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Article

Performance and Stability of Historic Casein Formaldehyde

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Abstract: Casein formaldehyde was manufactured between 1904 and 1982 in Western Europe both by International Galalith Gesellschaft (IGG) and Erinoid Ltd. (amongst others).
Charles Rennie Mackintosh used it in his designs for furniture commissioned by Wenman Joseph Bassett-Lowke.
Casein formaldehyde may be identified through a range of simple and analytical methods available to most conservators in private and public practice.
We can control the loss of colour and protect the surface finish by minimising light exposure.
Material, aged and distorted, may be reversed if the correct conservation procedures are observed and implemented.

Keywords: *Casein formaldeyde, early plastics, Erinoid, Galalith, furniture design, Wenman Joseph Bassett-Lowke, Charles Rennie Mackintosh, Peter Behrens, Knockaloe, 78 Derngate House, New Ways House, Northampton, identification, ageing, conservation.*

Introduction

During the first half of the twentieth century casein formaldehyde (CF) has been used among others as a decorative inlaid material in historic artefacts.[1] CF is not always recognised in heritage collections as it has a similar appearance to other types of plastic, such as cellulose nitrate (CN) and cellulose acetate (CA). It also has been given a wide nomenclature due to manufacturers trade names [2] with over 100 identified from *Alkalit* (Austria) to *Zoolite* (Italy). To date there is only a limited number of literature on conservation of casein formaldehyde.[3] This paper aims to provide some clarity on how to identify the material using simple methods of recognition supported by historical contextual information established from literature. The paper further uses data from experimental work conducted on samples of extant and new casein formaldehyde as well as reviewing historic trade literature and objects from casein manufacturers in order to observe the behaviour of this plastic material. Common forms of deterioration are given with recommendations for treatments provided based upon the experimental work.

Casein plastic is made by precipitating it from cows' milk through a biochemical reaction with rennet, the enzyme found in the stomachs of calves. The dried (powdered) casein is then processed by the manufacturer into sheets and rods in a wide range of colours and dimensions (cf. figure 1,2).[4]

Casein plastic was used as a decorative material by the architect and designer Charles Rennie Mackintosh (cf. figure 3a) for the commissioned furniture designs he completed for the businessman Wenman Joseph Bassett-Lowke (cf. figure 3b),[5] when remodelling his domestic house in Northampton,[6] in the early twentieth century. [7]

Some of the manufacture of the furniture were carried out between 1916 and 1919 by German citizens/POWs in the internment camp of Knockaloe (cf. figures 4-7) on the Isle of Man, UK.[8]

Bassett-Lowke was involved in organising this manufacturing as the visiting card shows that he visited the camp in 1916 (cf. figure 8).

The production of casein plastic in the UK began in 1911 by the newly formed company Syrolit Ltd.,[9] which subsequently was taken over in 1914 by *Erinoid Ltd.* in Stroud, England.[9] The *International Galalith Gesellschaft Hoff Co.* (IGG) in Harburg, Germany had produced casein plastics from 1904 [10] after A. Spitteler and W. Krische's [a] patents of 1897.[11,12]

Figure 1 Sample card, *Galalith*

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[a] Adolf Spitteler was a swiss inventor, Wilhelm Krische was a manufacturer of account books and art print papers in Hannover, Germany: see G. Lattermann, *Wer hat's erfunden? Adolf Spiteller und die Geschichte des Galaliths*, Ferrum - Nachrichten aus der Eisenbibliothek 89 (2017), p.26-34.

Figure 2 Sample card, *Erinoid*.

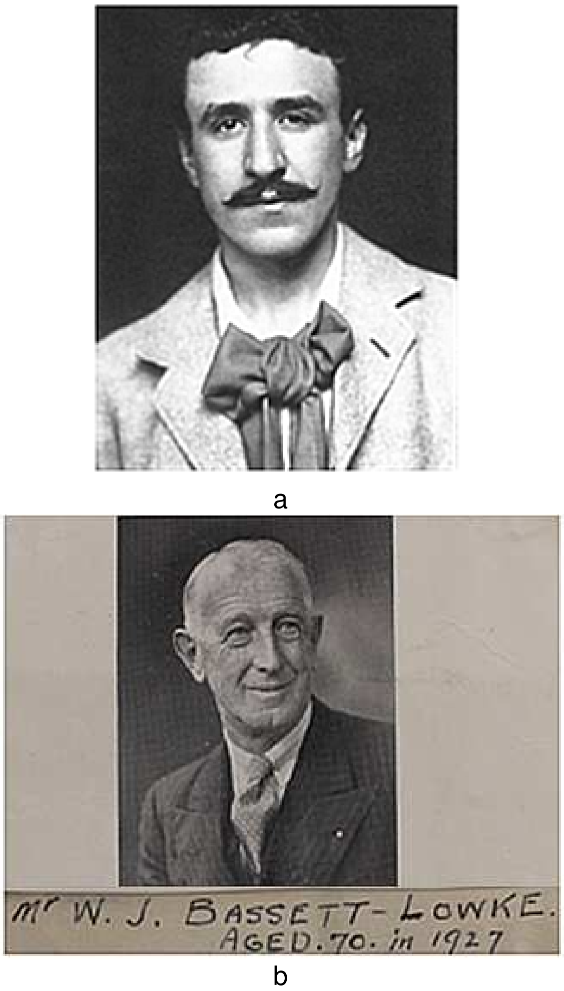


Figure 3 a) Charles Rennie Mackintosh, b) Wenman Joseph Bassett-Lowke.

Figure 4 Furniture for Northampton made at Knockaloe by German interns (1916-19).

Figure 5 Northampton furniture at Knockaloe camp.

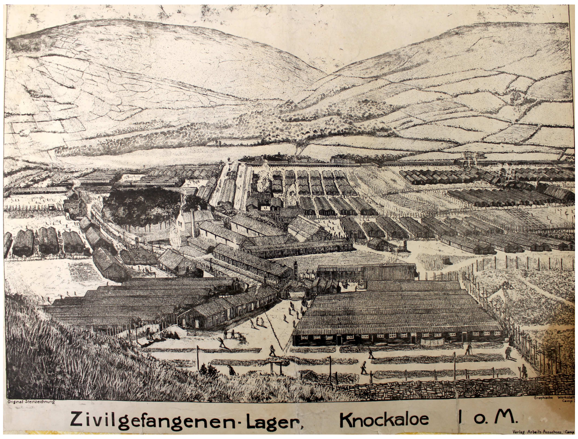


Figure 6 Knockaloe camp, Isle of Man.

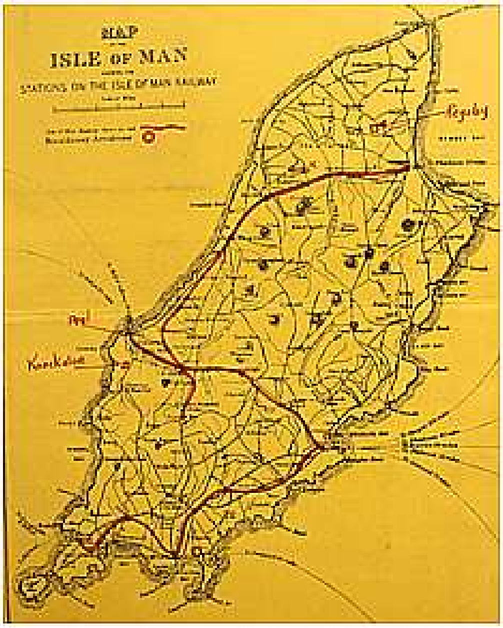


Figure 7 Isle of Man map showing position of Knockaloe.

PERMANENT PASS.

KNOCKALOE CAMP, PEEL.

Pass Bearer.......................

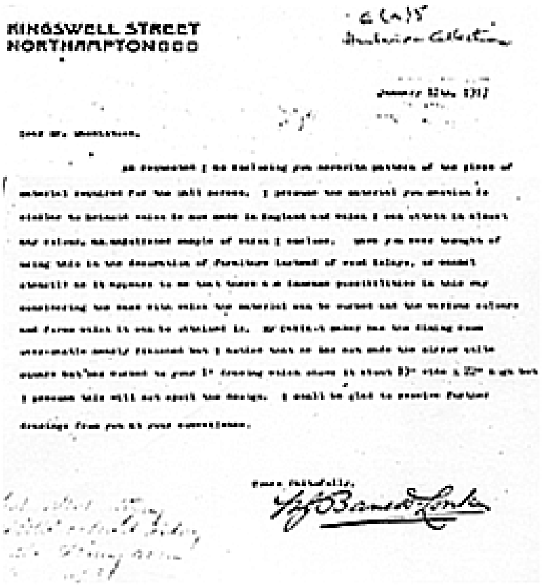
From ~~Compound~~..............to..............

Date.......................

Asst. Commandant
for Commandant.

To be examined by Sentry.

Figure 8 Bassett-Lowke's pass into the camp (dated 1916).



KINGSWELL STREET
NORTHAMPTON

Figure 9 Correspondence between Bassett-Lowke and Mackintosh which mentions *Erinoid*.

Correspondence between Basset-Lowke and Mackintosh (Jan 12th, 1917, cf. figure 9) illustrates that Bassett-Lowke was aware of casein plastic and requested that Mackintosh used it in the designs for furniture for his house in Derngate, Northampton, England *and which I can easily obtain*.[13] Bassett Lowke traded with Germany [14] for his engineering products and therefore may have been familiar with *Galalith* through his visits to Germany: [15] *"I presume the material you mention is similar to Erinoid which is now made in any colour, un-polished sample of which I enclose"* (Bassett-Lowke 1917)".[16]

The furniture designed by Mackintosh which has casein plastic inlaid as its main form of decoration demonstrated forward thinking at the time as the material was a representation of plastic not some other form of substitution, which was more commonly found in furniture of this period.[17] Plastic had also been used to imitate other more highly regarded semi-precious materials such as mother of pearl, turtle shell, ivory and ebony.[18] The manufacturers of semi-synthetic plastics had relied on their plastics being among others good imitations of these semi-precious materials and worked with product designers to create jewellery and other small decorative domestic's items such as dressing sets and table-ware.[19]

Charles Rennie Mackintosh designed a large amount of furniture which was distributed across a number of Bassett-Lowke's various residences [20] in Northampton (78 Derngate, Candida Cottage and New Ways, the latter designed by Peter Behrens in 1925/26, cf. figure 10). This unique furniture was later sold at auction by Bassett-Lowke's estate beneficiaries.[14] Some of it is now located in private collections, [21] whilst other items of furniture and clocks are in Museums in the UK and US.[22]

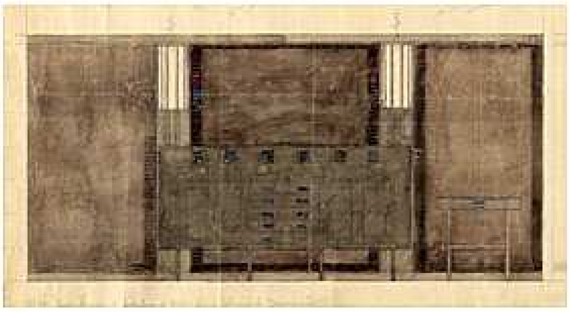


Figure 10 Mackintosh furniture designs for 'New Ways' in Northampton, showing *Erinoid* inlaid plaques.

The collection at Brighton Museum and Art Gallery has a number of pieces of furniture designed by Mackintosh [23] and these are the examples that have been observed here. The condition of the casein plastic in this furniture appears at first glance to be stable, however upon closer inspection distortion can be observed (cf. figure 11).

Observations [24] were conducted on the casein formaldehyde inlaid within the Brighton furniture to improve the understanding of the materials deterioration.

Figure 11 Brighton Art Gallery and Museum examples showing distorted casein plastic in Mackintosh Furniture.

These investigations led to possible treatments being identified and subsequently tested through experimental work. Replicated samples [25] were created and these were placed in various environmental conditions to observe chemical and physical changes of the plastic. The data generated from this work allows recommendations to be made for the treatment of distorted casein formaldehyde.

The work shows that the main agent of deterioration for casein formaldehyde is dehydration due to fluctuations in both temperature [26] and humidity. Colour fading is another common problem caused by ultraviolet light and visible radiation exposure.[27] Dehydration causes shrinkage and consequent distortion, whilst colour fading from light exposure and failure of colourfastness of the dyes employed in its manufacture damage visual appearance.

Background and historical context

Archival material [28] illustrate that casein plastic manufacture was a significant industry. The amount varies by source but Tilson (1999) and others states that many thousands of tons were produced yearly throughout the first half of the twentieth century.[29-31] *Erinoid* business records [32] illustrate that in the 1950s casein plastic was manufactured in the form of rod and sheet materials with production volumes reaching 105 tons in October 1954 for the home market and 19 tons for the same month in the overseas market.

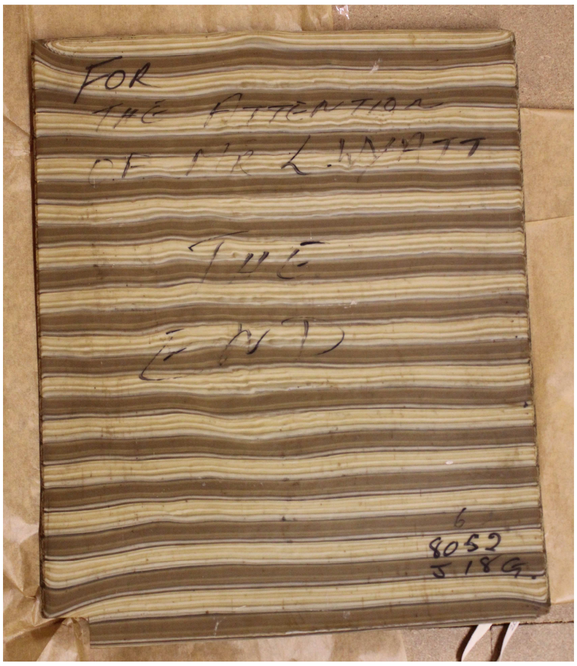


Figure 12 Last piece of *Erinoid* produced at Lightpill Mill, Stroud.

In the UK, the production of casein plastics ceased in 1982 when *Erinoid Ltd.* closed, then under the name of *British Plastics Ltd.* The last piece of provenanced *Erinoid* sheet [33] has been recently donated to the Stroud museum (cf. figure 12). It reads *'For the attention of Mr. L. Wyatt "the end".* L. Wyatt was the foreman in charge of the casein section of the factory,[33] which produced afterwords other plastic materials such as cellulose acetate.

Manufacture

Erinoid Ltd. purchased rennet casein powder from *Anchor* Dairies in Ireland and *United Dairies* in New Zealand (cf. figure 13).[34] Coarse casein powder was distributed in sacks to casein plastic manufacturers where it was further ground through a 40 mesh.[35]

A number 40 mesh sieve produces granules of 0.420 m.[36] The powder was mixed with water mechanically into a paste (cf. figure 14) ready for extrusion.

Figure 13 *Erinoid Ltd.* lorry collecting casein powder delivered by air from United Dairies.

Figure 14 Mixing shop at *Erinoid Ltd.*

The moistened casein mixture is extruded through heated nozzles at relatively high pressures (15-75 MPa).[37] The rod that emerges is cooled in water.

The resulting rods (cf. figure 15,16) would then be arranged into trays and pressed with heat and pressure. Some rod material was not pressed being used for the production of needles and pen barrels.[4]

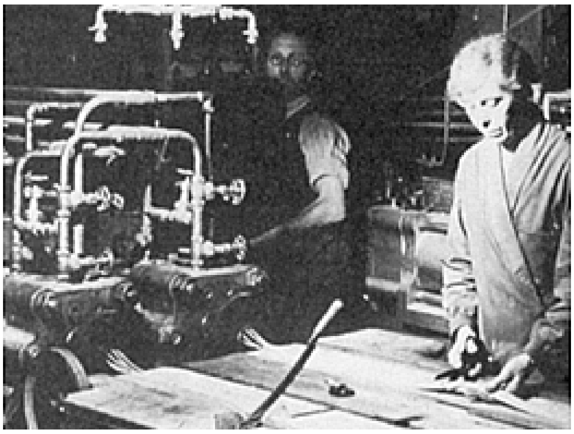


Figure 15 Extrusion of casein formaldehyde.

Figure 16 Casein formaldehyde rods at *Erinoid Ltd.*, Stroud.

If sheet is required, the freshly extruded rods [38] are place side by side in trays and formed into sheets in a heated hydraulic press (cf. figure 17).

Figure 17 Pressing of casein formaldehyde.

Polishing the plastic sheet and rods by abrasion and acid exposure [39] was done after the material was extruded and pressed.

The colouring of casein plastic is generally done prior to extrusion. This will ensure that the colour is consistent throughout the material. Colouring after manufacture is also possible. Erinoid advised its customers [40] who purchased non-coloured casein plastic in sheet or rod form to place the shaped articles that the purchaser had made into a muslin bag and immerse it into a hot solution of dyestuffs at 90°C in a copper, aluminium or glass ware vessel for 15 minutes. A large number of dye recipes to achieve a range of colours (cf. figure 18) were available in the *Erinoid book of Dye Recipes*. 41

Figure 18 *Erinoid* shade card.

In the 1920s *Erinoid Ltd.* advertised 285 different colours,42 but the actual range was infinite. Specials were done for clients as and when required, for a higher price.[43]
An arrangement of different colours (nibs) will produce a spectacular effect. [44]

The final process was the hardening of the product and this was achieved by immersion in a 5% formalin solution [34] at 16°C for a minimum of 2 days. For thicker masses, hardening was known to have taken up to 3 months.[45] The formalisation (hardening) process introduces cross links between the peptide groups of the casein process, which causes an increase of the material's hardness, insolubility and a certain resistance to swelling in moisture.[46]

The material was then racked and dried. Drying time depended on the thickness of the material, 4 mm sheet: 13 days, 8 mm sheet: two months, 10 mm sheet: three months.[47] Sheet and rod was produced in standard sizes. Sheet material was 20 inches (50.8 cms) x 16 inches (40.64 cms) and ranged in thickness from 2 mm to 12 mm, [47,48]whilst rod was produced from 4 mm diameter to 31 mm diameter (cf. figure 19,20).[47]

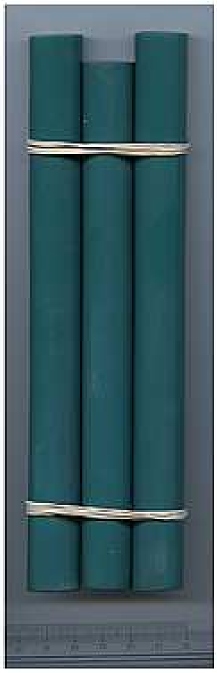


Figure 19 *Galalith*, green rods

Figure 20 *Mibrupo* [48] turtle shell pattern sheet.

Erinoid (cf. figure 21) was manufactured using the same dry process as for producing *Galalith* in Harburg, Germany.[34]

Figure 21 *Erinoid* catalogue – back page of *Erinoid the all British Material* 33pp.

Earlier, in 1904, the *Vereinigte Gummiwarenfabriken* in Harburg acquired the French *Compagnie Francaise de la Galalith*e at Levallois Perret, combining both CF productions to form the *International Galalith Gesellschaft Hoff & Co.*.[49] In a newly built branch at Harburg, the German *Galalith* was produced and most surviving casein plastics objects originate from here. The cessation of casein production in Germany and France takes place at 1978.[4,49]

Conservators should acknowledge that the production of casein was a batch process and hence batches achieved unique examples with every batch being slightly different with a wide range of colour configurations.[34]

Properties of casein plastic

Casein is a globular protein in which the arrangement of the polypeptide chains is much less regular than with other protein based molecules such as keratin or collagen that are fibrous proteins. [1]

The primary structure of the casein molecule is characterised by the ordering of the amino acids along its peptide backbone. The secondary structure may be given as the way in which the polypeptide chains are arranged in relation to each other. Both cause crystallinity which is among others responsible for the casein material's brittleness and high risk of fracture.

Thermosetting polymers are generally composed of three-dimensional cross-linked chains, which are usually relatively short, whilst thermoplastic polymers are normally composed of un-crosslinked, long linear chains.[50] The arrangement of side chains and the relative movement of the bonded atoms of polymers also affect the properties of plastics, such as flexibility and brittleness.

To understand plastics, it is important to understand their composition, how they are formed in terms of molecular chains. To enable a good understanding of degradation, it is important to comprehend how these chains may be affected, attacked or broken down. Morgan [51] states, *'since mechanical properties are very much dependent upon the length of the polymer chains any reactions which cause chain scission are potentially very serious.'* Because of their network structure thermosets can with stand more chain scission than thermoplastics and are generally found to be more stable.[13]

Casein formaldehyde (CF) has been described as a thermoset.[52] However as will be identified (see experimentation below), it initially appears to have thermoplastic properties. This ambiguity was recognised by Sutermeister who noted that as CF is heated, it softens between 190°C and 212°C),[53] yet quickly returns to a rigid state.

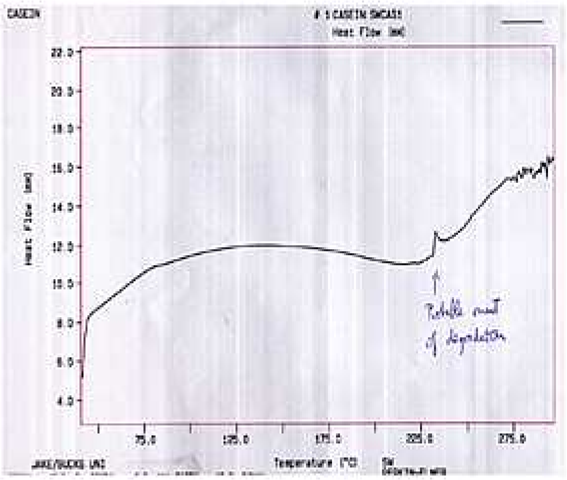


Figure 22 Probable onset of degradation of casein formaldehyde CF (abscissa °C).

Here, he is referring to a possible melting point which we found to be above ~230°C (cf. figure 22). Strictly speaking CF does not have a real melting point. However, at certain temperatures it softens just prior to its degradation.[54] Sutermeister further claims that '*it is therefore possible to bend and emboss casein plastic to some extent, but not to mold it'*.[53]

As is known, before hardening (crosslinking) it in the formalin bath, objects were pressed into forms. Apparently just after hardening to a certain extent, samples can be softened for investigations to a certain extent. (see below: chapter 'Treatment'). Of course, this was never used in an industrial process.

Both the *International Galalith Gesellschaft* and *Erinoid Ltd*. provided the working instructions for purchasers of casein sheet and rod material in published literature.[55]

The final moisture content of CF manufactured through the dry process is between 20% and 35%.[56] It was claimed by the manufacturers that Casein plastic was resistant to organic solvents and weak acids. However, it decomposes with strong acids and strong alkalis.[57]

Identification

Now we know more about the history and manufacture of CF, identification is more achievable. The analytical method of choice to identify CF is FTIR (Fourier Transform Infrared). Using a mobile unit may be regarded as non-destructive.

Other methods are more likely to be destructive to the material, as samples must be destroyed when conducting a flame test or require grinding into powders for odour tests. Simple identification methods include observation of production methods, such as process marks. Others might be hardness testing and observing visual properties at low magnifications. Surface topology can be inspected with SEM (Scanning Electron Microscopy) and high magnification microscopy.[58] *Erinoid Ltd.* advised its customers to add glycerol to hide glue when attaching casein plastic to other materials such as wood.[59] This modification would provide an extended open time.

Conservation

There are many problems associated with the conservation of plastic materials and these have been identified over the past twenty years by a cooperation of scientists, conservators and curators.[60-61-62] However, not much attention has been given to the treatment of casein plastics. This may be because CF is not regarded as a complex polymer and therefore there is a perception that it is simple to treat.[63] It may also be that it has been misidentified as celluloid nitrate or acetate, which also was manufactured in similar ranges of colours and textures.

Historic casein plastics frequently may be sometimes distorted, can suffer colour loss or may fade and degrade to some extent, e.g. pitting and fracture.

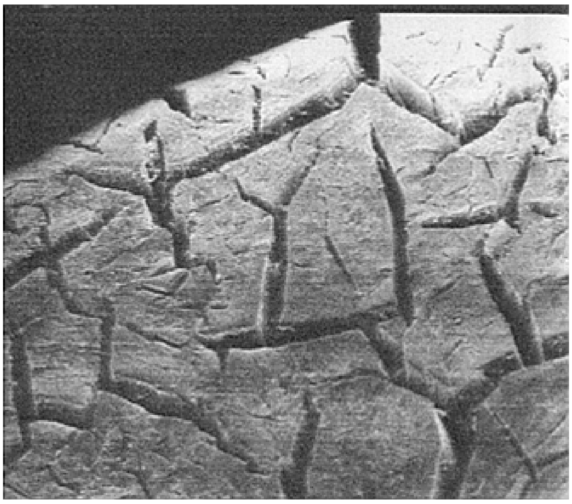


Figure 23 Surface fracture, x 20.

There are many questions that the curator and conservator need to consider taking advice from the conservation scientist to ensure the longevity of these materials.

Some of these questions are, should distorted casein plastic be replaced with new casein plastic? Where can this be sourced? Will the appearance be similar to the lost pieces or can new pieces be artificially aged to replicate similar visual appearance?

Other questions about the physical properties of casein plastic should also be asked, such as, do they off gas or leach the colorants used to dye them when manufactured? How should they be stored and what environments should they be displayed in?

The work done for this project was to focus on distorted casein plastic, which had been identified in a number of pieces of Mackintosh furniture where inlaid panels of casein formaldehyde displays shrinkage due to fluctuations in temperature and relative humidity which have occurred over a long period of time (50+ years). As the material is exposed to fluctuations it causes it to expand and contract. When this process is completed it results in loss of moisture resulting in a reduction in the mass of the CF causing surface fractures as illustrated in figure 23.

Rehydration experimentation

The intention here was to examine the effects of the plasticisation on casein formaldehyde replicated samples to establish a suitable method for the reversal of distorted casein plastic. Hot water (just below boiling point) was used as a plasticising agent. The three-point bend test was then conducted to establish variants within the elastic and plastic limits of the samples. The results were compared between the treated and non-treated samples to establish noticeable variations in the physical properties of the material, observed through Modulus of Rupture (MoR) and Modulus of Elasticity (MoE).[64]

Methodology

12 casein formaldehyde control samples were cut and prepared to 150mm x 10mm x 5mm. These were subjected to the three-point bend test as the parent group to establish a set of control data (cf. figure 24).

The distance between the two horizontal points (the span) supporting the sample was 80 mm in compliance with the British standard for testing wood with this length of sample (150mm). The vertical point, which applied a force at a consistent increasing amount, moved at a constant rate of 6 mm per minute. The points of deflection were set at 2, 3 and 4 mm (PPT1-PPT2+ 1.0 mm & PPT1-PPT3 = 2.0 mm).

Treatment

The replicated samples previously being distorted by 50% were immersed in hot water (95°C) for three minutes, at which point they were flexible and were then placed in a flat former to correct the distortion to 0%. They were secured and left to dry for 72 hours.

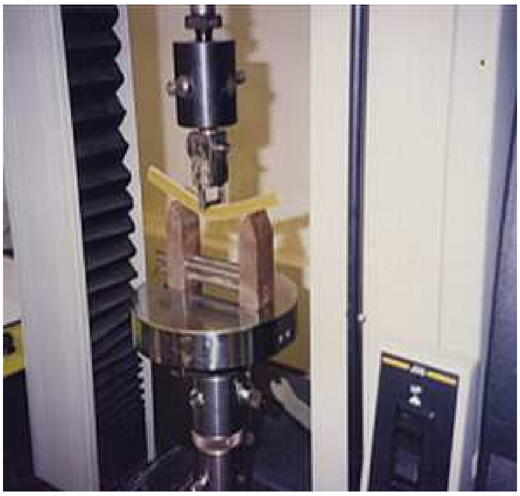


Figure 24 Three-point bend test.

These 12 treated samples were also subjected to the same three-point bend test as the control samples to determine if any changes in MoR or MoE had occurred due to the treatment. During the 3-point bend test the samples broke in a consistent manner displaying firstly failure and secondly a tension break (cf. figure 25).

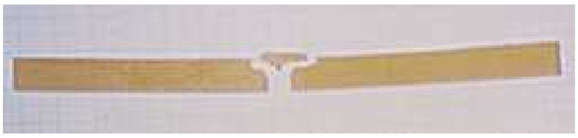


Figure 25 Failure and Tension break of typical sample.

The comparison between the control group and the treated group of samples illustrated significant differences between the control samples and the treated group of samples. The plastic deformation point of the treated group is far higher than the control group mean showing a 29.2% greater modulus of rupture. The modulus of elasticity of the treated group is considerably higher than the control group showing an 81.6% increase.

So what does this mean for conservation of distorted casein formaldehyde?

It is clear that it is possible to treat distorted casein plastic by exploiting the thermoplastic properties of the material. The results of the experimentation illustrate a large increase in Modulus of Elasticity. This may be explained to some degree by the density of the sample. In short, the moisture content has been increased in the treated samples as the plasticiser has not been reduced to the 20% to 35% moisture content as achieved in manufacture. For conservation purposes the 72 hours drying time should be increased in an appropriate environment to reach the required moisture content. Post treatment it is recommended that casein formaldehyde is maintained in an environment above 40% Relative Humidity (RH) and below 55% RH to avoid cracking due to further expansion and contraction followed by shrinkage, which causes cracking (cf. figure 23).[65]

Relative Humidity (RH) experimentation

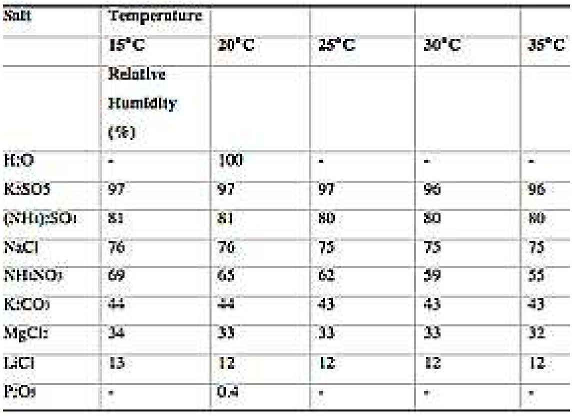
This was conducted to investigate the effects of different relative humidities applied to casein formaldehyde samples in controlled conditions. The experiment provided evidence that some reversal of the physical properties is possible through the control of RH in sealed microclimates. The effects on the samples were measured through weight (mass), dimensional change and hardness.

The aim of the testing was to establish if casein plastic is able to tolerate RH variations for sustained periods to see if irreversible physical damage occurs as a result of this treatment. Possible forms of damage anticipated were chain scission, warping, twisting, expansion, contraction and the loss of colour. Over one hundred samples were used in rod and sheet form. 50% of the samples were newly manufactured material supplied by a sheet manufacturer from Holland [48] whilst the remaining samples were aged from pre 1970.[66]

The samples were measured prior to treatment to record their original mass. Their dimensions were also recorded. Samples were then placed in a variety of salt solutions following the HMSO [67] RH standard guidelines. Eight solutions were used to provide a good range across the RH range with distilled water (H_20) representing 100%.

The solutions for 100% and 0% RH are not included in the HMSO standard (1970). However they were added here to establish maximum and minimum parameters (Cf. Table 1).[68]

Table 1 Measurement of Humidity' recommended salts and humidities (HMSO 1970). The distilled water and phosphorous pentoxide are not included in the HMSO reference.



Salt	Temperature				
	15°C	20°C	25°C	30°C	35°C
	Relative Humidity (%)				
H_2O	-	100	-	-	-
K_2SO_5	97	97	97	96	96
$(NH_4)_2SO_4$	81	81	80	80	80
NaCl	76	76	75	75	75
NH_4NO_3	69	65	62	59	55
K_2CO_3	44	44	43	43	43
$MgCl_2$	34	33	33	33	32
LiCl	13	12	12	12	12
P_2O_5	-	0.4	-	-	-

Each sealed microclimate was placed in a lab [69] that had a stable environment (the temperature was consistent at 20°C and the RH was 50%).

The sealed microclimates were opened after 54 days when each sample was weighed and dimensionally recorded (measured) observing any changes to expansion or contraction. Comparing the sample groups in the 100% and 0% microclimates extreme results were observed showing that the material has the ability to expand and contract considerably. Loss of mass was seen on the 0% RH samples and mass gain was seen on the 100% RH samples. The testing showed that adverse effects occur to casein formaldehyde when subjected to extreme ranges of RH, both in terms of changes to dimension and mass. There were minor differences between new and old casein formaldehyde. In fact the old casein formaldehyde had a higher increase in mass gain than the newly manufactured material. This may have been anticipated as the older material has a slightly reduced moisture content than when first manufactured of about 2% (approx.).[70]

The testing showed that the old casein had an increased mass of approx. 5% which is a significant point for exhibiting casein plastic objects. In the higher end microclimates mould growth was observed. Changes to the material were also observed through hardness testing. The Vickers diamond pyramid system testing was conducted at Brunel University materials labs, where the sample indented by the diamond pyramid centre point at a 1 kg load with a bi-ocular reading, which was converted into DPN (Diamond Pyramid Hardness Number) or HV (Vickers Hardness Pyramid Number). The treated samples were compared to untreated samples. The samples that had been subjected to the 0% microclimate showed a significant increase in hardness. Pre treated it was 21.2 DPN and post treatment was 32.4 DPN.

The sample subjected to the 44% RH microclimate showed minimal change. The sample at 100% RH was soft, being off scale.

So what does this mean for conservation of distorted casein formaldehyde?

Casein formaldehyde should be kept at a stable environment at or above 44% RH and below definitely below 69%RH.

Conclusion

We now know that Casein Formaldehyde was manufactured between 1904 and 1982 in Western Europe both by *Erinoid Ltd.* and *Intern. Galalith Gesellschaft* (amongst others). It continues to be produced for the button manufacture industry by others. The plastic material has a wide nomenclature and these titles were often developed as trade names.

C.R. Mackintosh used it in his designs for furniture commissioned by Bassett-Lowke, the main body of work by Mackintosh outside of Scotland of which some objects are located in public collections.

Casein formaldehyde may be identified through a range of simple and analytical methods available to most conservators in private and public practice.

A stable environment may extend the longevity of historic casein formaldehyde where RH and temperature are controlled. We can control the loss of colour and protect the surface finish by minimising light exposure.

Finally, the treatment of the material, which has become distorted due to dehydration, may be reversed if the correct conservation procedures are observed and implemented.

Appendix

Trade names for CF (abstracted from the Plastics Historical Society (PHS) list, Edwin Sutermeister, *Das Kasein*, Julius Springer Verlag, Berlin 1932, p. 123; Arthur Sommerfeld, *Plastische Massen*, Springer Verlag, Berlin 1934, p. 151; Kurt Brandenburger, *Kunststoff Ratgeber*, Verlag W. Girardet, Essen 1939, p. 23-30; Kurt Thinius, *Analytische Chemie der Plaste*, Springer Verlag, Berlin etc. 1952, p. 47; The Author's and G. Lattermann's list).

Akalith	Akalith Kunsthornwerke A.G., Vienna, Austria.
Alkalit	Alkalit Kunsthornwerke A.G., Vienna, Austria.
Aladdinite	Aladdinite Co. Inc., Orange, NJ, USA.
Algalith	de Charraud, Rueil, France.
Ambloid	Japan
Ameroid	American Plastics Corp., New York, USA.
Argolit	Argo Chemische und Nahrungsmittel-Fabrik, Prerov, Czechoslovakia.
Axolith	Soc. l'Oyonnaxienne, Oyonnax, France.
Beroliet	Emmericher Kunsthornfabrik GmbH, Emmerich, Germany
Bucholith	Johann Buchsteiner, Gingen, Germany
Britmac	CH Parson Ltd., Birmingham, UK.
Carnalithe	Barthelemy
Casélithe	Le Casélith National, France.
Casoide	
Casolithe	Hollandsche Casolithwerken, NL. L.M. Mears & Co., London, UK.
Cassoid	Maison Blanpain, Ezy, France.
Cellulit	Soc. Industrielle du Celluloide, Paris, France.
Celluvert	Soc. Industrielle du Celluloide, Paris, France.
Claudilithe	Etabl. Meinier SARL, St. Claude, France.
Clemateit	
Corlit	Corlit S.A, France
Cornalithe	De Charraud, Rueil, France.
Corozite	Soc. Anon. Prodotti Corozite, Gorlago, Italy.
Decora	
Dobsoid	John Dobson Ltd., Milnthorpe, UK.
Dorcasine	Charles Horner Ltd., UK.
ECA	Bruggemann & Cia., Mexico

Eirelith	
Ergolith	Chemische Fabrik Ergolding AG, Ergolding, Germany; McLeod & McLeod, London, Stroud.
Erinoid	Erinoid Ltd, Stroud, UK.
Esbrilith	Rheinische Kunsthorn und Leimfabrik Esbrilith GmbH, Gernsheim, Germany
Fantasit	Rhein. Westfäl. Sprengstoff AG., Troisdorf, Germany.
Galacromos	
Galakerite	Soc. Ital. Galakerite, Milan, Italy.
Galalith	Intern. Galalith Gesellschaft. IGG, Harburg, Germany.
Galatix	Lumos & Co., London.
Galliperle	Cie. Generale d'Electricite, Paris, France.
Globerite	Soc. Industr.. Globerite, Milan, Italy.
Glorith	Schiel & Co.., Sternberg. Czechoslovakia
Haefelyte	Emil Haefely & Cie. Basel, Switzerland
Hastra	Hastra Kunstharz Presswerk, Vienna, Austria.
Hornit	Gottfried Probst, Nürnberg, Germany.
Inda	Amer. Machine & Foundry Co., Brooklyn, USA.
Idealith	Idealith-Werk Joseph Hermann Bolkart, Nürnberg.
Isogalithe	Garraud, Tailleburg, France.
Ivogalith	
Ivryne	Establiss. Feuillant, France.
Karolith	Karolith Comp., American Plastics Corp., New York, USA.
Kasinoid	AS Kanis, London, UK.
Keralon	
Keronyx	Aberdeen Combworks Co. Ltd, Aberdeen, UK.
Kyloid	Kyloid Co., Muskegon, Michigan, USA.
Lacrinoid	Lacrinoid Products Ltd. London, UK.
Lactilith	Charles C. Fitzroy, London, UK:
Lactite	
Lactoid	British Xylonite Co., London, UK.
Lactoite	France.
Lactolithe	Cie. Générale. d' Electricité, Vitry France.
Lactoloid	Dai Nippon Celluloid Co., Osaka, Japan.
Lactonite	British Lactonite Co., London, UK.
Lactophane	Poyser Advert. Agency, London, UK.
Lactorn	British Xylonite Co. Ltd., London, UK.
Laetelite	
Lithocorn	August Ehlhardt Söhne, Chemische Fabrik Durlach, Durlach, Germany.
Lupinite	
Luxalith	Soc. l'Oyonnxaienne, Oyonnax, France.
Luxolith	Soc. l'Oyonnaxienne, Oyonnax, France.
Mergalthe	Soc. De Charraud, Rueil, France.
Modelith	Celler Preßwerke GmbH, Celle, Germany
Moskalit	Moscow State Chem. Trust, Moscow, USSR.
Neolith	Deutsche Kunsthorn-Gesell.., Troisdorf, Germany.
Osalith	Matthias Öchsler & Sohn, Ansbach, Weißenburg, Germany.
Oxygalalith	France
Oyogalithe	Soc. l'Oyonnaxienne, Oyonnax, France.
Oyonnithe	Soc. Petit Collin-Oyonnithe, Paris, France
Plyafix	Jos. Nathan & Co., London, UK
Plynalith	Isaac Frenkel, Paris, France.
Porcellanite	Soc. De Charraud, Rueil, France.
Primalithe	Cie. de Procedes Plinatus, Paris, France.
Proteolite	Ind. Ital. della Proteolite, Milan, Italy.
Rexalith	Soc. La Rexalith, Paris, France.
Roalit	Kunsthornwerk Karl Schwab, Nürnberg, Germany.
Rondelle	Hannoversche Kunsthornges., Hannover, Germany.
RJR	Afcom Ltd., London, UK.
Satolite	Sankyo Kabushiki Kaisha, Tokyo, Japan
Sicalite	Soc. Nobel Francaise, Soc. Industrielle du Celluloid, Paris, France; Sicaloid Ltd., London, UK.
Sicoid	Soc. Nobel Francaise, Soc. Industrielle du Celluloid, Paris, France; Sicaloid Ltd., London, UK.
Syrolit	Deutsche Syrolit-Fabrik, Arno Breitkopf, Berlin, Germany; Syrolit Ltd., Stroud, UK.
Zoolite	Soc. d'Esportazione Polenghi Lombardi, Codogno, Italy

Picture credits

Fig. 1	Sample card, *Galalith* (Stroud Museum Archive, accession number 1989.105)
Fig. 2	*Erinoid* (Stroud Museum Archive, accession number 1989.105)
Fig. 3	a) Charles Rennie Mackintosh, b) Wenman Joseph Bassett-Lowke (Photo © by T&R Annan, Glasgow and B-L photo courtesy Manx National Heritage Archive)
Fig. 4	Furniture for Northampton made at Knockaloe by German interns (courtesy Hunterian Museum Archive)
Fig. 5	Northampton furniture at Knockaloe camp (courtesy Manx National Heritage Archive)
Fig. 6	Knockaloe camp, Isle of Man (courtesy Manx National Heritage Archive)
Fig. 7	Isle of Man map showing position of Knockaloe (courtesy Manx National Heritage Archive)
Fig. 8	Bassett-Lowke's pass into the camp (dated 1916) (courtesy Manx National Heritage Archive)
Fig. 9	Correspondence between Bassett-Lowke and Mackintosh which mentions *Erinoid* (courtesy Hunterian Museum Archive)
Fig. 10	Mackintosh furniture designs for 'New Ways' in Northampton, *Erinoid* inlays (courtesy Hunterian Museum Archive)
Fig. 11	Brighton Art Gallery and Museum examples showing distorted casein plastic in Mackintosh Furniture (photo - author)
Fig. 12	Last piece of *Erinoid* produced at Lightpill Mill, Stroud (courtesy Stroud Museum Archive, Accession number 2016.27)
Fig. 13	*Erinoid Ltd.* lorry collecting casein powder delivered by air from United Dairies (courtesy Stroud Museum Archive, accession number 2016.9/8)
Fig. 14	Mixing shop at *Erinoid Ltd.* (courtesy Stroud Museum Archive, Accession number 2016.9/4)
Fig. 15	Extrusion of casein formaldehyde (courtesy Stroud Museum Archive, Accession number 2016.9/12)
Fig. 16	Casein formaldehyde rods at *Erinoid Ltd.*, Stroud (Stroud Museum Archive, Accession number 2016.9/6)
Fig. 17	Pressing of casein formaldehyde (courtesy Stroud Museum Archive, accession number 2016.9/11)
Fig. 18	*Erinoid* shade card (courtesy Stroud Museum Archive, Accession number CM.3359)
Fig. 19	*Galalith*, green rods (photo Authors collection)
Fig. 20	*Mibrupo* [48] turtle shell pattern sheet (photo Authors collection)
Fig. 21	*Erinoid* catalogue – back page of *Erinoid the all British Material* 33pp. (courtesy Stroud Museum Archive, Accession number 1973.298/2)
Fig. 22	Probable onset of degradation of casein formaldehyde CF (Conducted at Brunel University)
Fig. 23	Surface fracture x 20 (macro photo - Author)
Fig. 24	Three-point bend test (photo - Author)
Fig. 25	Failure of tension break of typical sample (photo - Author)

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[24] Macro photography and Scanning Electron Microscopy were employed to inspect the surface of the plastic material.

[25] Samples that replicated the existing inlaid casein formaldehyde were constructed using new casein formaldehyde sourced from a casein manufacturer in the Netherlands.

[26] Temperatures above 25°C and Relative Humidity (RH) below 40% or above 65% moisture content put the material at risk.

[27] Recommended maximum light levels for casein plastic is 200 lux for display for a maximum period of 6 months.

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[33] Stroud Museum Archives, Gloucestershire, UK. Accession number 2016.27: Large sheet of brown and cream striped *Erinoid* casein, possibly used as a faux horn or a shell substitute. The sheet is marked across the middle in pen with the following "FOR / THE ATTENTION / OF MR L WYATT / THE / END".

[34] John Morgan, *Centenary,* loc. cit. [10], p.44-50.

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[36] URL: http://www.sigmaaldrich.com/chemistry/stockroom-reagents/learning-center/technical-library/particle-size-conversion.html

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[65] Yvonne Shashoua, *Conservation,* loc. cit.[3], p.195.

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[68] The solutions providing these micro climates were H_20 – 100% RH (Distilled water), K_2SO_4 – 97% RH (Potassium Sulphate), $(NH_4)_2SO_4$ -81% RH (Ammonium Sulphate), NaCl – 76% RH (Sodium Chloride), NH_4NO_3- 69% RH (Ammonium Nitrate), K_2CO_3 – 44% RH (Potassium Carbonate), $MgCl_2$ – 34% RH (Magnesium Chloride), LiCl – 13% RH (Lithium Chloride), P_2O_5 – 0% RH (Phosphorous Pentoxide).

[69] The laboratory was located at Buckinghamshire New University.

[70] The 2% reduction refers to the old samples.