Foreword of Colin Williamson, polymer specialist

This book is about both art and science and how the use of plastics by artists generates a unique set of problems for conservators working in museums, galleries and academic laboratories all over the world. It is not an art picture book although it contains many pictures of works of art, and it is not a scientific treatise although it does include chemical formulae. It is a book created for conservators, art historians, museum and art gallery curators and collectors of art and design works that happen to be made out of plastics. Essentially, this book is a record of the latest conservation science and technology as applied to plastics work of art. It is also a report on the POPART project – the Preservation Of Plastic ARTefacts in museum collections.

Plastic materials have been used by artists and designers for over 100 years and today it is well-nigh impossible to enter a museum of modern art without seeing sculptures made from plastic. It is a commonly held belief that plastics "last forever" but this concept relates (mistakenly) to the most commonly found plastics items in our 21st century lives – items such as packaging. Compared with paper and cardboard, plastics might seem everlasting but compared with glass and many metals, plastics materials are generally short-lived. It is these short-life properties that challenge the conservator because without intervention, many works of art would degrade and self-destruct, sometimes causing serious damage to nearby objects. This book describes the "state of the art" in conservators' attempts to delay this degradation or somehow save some of the world's modern art treasures so that future generations might enjoy the actual objects rather than images of works that had self-destructed generations before.

So, what are these plastics materials that artists and designers have used? When and how were they discovered and why have we developed them for everything from ping-pong balls to racing cars and from fashion jewellery to replacement heart valves? The answer lies, of course, in the tremendous versatility, convenience and low cost that plastics raw materials offer the product designer and industrialist as much as the artist.

It is generally accepted that plastics are organic (i.e. based on carbon – something that once lived), polymeric (i.e. a large molecule based on repeating smaller units like individual links making a chain) and are normally heat moulded to the desired form. Many natural materials would also be included in this catch-all definition, materials like beeswax and pitch and certainly these materials have been used since pre-history, but moulding technology as we understand it today has its origins in the middle of the 19th century.

In 1858, nearly 10% of British patent applications included the word "moulding" and referred to the industrial mechanisation of the hand craft of carving. By this time the industrial revolution had transformed most traditional crafts to major industries and made fortunes for the entrepreneur inventors. Thus, the village spinner and weaver had lost their livelihoods to the new, giant and low cost textile mills; the blacksmith was relegated to being a shoer of horses and repairer of pans as his original manufacturing craft was taken over by massive foundries; the village potter lost his kiln to the pottery and porcelain factories situated where clay and fuel were abundant and labour was cheap. What could be more natural for entrepreneur industrialists than to search out and replace other village crafts like hand carving, and in doing so create a fortune? The moulding technology was available from the metals and ceramics industries, what was lacking was a suitable moulding material – the search to develop low cost plastics had started.

Some natural "plastic" materials were used in their natural form; others were blended into compositions to make them less brittle, mouldable or cheaper. Horn, one of the first such materials, was moulded into snuff boxes in the early days of the 18^{th} century by John Obrisset of London. His competitors would have had to hand carve both the top and the base to a sliding, snuff-tight fit, a time-consuming exercise, whereas John Obrisset, provided that the first "moulding" came out of the mould at the correct size, so would the second, the 22^{nd}, and the 122^{nd} also. The speed advantage that Obrisset had over his "hand-carver" competitors would have given him a distinct commercial advantage.

Other natural plastics needed to be modified in order to make them usable. Shellac is exuded as a gum by members of the Lac insect family as a protective adhesive, sticking the insect to a twig and creating a difficult barrier to birds and other predators. Once purified, shellac makes a good moulding material except that it is very brittle. In the USA in the 1850's, daguerreotypes and ambrotypes (early photographic images) were kept in folding Union Cases made from shellac, blended whilst molten with powdered wood as a reinforcing agent. As Obrisset had found 150 years earlier, moulding the cases from a "plastic" material made good commercial sense, especially as a popular image could be incorporated in the case design. By the middle of the 19^{th} century inventors had developed the early plastics Vulcanite, Bois Durci and similar compositions like Carton Pierre and *papier-mâché*. Hundreds more inventions were discarded as unworkable, but the financial potential justified the expensive and unsuccessful trials, the end goal was, of course, financial rather than aesthetic or academic.

Rubber is extracted from trees as a latex and was known as a chemical curiosity called caoutchouc until Joseph Priestley described that it would "remove the marks made by a black lead pencil", and caoutchouc became "rubber". Hancock, in the 1830's, discovered the vulcanisation process whereby the addition of sulfur to rubber at an elevated temperature changed the nature of the material into the flexible, bouncy, durable material we know today. He also discovered that if you add up to 30% sulfur then the rubber is transformed to a hard, rigid material with excellent moulding properties – vulcanite (or ebonite) was launched. Designers took advantage of vulcanite's excellent properties to mould it into pipe stems, Vesta match boxes and, eventually, many pieces of electrical equipment as vulcanite also possessed excellent insulating properties.

In France, François Charles Lepage (described in his patent as a "literary man of Paris") mixed animal blood with powdered wood to make a moulding composition he termed "Bois Durci". Bois Durci mouldings exhibited excellent characteristics and are arguably the best quality "artistic" and fashionable plastics mouldings commercially made in that century.

1862 is generally accepted by plastic historians as the date when the first of the new family of semi-synthetic plastics were shown to the public. The British inventor Alexander Parkes had taken pure cellulose in the form of common cotton wool and changed its nature by reacting it with nitric acid to produce cellulose nitrate. He made this into a moulding material by blending it with plasticisers including castor oil and camphor and exhibited them at the 1862 Great Exhibition in London. His new material was excellent for moulding but his manufacturing company, Parkesine Ltd, failed in 1868. Parkes went on in other directions but his invention was experimented with and developed by others but it took some 15 years before a suitable moulded product was identified. This was the collar and cuff made from the American cellulose nitrate material called

Figure 1. Photograph frame made from Bois Durci, made ca. 1870 in France, 160x110 mm (private collection of Colin Williamson, photo by Colin Williamson)

Celluloid. Why such an unexpected product should be successful is an interesting marketing study and starts in offices all over the world. Clerks, sitting at their high desks, calculating and writing into ledgers and record books, would not have had available scrap paper for notes or calculations so they would have used their starched linen cuffs as notepads. Laundry was expensive so at the end of a week, the cuffs and collar must have been very dirty, even without all the pencil marks. When Celluloid collars and cuffs became available they could be simply rinsed clean under a tap, shaken dry and worn again the next day looking pristine – just like the boss! This success lead to success making Celluloid the first truly successful plastic material and by the 1930's most western middle-class households contained some items made from it, probably coloured to imitate ivory or tortoiseshell. Celluloid was capable of being fashioned into any colour or pattern and as such was quite different from the modified natural plastics hitherto made which were, by technological necessity, dark in shade.

Celluloid was also the first plastic material that enabled completely new concepts to be introduced to the market, for example, sound recordings and cinematography film. Sound recordings were previously made on wax cylinders but when Edison discovered Celluloid he introduced a range of Ambrol Blue cylinders that could be played over and over again without significant wear. The availability of a flexible, transparent substrate was critically important for the launch of the first cinematographic films in the last years of the 19th century, indeed the name "Celluloid" is synonymous with movies.

One unfortunate property of Celluloid is its flammability – a slightly different version of the same cellulose nitrate is the explosive gun cotton. We also know now that the material itself is highly unstable, degrading under exposure to UV light and moisture and in doing so producing nitrogen oxides which then react to produce nitrous and nitric acids which in turn cause further breakdown of the cellulose molecule backbone. Most Celluloid ever made has now degraded and the films still existing are stored under cold, controlled humidity conditions to delay their inevitable degradation.

Celluloid was also the first plastic material to be used extensively by artists in the early decades of the 20th century. The revolution in fine art was already well established by the breakthroughs of Cubism and by the 1920's artists like Naum Gabo with his Realistic Manifesto believed that art should be a critical force in re-ordering modern life. In his essay on Gabo, (Nash and Merket 1985, 11) Steven Nash quotes from Three Lectures, "Gabo sought new images 'not for the sake of their novelty but for the sake of finding an expression on the new outlook on the world around me and the new insight into the forces of life and nature in me'. Recent discoveries in science (especially Rutherford's splitting of the atom) had profoundly affected the perceptions of natural law, stretching the modern imagination in new directions, and Gabo was amongst those artists who responded with a search for visual modes to understand these emerging realities". He continues, "Gabo's quest therefore, centred on a means of expressing his concepts of space, structure and the energy of motion as well as the general technological ethos which characterised the era". Gabo's use of clear, transparent Celluloid sheet "permitted a new tangibility of light and space" (Nash and Merket 1985, 21). What could be more stimulating for Gabo than Celluloid, a new material, a product of science instead of nature, as transparent as glass but more usable and "new" to the modern public?

Gabo's use of cellulose nitrate sheet is one of the reasons why there exists in conservation science an urgent interest in the degradation of all plastics, how this degradation can be slowed down and what to do with works of art that have degraded so far that they are unlikely to represent the artist's original concept.

Plastics technology advanced and to help overcome the flammability problems associated with the nitrate ester of cellulose, the industry introduced the less flammable acetate ester of cellulose. For the film industry this was termed, "safety film" and it was widely assumed that "safety" also included the concept of "long life". The original research work into "CA" was performed by Schutzenberger in the 1860's but commercial development was one of the outcomes of the First World War. Exploited as a lacquer, a fibre and a sheet material, CA was one of the first work-horses of the plastics industry but for the artist, its flammability advantage over cellulose nitrate was not enough to overcome the simplicity and experience gained with CN.

Casein based plastics were successful in the first half of the 20th century after early developments in Germany. Casein, a protein found in milk can be reacted with formaldehyde to produce a rigid, water horn-like material that is poorly thermoplastic. It was used between WWI and WWII for the manufacture of highly decorative pen and pencil barrels but its largest market was in the manufacture of buttons where its ability to accept water based dyestuffs and hence be coloured in small batches made casein buttons ideal for the fashion clothing trade. Casein absorbs and then releases water according to the local humidity and in doing so swells and contracts slightly. Consequently casein items are commonly found covered with a haphazard network of fine crazing.

Coincidentally with the introduction of casein formaldehyde and cellulose acetate in the early days of the 20th century, other chemists were researching into fully synthetic polymeric materials. Before that time the available plastics materials on the market were based on either natural polymers or chemically modified natural polymers, the actual polymerisation process was largely left to nature.

In the USA a Belgian chemist, Leo Baekeland had developed an electrically insulating varnish by controlling the condensation reaction between phenol (hydroxybenzene) and formaldehyde (methanal). He also discovered that the syrup he created could be cast in lead moulds where it would slowly "cure" to a hard, clear amber like solid. This "cast phenolic" was used to produce a wide range of decorative items from necklaces to knife handles and umbrella handles to wirelesses. The curing reaction was slow, sometimes taking several days on large items and in an industrial society where "time is money" such expensive delays were expensive. Baekeland attempted to speed up the reaction but the end product was brittle. He overcame this brittleness problem by adding wood flour (powdered wood) to the resin as a reinforcing agent and the resultant mottled brown mouldings became widely known as "Bakelite".

By the late 1920's the reaction of formaldehyde was extended from phenol to urea and thiourea giving clear, water white resins without the amber tint of the phenol compounds. When reinforced with paper fibres, urea formaldehyde made possible "unbreakable" picnic sets and pale coloured electrical appliances. The major decorative laminate sheet materials were made using these resins with the designs printed on the paper layer.

The Second World War was a driving force behind the industrial development of a new range of plastic materials, polyethylene, poly(vinyl chloride), polystyrene, polyamide and polyurethanes. Most of these materials were produced before the war started but the drive for new materials stimulated the investment in large manufacturing facilities to support the war effort.

Amongst these materials was poly(methyl methacrylate) or PMMA, available as a liquid resin that could be cast into new shapes or as a sheet. Artists and designers exploited its clarity, its crystal brightness and its ability to be heat formed into new shapes. It could be relatively easily cut, glued and polished and earned the description "acrylic glass". PMMA was used in the 1930's by Gabo, Duchamp and Pevsner, in the 1940's by Moholy-Nagy and Archipenko. By the 1960's, PMMA was almost mainstream with Wurmfield, Magrini, Cuetara, Judd, Kolig, Reimann, Beasley, Wesselmann, Castro, La Pietra, Marotta, and Nevelson using this "new" plastic.

In her book, Transparency into Art (Arghir 1988, 15), Anca Arghir reports an event from 1967 whereby, "two British pop-artists… asked the opinions of 137 art collectors, dealers and artists on how a modern sculpture should look. The answer was 30% Plexiglass, 29% aluminium, 24% brass and 17% plastic – the whole worked into a non-figurative sculpture standing at an ideal height of 1.33 m. Both artists – Gerald Laing and Peter Phillips – then created a sculpture according to the data fed into a computer and called it, significantly enough, "Hybrid". It is evident from this that Plexiglass (PMMA) was not considered as a "plastic" and should be seen as a material in its own right; such was the negative public perception of plastics as a group of materials.

The other 1930's/40's introduced plastics were of less interest to artists, although many plastics products would find themselves being used by artists, not because they were made from plastic but because they were the products they were, light fittings, polyethylene bags and of course textile fibres based on the new plastics. Polyurethane resins were used as adhesives and rigid insulation in the 1940's, but by the 1960's was being used by artists Gilardi, Cesar, Chamberlain and Bonnier.

One of the new materials was unsaturated polyester, available as a liquid resin which could be cast or, especially, used as a bonding agent between layers of glass fibre to enable GRP (Glass Reinforced Polyester or commonly known as "Fibreglass") mouldings to be constructed. GRP enabled large mouldings to be produced as one-offs or limited production runs. Ideal for boat hulls, kit-cars and outdoor sculptures, the simple technology was perfect for craftsmen and the artists St Phalle, Klasen and Jaco and the super-realist Duane Hansen.

The volume of plastics now produced annually exceeds that of all metals and plastics are an essential part of 20th century life. There is no activity that we undertake that does not rely upon or is not strongly influenced by plastics. Telecommunications, electricity, transport, packaging, clothing, sport and almost everything else needs plastic. Little wonder therefore that artists and designers use plastics on a daily basis as first choice or "no-alternative" materials. We are now in the first decades of the 21st century and modern plastics have been available for only 60 years yet they have penetrated our everyday lives to become an indispensible part of modern life. Developments will make them stronger, tougher and more rigid, make them conduct electricity and be body friendly. Plastics in the future will be made from renewable resources or produced by micro-organisms fed on sunlight and carbon dioxide and at the end of their useful lives will be collected, sorted and recycled into new objects again and again. Many artists, of course, will prefer to use traditional materials but it is inevitable that many will use complex plastics to generate their works of art.

Artists and designers are generally unaware of the short life time expectancy of most current plastics materials. Making plastics last a long time is not difficult, poly(vinyl chloride) window frames can last under the most harsh conditions for decades with only surface and minimal degradation, frequently not of the polymer itself but of the colourants used. Stabilising plastics is, however, expensive and if the expected lifetime of the object is limited, then why waste money and resources on making the object last longer than is necessary? The issue with artists and their works is that commonplace, short-life objects are often used as integral parts of the artwork whereas most artists (and certainly their customers) would prefer that the works remain unchanging for ever, or at least, as long as possible. Unfortunately these preferences are not fulfilled and the works start to degrade almost as soon as they are put on display.

If one combines the ubiquity of plastics in artworks and other museum objects with the relatively short life expectancy of plastics, and the currently low level of conservator expertise in plastics, then it is clear that a massive problem faces the art world of the future as they try to grapple with decaying artworks in which pension funds, museums and collectors have invested heavily.

This dilemma is the subject matter of this book and we hope that the POPART project is seen in the future as a seminal work in the science of plastics conservation. So, how have we gone about this work and tackled the subject?

The book is divided into several sections addressing different issues, how to determine if a museum has a problem, what the items are made from, what chemical processes are going on, how to clean plastics items and the book covers in some detail the specific problems associated with polyurethane foam. It also addresses the issues of publicity by the development of Polly, a doll made from a variety of plastics materials so that degradation can be observed under the public gaze.

Degradation, almost by definition, starts slowly and maybe unnoticeable and when it has become apparent it is often too late to take remedial action – the degradation is a chemical process that cannot be reversed. The best that can be achieved is the slowing down of future degradation.

This book explains how to make a survey of plastics in museum collections, what are the tell-tale signs that degradation has already started, has it changed colour, gloss level or even size and format? Is the surface blistering, cracking, weeping or does the item smell of vinegar or has it gone acidic? What is the packaging? is this showing unusual signs of decay and are nearby items suffering unexpectedly? All these are signs that the plastic is degrading and should act as a red warning light to the conservator.

Before a conservator can address the problems of a work of art, a design object or indeed any plastic item or component in a museum collection, it is critically important to determine the type(s) of plastic that have been used in its production. Some conservation activities and storage conditions might be ideal for one plastic but might accelerate degradation in another. To aid this preliminary investigation it was agreed that a database of known materials should be established and shared by all members of the project. SamCo, a collection of some 50 reference materials including most of the commonly found plastics was established to facilitate this.

Having a reference database is essential but is a long way from being able to non-invasively identify the plastics in an object. The last 15 years have seen massive advances in the various instrumental techniques available, in 1990 FTIR was the premier method but was unreliable, frequently giving inaccurate results as operator experience and expertise was limited. Most of the work had been centered on the issues associated with cellulose nitrate cinematographic films but as soon as the analytical technology was directed towards the modern thermoplastics and strongly coloured items it left many questions unanswered. Since then, the advances have been rapid and a round-robin trial of some 35 unknown samples were correctly identified by several of the participating laboratories, something which would have been impossible as recently as ten years ago. The book describes in some detail the currently available methods including the two arguably most useful technologies, FTIR and Py-GCMS.

A historical overview is given covering the degradation pathways of various plastics, with a more detailed examination of the evaluation of the factors related to degradation.

Once the nature of the plastics present in the object is known, then a logical question of how to go about conservation follows. Should the items be cleaned, should conservation be active or passive, or should the item be returned to the curator as ok? Extensive work is reported on the methodology of cleaning the surface of plastics items, what tools to use, how to perform it with or without cleaning fluids or solvents. Inappropriate cleaning of works of art made from oil paints, stone, metals and other materials has now been consigned to the history books but bitter and expensive errors have carried conservators to a good level of expertise in these materials. It is clearly imperative that similar mistakes with plastics materials are not undertaken due to ignorance.

It is generally accepted that the plastics most in danger are the cellulose esters, nitrate and acetate, plasticised i.e. flexible poly(vinyl chloride) and polyurethane (PU) foam. The POPART project carries the research forwards by including a significant amount of work on polyurethane foams. This is presented, not as a solution to the degradation problems of PU foams, but as an on-going research programme with interesting initial conclusions.

Polly, a plastics doll made especially for the POPART project is a doll, deliberately made from different but known plastics products to show how plastics degrade when kept on display in a museum environment. Polly was conceived and born in 2009 and is currently living in several museums across Europe. She has been a remarkable success story with much media publicity and will probably become the icon of the POPART project.

This book answers many questions but it asks many more. It is a significant milestone in the journey towards understanding the issues associated with plastics in museum collections, and equally importantly it helps point the way forward for future work. Just as plastics are relatively young materials, so the science of their degradation is a relatively young science, and the understanding of how we should care for our plastics heritage is still in its infancy. The POPART project should not be just one project, and, as it grew out of the Modern Art: Who Cares project of the 1990's, so it should itself be a base from which the next research projects are launched. We want future generations to be able to see plastic works of art and museum objects in their original form, and not just as 3D images and voice memories. This book provides a valuable step towards that worthy objective.