated by corona discharge to raise their energy levels. Whilst this is not necessary for diacetate films, it can be used with them to raise surface energy a few mNm^{-1}. Excessive corona treatment should be avoided.

5.3.3.10.2 Surface Friction

Partly because of their very flat surfaces and, perhaps, partly due to the relative polarity of the polymer, diacetate films show rather high film on film surface frictions. The static coefficient of friction for gloss film is typically 0.45-0.65 and the dynamic coefficient 0.4-0.55 (ISO 8295, BS2782 Part 8). Matt film surfaces have somewhat lower friction coefficients (0.3-0.4), as a result of the reduced area of contact with such surfaces. Where necessary acetate films can be formulated to provide very low surface frictions (0.2-0.3). This is especially useful where film is required to run on very high speed packaging lines, and where high scratch and mar resistance is needed.

5.3.3.11 Chemical Resistance

The resistance to a range of chemicals and solvents is listed in Table 9.

Table 9 Chemical Resistance of Cellulose Diacetate Film. [9].

CHEMICAL	Resistance
Water	A
Ethanol / Methanol	B
Ethyl acetate	D
Tolulene / Heptane	A
Motor fuels	A
Carbon tetrachloride	A
Antifreeze (Ethylene Glycol)	A
Detergents	A
10% Acetic acid	A
Benzyl alcohol	B
Brake fluid	B
Trichloroethylene	B
10% Potassium hydroxide	B
2% Salt solution	B
38% Hydrogen peroxide	B
10% Hydrochloric acid	C
10% Sulphuric acid	C
Glacial acetic acid	C
Acetone	D
MEK	D

KEY A = total resistance after 7 days immersion
B = intact after 7 days total immersion but dimensional changes
C = resistant after 24 hours but not 7 days total immersion
D = no resistance. Dissolves within 24 hours total immersion

Cellulose diacetate films generally show good resistance to non-polar chemicals such as hydrocarbons, but poor resistance to more polar solvents like ketones and esters. The polymer resistance to dilute acids/alkalis is only fair, and poor at higher concentrations.

5.3.4 Environmental Aspects

The cellulosic backbone of diacetate polymer gives a range of environmental features and options which are not available with most films based purely on petroleum derived raw materials. The distinctive characteristics of CDA, including its biodegradability, are discussed in Chapter 4.3.

5.3.5 Applications

Current and future applications centre on acetate film's specific physical, chemical and environmental properties, which are employed to produce finished products demonstrating desired features at acceptable cost. This was not invariably the case in the past. As one of the first commercial "plastic " films available from the 1940s, acetate film was chosen almost automatically for many applications, often when all that was really required was a "clear plastic". The range of gauges, finishes and formulations of acetate films continued to develop. However, there was also a proliferation of low cost, improved quality polymer films, specifically designed to meet the new applications. Conversely, appreciation of the unique characteristics of acetate film has developed and today this means that acetate film applications are solidly based on grounds of functionality, consumer appeal and economy. Technical performance is the driver both today and increasingly so in the future, which will determine where acetate film is used. Further exploitation of acetate's unique properties are likely to open up whole new fields of application, some of which are already starting to emerge, such as optical-electronics.

5.3.5.1 Past Applications

The following list is not fully comprehensive, but represents uses for acetate film more common in previous years than today. Recent developments in acetate technology mean that certain applications may well be re-established, for instance, due to environmental factors and the availability of new grades of acetate film with enhanced properties.

Table 10 Past Applications

Anti-fog mirrors	Furniture mouldings	Printed revolving shades for lanterns
Candle wrapping	Hat stiffeners	Shoe lace tags
Cartoon animation cells	Kaleidoscopes	Shop window display film for U.V. light protection
Cigar box lids	Litho masking film	Syringe packs
Cine leader tapes	Motor cycle and welding visor "rip-offs"	Tennis visors
Coloured film for theatrical lighting filters	Name badges	Transparent boxes and cylinders
Cotton reel outer wraps	Newspaper game cards	Vacuum formed medical packs
Electrical cable wraps	Packs for needles	Windows for explosives
Filing strips	Printed film for wrapping cartons – "whisky wrap"	Wire reinforced film for agricultural cloches
Finger print storage	Printed fly sheets for Greetings cards	

5.3.5.2 Present Applications

Some current applications, as featured below, such as print lamination and window cartons, are amongst the original uses to which acetate film was put, but in terms of product range, refinement and performance these uses have evolved and developed strongly over the course of time. For example, in the field of print lamination, gloss film is today available in gauges down to 14 microns and has been augmented by deep matt finishes and satin and textured finishes with a range of colours and embossed effects also available. Turning to window cartons, acetate film usage has increased strongly, especially for the packaging of moist foodstuffs. These benefit from acetate's moisture permeability and thus ability to resist misting caused by condensation. Acetate window pack functionality has been augmented by the availability of U.V. light absorbent film grades that can prolong the shelf life of certain foods and confectionery

Table 11 Present Applications

Adhesive Tape	Clear stationery tapes Matt "invisible" tapes
Graphic Arts	Document covers and binders, thermal binders, Artists pads
Pressure Sensitive Labels	"Invisible" clear and matt labels. Tamper evident seals
Photo Negative Sleeves	Clear and matt on one side versions
Print Lamination	Carrier bags C.D. and D.V.D. sleeves File dividers Menus Perfumery, cosmetics and skin care cartons Point of sale displays Promotional literature, Company reports, Annual Accounts
Transparent insulation	Glazing applications e.g. roof light insulations Railway carriage cavity insulation
Others	3D Spectacles Electronic display screens Gaming chips Medical specimen testing kits Polarising optical applications Sequins Thermal lamination film

Acetate film's continued use for both clear and matt ("invisible") mending tape and for pressure sensitive labels, makes use of its ready acceptance of adhesives, a wide range of printing inks and techniques, acceptance of foil blocking and write-on capability. The film's ready tear characteristic is used to advantage for tape in facilitating cutting to size without recourse to a metal cutter bar, whilst for labels, acetate's tear properties are employed for tamper evident seals.

5.3.5.3 Future Applications

Future applications are likely to see further development of existing applications, especially where increased functionality can be built into the film by incorporation of additives such as holographic particles, dyestuffs and thermo-chromic, photo-chromic and phosphorescent agents. Acetate film's manufacturing process, which facilitates incorporation of acetone soluble chemicals in relatively modest quantities, is well suited to production of grades customised to customers' particular requirements. Manufacture of products under non-disclosure agreement, especially in security and anti-counterfeit fields, is therefore likely to grow further.

Currently, acetate film's environmental credentials are coming to the fore, especially with regard to packaging recovery, composting and recycling and this is likely to widen acetate film's area of application in window cartons, labelling and print lamination.

The "second wave" of acetate film development which has been undertaken following an extensive reassessment of acetate properties and their exploitation in conjunction with new technology, has already started to open up new fields of use. In particular, cast acetate film's optical properties such as low and controllable birefringence coupled with excellent optical transmission means that diacetate film will have a growing role in electronic displays, including in respect of developing flat screen technology. Also of importance in this field will be the understanding gained in extending diacetate's dimensional stability and upper temperature performance.

Besides the development of "high technology" applications and evolution of existing uses, decorative and textural product innovations will see the use of acetate film – sometimes in combination with other polymers – in a range of flexible packaging applications currently the reserve of "commodity" plastics. This will extend to personal care products and promotional gifts. There is also likely to occur a "reinvention" of some traditional applications, such as Greetings Cards, where acetate film's new decorative finishes offer enhanced design options.

5.3.6 References

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