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Article

Glass and Plastics – a Concise Comparison of Two Kinds of Polymeric Materials

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Abstract: The first part of this paper will introduce the material's rating in art history in general.
The second part will present the definition of glass as an inorganic polymeric material, a concise history and its rating as a material for different objects.
The third part will present a concise history and rating of plastics as organic polymeric materials.
Finally both polymer classes will be compared with respect to their material history and significance and ranking.

Keywords: *Art history, design history, glass, inorganic polymers, littering, materiality, material iconography, material history, organic polymers, plastics.*

1. Introduction: general material's rating in art history

Until recently, materiality in general was something like a '*terra incognita*' in the history of art and design.

The philosopher Georg Wilhelm Hegel (1770-1831) stated (translated): *"The distinctive feature of material is that it has no verity, no autonomy versus that what is immaterial"*. To this day, Hegel's philosophical reflections have strongly influenced, amongst others, the philosophy of history and art theory.[1]

On the other hand, the famous architect and art theoretician Gottfried Semper (1803-1879) already wrote in 1869 (translated): *"Style is the congruence of an art phenomenon with the history of its formation … Additional to the tool and the hand, which uses it, there is the treated material, transmuted into a form. The substantial matter exists first, which should be reflected by the appearance of an art work"*.[2]

These two different positions are still in discussion.

Rüdiger Joppien, a renowned art historian and curator at the Museum für Kunst und Gewerbe (Museum of Applied Arts) in Hamburg stated in 2002 in his article in "New Materials in Artisan Handicraft and Design" (translated): "*It is not necessary to specially emphasise , that in museums of applied arts 'material' has now been neglected for more than 100 years. ...So, it remains for us to wait and see if something will change this attitude in the next years*".[3]

Thomas Raff, professor for art history at Augsburg University with special emphasis on materials iconology wrote in 2008 in his book "The Language of Materials" (translated): "*Until now, art historians astonishingly seldom ask questions with respect to… the ‚iconology of materials'. Apparently, this discipline, traditionally oriented towards the analysis of form and history of style, regarded the reflection on materials of art works as a minor, if not unworthy task*".[4]

And Gert Selle, professor emer. of theory, didactics and aesthetic education at Oldenburg University and doyen of design historiography in Germany wrote in 2007 in his well-known book "History of Design in Germany" (translated): *"Material was and is a fundament of conceptual design and the production of objects."... „One could write a design history, only related to the use of materials".*[5] Apparently, the last sentence means that until that time nobody had ever written a design history with respect to specific materials.

On the other hand, pioneering work was achieved in art history in 2001 by Monika Wagner, professor emer. for art history at Hamburg University in her books, e.g. "The Material in Art - Another History of Modernism" (translated).[6, 7] She wrote (translated): *"Materials belong to the neglected domains in art history.... In art history - as in the humanities in general – material has only a minor ranking. ...Accordingly, the hierarchy of arts was orienting on the overcoming of material, valued as raw, unsightly, natural or even female - in any case low in rank".*[8]

In the context of an apparently rare reception of materials history and iconography, the significance and acceptance of two special groups of materials, i.e. glass and plastics are compared in this paper.

They are much more closely related than public opinion commonly realises. By means of the history of both kinds of inorganic and organic polymeric materials, the intention is to show that materials iconography is astonishingly dependant on outer factors like e.g. the period of invention, method of processing and use in social groups. And that - even when some of those factors are changing – a positive or negative rating once gained is highly persistent over a long time.

2. Glass: definition as an inorganic polymeric material

The basic component of glass is silica (silicon dioxide, SiO_2). It is formed by a natural or synthetic chemical reaction via poly(silicic acid) (cf. Figure 1).[9,10]

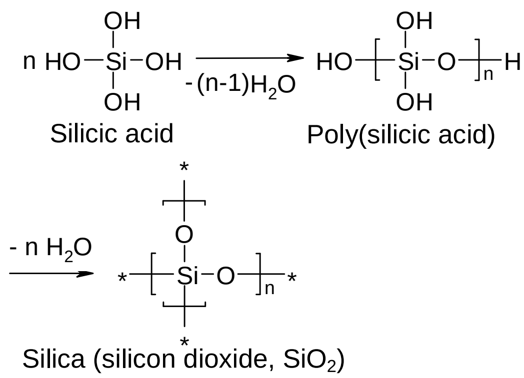


Figure 1 Natural or synthetic chemical formation of silica.

As a result, infinite, three-dimensionally crosslinked SiO_2 polymeric chains are formed via real chemical i.e. covalent bonding. Silica is one of the numerous inorganic polymers which on their part may exhibit many different atoms bound covalently in the main chains (phosphor, sulphur, boron etc. (cf. Figure 2).[11]

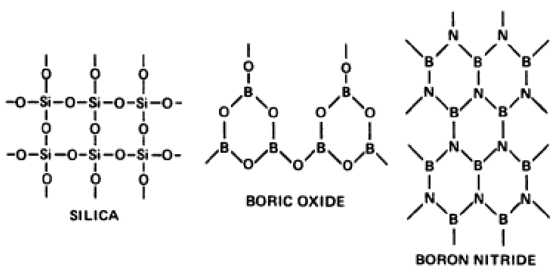


Figure 2 Inorganic polymer networks with different, covalently bound atoms.[12]

Pure, anhydrous silicon dioxide can exist in different crystalline morphologies, e.g. '*α-quartz'* (rock crystal) (cf. Figure 3) or '*crystobalite*' etc., in every case with a 3d-regular crosslinked, i.e. crystal network structure (cf. Figure 4a,c).

Figure 3 '*α-Quartz'* (rock crystal).[13]

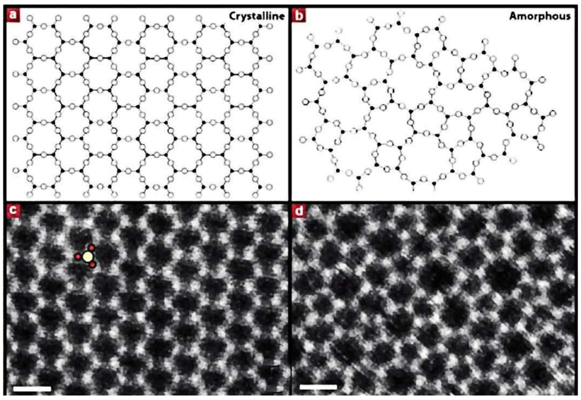


Figure 4 Crystalline and amorphous structures of SiO_2. a) Crystalline Quartz. b) Amorphous glass. c,d) Relevant electron microscopical pictures.[14]

If a silica melt has rapidly cooled down it can form a 'supercooled liquid", which in its solid, i.e. glassy state exhibits an irregular, amorphous network, [15] as shown in Figure 4b,d)

Natural SiO_2 silica glasses are known as rapidly cooled down lava under the name of '*obsidian*' (70-80 % silica, softening, i.e. glass transition temperature T_g ~1000 °C) [16, 17] (cf. Figure 5), '*lechatelierite*' from melting of quartz by meteorite impacts ('*tektite*', e.g. *'moldavite'*, which originates from the Nördlinger Ries impact 14.7 million years before present (mio BP) [18] (cf. Figure 6) or by lightning strikes, e.g. '*fulgurite*' [19] (cf. Figure 7).

Figure 5 *Obsidian.*[20]

Figure 6 *Moldavite*.[13]

Figure 7 *Fulgurite*.[21]

Most of the prior known glasses are silicate based. Silicates are simply spoken salts of poly(silicic acid), obtained by its reaction with different components, e.g. with soda (cf. Figure 8). Fully reacted sodium silicates, e.g. ‘waterglass’ (‘liquid glass’), are water-soluble.

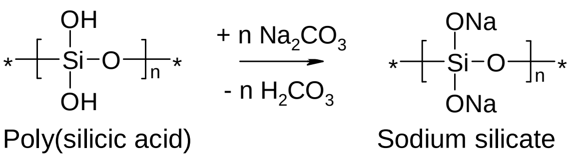


Figure 8 Formation of water soluble sodium silicate.

Multivalent salt components like e.g. calcium or aluminium ions, form insoluble products. With a lower salt content, a no longer regular and crystalline, but irregular, amorphous network is favoured again (cf. Figure 9).

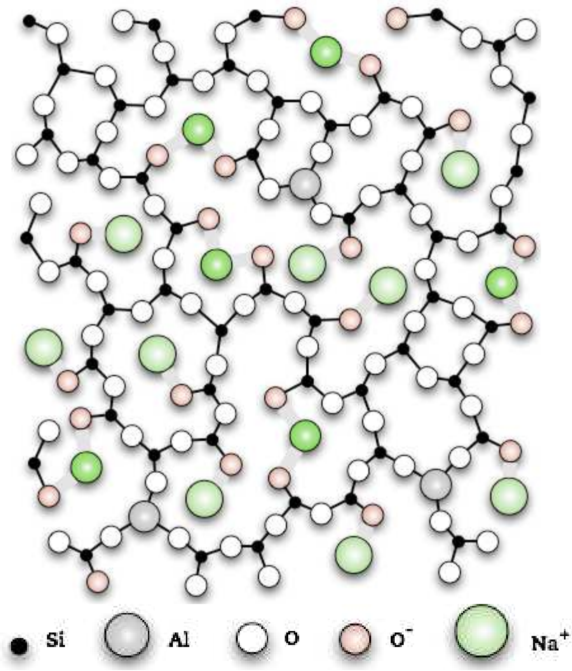


Figure 9 Irregular network structure of glasses with multivalent ionic components.[13]

The most wide-spread group of what we commonly call glass are the so-called ‘soda-lime glasses’. Here, the melting temperature of the highest crystalline pure SiO_2-modification ‘*crystobalite*’ is lowered by an incorporation of sodium and calcium ions from 1710 °C to a softening of the amorphous, glassy state at the glass transition temperature T_g ~700 °C by a content of 22% soda and ~5% calcium oxide,[22] which enables its easy processability since ancient times.

3. Glass: early history; a luxury material

It is assumed that in the beginning glassy substances were discovered by chance rather than being manufactured. Glassy material could be formed by an association of a silica-rich material with an alkaline plant ash (potash) and would even be formed when sandy grassland or a wheat field was on fire. The relatively high temperatures of the glass forming process (~1400 °C) could also be achieved in the context of metal production, when the silica in crucibles or in furnace walls fused with alkaline plant ashes in the environment, which may be present when burnt wood is used as a fuel. [23] Copper production began between 7000 - 6000 BC in Anatolia [24]. But it needed more than 3000 years before the first man made production of glass was localized in Mesoptamia at ~3500 BC, found as siliceous glazed stones and ceramics (Ubaid period) [25] and later on as glass beads.[26] In Egypt, artefacts made from glass beads appeared in the 6^{th} Dynasty at ~2300 - 2200 BC [27] (cf. Figure 10).

Figure 10 Collar, glazed beads (faience), Egypt, 7^{th}-11^{th} Dynasty, ~2200 - 2000 BC.[28]

So, the first vitreous materials were thin glazed coatings. In ceramics it is called '*faience*', later on '*enamel*' on metal.[29]

Glass vessels were first produced in quantity in Egypt in the New Kingdom, presumably introduced from Syria by the successful campaign of Thutmose III (1486 - 1425 BC). Two such early vessels are inscribed with the name of the pharaoh [30,31] (cf. Figure 11a,b).

a b

Figure 11 Glass ware for Thutmose III (1486 - 1425 BC). a) Blue glass jug.[30,32] b) Glass goblet.[13]

Apparently, it was a privilege of the pharaoh's court to possess the first precious objects made by the new technique of forming glass vessels by the sandy core method.

Glass in earlier periods was an expensive commodity, used for producing luxury items owned by the royalty and the elite,[33] (as it was much later on with the Meissen porcelain at the court of Saxony).

Nearly two thousand years later, there are examples of a then extremely developed glass artisanry, which was able to produce precious luxury goods for the upper strata of Roman society in the late imperial period: the famous roman cage cups, the *diatretum* glasses (cf. Figure 12).[34,35]

Figure 12 Cage cup, *diatretum*, Roman, ca. AD 350.[13]

During all the following European periods, luxury glasses have been continuously produced for a highly ranked clientele in different countries. Some examples from Frankish to baroque times are shown in Figure 13 and 14.

a b

Figure 13 a) Frankish claw beaker, ca. AD 600.[36] b) Goblet for the Hungarian King Matthias Corvinus, Breslau, ca. 1480.[37]

a

b

Figure 14 a) Goblet, Nuremberg, ca. 1600.[38] b) Goblet, for King Charles XI, Stockholm, ca. 1690.[37]

4. Glass: a material for imitation or 'ersatz'

Beside the characteristics of a very early production and its long-standing use as a rare luxury good, it is interesting to discuss another aspect of glass. Glass was predominantly decorative rather than utilitarian and appeared to have also been strongly associated with semi-precious stones in the mind of early users.[39] Mesopotamian cuneiform recipes describe deep blue glass as artificial lapis lazuli, pale blue grades were compared with turquoise, and purple glass with fluorite. In Egypt, glass-workers imitated emerald, jasper, lapis lazuli and carnelian to such perfection that sometimes it is not easy to distinguish at first glance the real stone from the false.[40]

After having been imported earlier from the Roman Empire, glass was produced for the first time in China itself since the Sung-Dynasty (AD 424 - 454). During that period, bowls and wine cups were made of colourless glass, imitating precious natural rock crystal. Furthermore small carved objects of jade, agate and other semi-precious stones were copied by the new, cheaper material, appropriately tinted.[41]

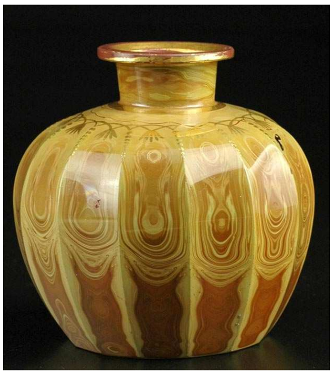
In modern times, i. e. at the beginning of the 19th century, imitation of precious stones by glass mass became quite popular and was highly estimated.

Inspired by the success of Wedgewood's black basalt ware (~1760), the Bohemian Count Georg Franz August Bouquoy experimented from 1816 onward with black, lustrous '*Hyalith*' glasses, imitating black onyx. In 1820, he obtained the privilege for production (cf. Figure 15). Later on he also produced red and marbled *'Hyalith'* glass objects.[42]

Figure 15 '*Hyalith*' beaker.[43]

Around the same time, the Bohemian glass maker Friedrich Egermann produced similar looking glass vessels, which likewise imitate precious stones like agate, but now by staining the surface of ground glass. In this manner he produced his '*Lithyalin*' glasses from around 1828 onward (cf. Figure 16).

a



b

Figure 16 a) *'Lithyalin'* beaker.[44] b) '*Lithyalin'* vase.[45]

5. Glass: a mass production material

First glass pressing techniques date from the Hellenistic period (3rd – 2nd century BC) to Roman times.[34,35] More or less parallel they were developed by the Chinese Western Han dynasty between 180 – 157 B.C.[46] Only at the end of the 19th century, compression moulding of glass became a manufacturing process. Hobb, Brockunier Co., USA, as the largest pressed glass manufacturer in the world created a huge export market, because pressed glass was substantially cheaper than glass grinding [47] (cf. Figure 17

Figure 17 Compression moulded glass (ca. 1880 - 1900).[13]

As an imitation of cut glass, these mass products did not have the best reputation in applied art and design. This definitely changed when from 1935 onward one of the most influential German designers - Wilhelm Wagenfeld, educated at the Bauhaus – was commissioned to create a new design for the entire production of the glass factory Vereinigte Lausitzer Glaswerke AG VLG. From that time on, mass produced glassware obtained an early industrial design (cf. Figure 18).

Figure 18 Vases, pressed (middle, right), Wilhelm Wagenfeld for VLG, 1935 - 1939.[48]

However, the beginning of industrial design in modern mass production took place earlier and indeed arose with the production of plastics (see below).

The glass blowing technique was introduced somewhat earlier than glass pressing, i.e. in Syria between 300 and 20 BC. [49] In recent times, this method was developed for industrial mass production too (cf. Figure 19).

Figure 19 Industrial glass blowing.[50]

6. Glass: a material with toxic additives

Until today glass is widely regarded as a suitable, food-grade material. Michael Erlhoff, professor at Cologne International School of Design stated in 2006 (translated): *“I only trust glass to be suitable for it. I don’t have this confidence in plastics”*.[51]

However, glass can contain toxic compounds from early time onward.

Yellowish, pale-green glass *tesserae* from a mosaic in the roman imperial villa of Cap Posilipo was dated to 79 BC and analyzed to contain 1,5% uranium oxide. [52] Unknown during medieval times, uranyl glass was produced again from around 1830 by Bohemian glass factories and later on since the end of the 19th century in the whole of Europe and the USA, where it is known since 1937 as “Vaseline” glass” [52] (cf. Figure 20a). Its radioactivity (α- and β-radiation, detectable with a Geiger-Mueller counter) is responsible for the prohibition of uranium colouring in Germany.

a

b

Figure 20 a) Uranyl glass.[53] b) Lead crystal, G. Ravenscroft, 1673/74.[54]

From 1673/74 onward, the English glassmaker George Ravenscroft invented, developed and produced lead crystal glass with a lead oxide PBO content of ~15% [55] (cf. Figure 20b). Newer tableware contained up to ~40 % of PBO.[56] Because the production is hazardous especially with respect to the workers and the environment, lead-free alternatives have in the mean time been searched for.[57]

Since ca. 2009, the glass company Schott AG offers "environmentally-friendly" glasses like lead free optical fibres "*Puravis*" or arsenic and antimony-free "*Eco*" thin glass (cf. Figure 21). [58] This means that these components were present before.

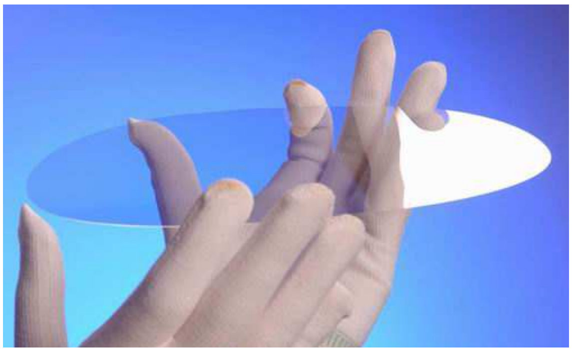


Figure 21 "*Eco*" thin glass, arsenic and antimony-free, 2009.[59]

7. Glass: littering

Finally it should be mentioned that of course it cannot be avoided that glass is littered and thus pollutes the environment (cf. Figure 22).

Figure 22 Glass littering during carnival 2015.[60]

8. Glass: summary

In summary:

- Glass was produced very early on, which resulted in its use as a precious luxury good for the nobility and elites.
- Glass was used early on for the imitation of other more expensive materials like semi-precious stones.
- Glass was mass produced by compression and blow moulding techniques.
- Glass can contain toxic products to a large extent.

- Glass, when littered pollutes the environment.

Let us now consider similar developments with plastics. It is more or less common knowledge that plastics are organic polymeric materials which consist of linear, branched or crosslinked macromolecular chains with covalent C-C bonds. Many further additives contribute to their role as plastics which are ubiquitous in our daily life.

9. Plastics: some examples of the history of organic polymeric material

It is almost unknown that plastics, e.g. polystyrene, likewise have an age-old history. Fossil polystyrene was already formed by nature as a biopolymeric material in the Eocene, 55-35 mio BP. Pieces of '*Siegburgit*' can be found in the open cast mining at Siegburg or Goitsche/Bitterfeld, Germany (cf. Figure 23a). The soluble fraction consists of 80 % polystyrene, the non-soluble fraction was also shown to be polystyrene, crosslinked via different side groups.[61]

Another fossil biopolymer is "Affenhaar" ('ape hair'), a fossil rubber/caoutchouc, which also ranks among the oldest known polymeric materials with respect to its period of formation, the Eocene 55-35 mio BP (cf. Figure 23b). It was found in older brown coal layers in Central Germany. Numerous and exact analysis identified its rubber structure. The filaments were formed by crosslinking, i.e. hardening reactions of the polyisoprene latex content of vascular threads of fossil rubber trees.[61]

The use of biopolymers as basic material used by mankind is not much younger than any other matter like stone, ceramics, metal or just glass.

Beside the very early use of e.g. birchbark pitch (220,000 BC), bitumen (ca. 70,000 BC, or amber (12,000-10,000 BC),[61] one of the first kinds of materials

a

b

Figure 23 a) '*Siegburgit*', fossil polystyrene, Eocene, 55-35 mio BP.[62] b)*"Affenhaar"*, fossil 'vulcanised' rubber on brown coal sheets, Eocene, 55-35 mio BP.[63]

used until today is natural rubber. For the pre-Columbian 'La-Venta' civilisation (Olmecs, from ~1600 BC) as well as for the Mayas and Aztecs later on, rubber 'technology' played an important role for over 3000 years (cf. Figure 24).[61]

Figure 24 Solid rubber ball, Olmec, 'La-Venta' civilisation, ca. 1600 BC.[64]

In Europe, the first semi-synthetic plastics, i.e. the rubber, gained industrial importance after the discovery of 'vulcanization' with sulphur by Charles Goodyear (1800-1860) since 1839 and his patents from 1843/44. The raw material came from plantations in South America, South-East Asia and Africa (cf. Figure 25.)

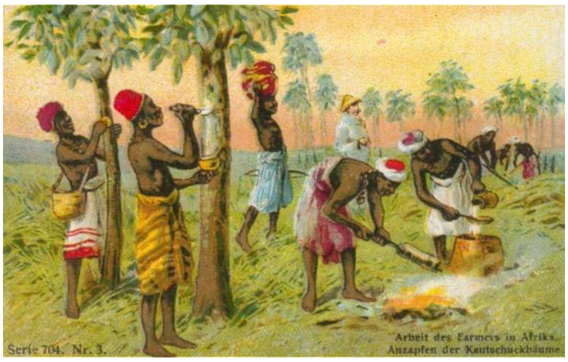
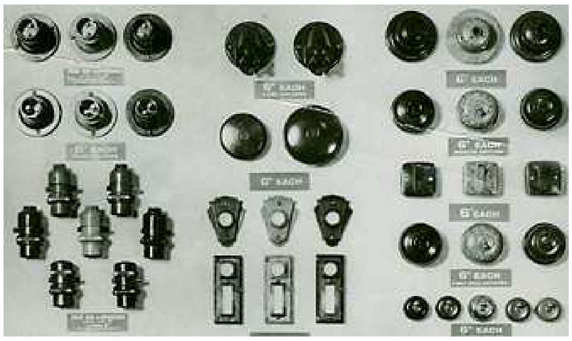


Figure 25 Work on an African rubber plantation.[65]

The first fully synthetic plastic, enabling mass production, was the phenolic resin '*Bakelite*®', its manufacture claimed in 1907 by Leo H. Baekeland (1863-1944) with his 'heat-pressure patent'. This "*material for a thousand uses*" was not at all a simple surrogate or substitute for other, older materials, but played, amongst other things a new and fundamental role in the development of the electrical industry, where it was used as an innovative insulation material (cf. Figure 26a).

The new thermosets began to take over the role of conventional materials like metal, ceramics or wood. Thus, the first desk lamp entirely made of phenolic resin was designed in 1929 by Christian Dell (1993-1974), a former metal workshop master at the Bauhaus (cf. Figure 26b). Later on he was to become one of the most successful pioneers of lamp design.[66,67]

A further design icon is the tea service made of urea resin, designed by Christian Dell, where he developed for the first time the principle of interleaving stacking of objects. It was possible to stack six cups, saucers, the milk jug and the sugar bowl (cf. Figure 27a,b) in Dell's "*Wunderkanne*" ("magic coffee pot"). [66-69]



a

b

Figure 26 a) Electrical equipment, made of phenolic resin.[70] b) Phenolic resin desk lamp, design Christian Dell, 1929.[71]

a

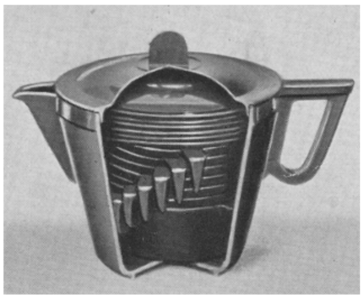


Figure 27 a) "*Wunderkanne*", Resopal, design Christian Dell, ca. 1935.[72]
b) "*Wunderkanne*", design Christian Dell.[73]

Two of the first radio cabinets made entirely of compression moulded phenolic resin were the “Geadux 112” of the AEG Company (cf. Figure 28a) and the so-called “Volksempfänger VE 301”, both designed in 1932 by Walter Maria Kersting (1889-1970) (cf. Figure 28b). [67,75]

Christian Dell and Walter Maria Kersting belong with others to the group of “forgotten pioneers” of plastics and industrial design in Germany between 1929 and 1932.[66]

a

b

Figure 28 a) Radio Geadux 112, AEG, Design Walter Maria Kersting, 1932.[62] b) Radio “Volksempfänger”, Design Walter Maria Kersting, 1932.[62]

10. Plastics: mass production, toxic additives, littering

The invention and use of synthetic plastics fell together with industrialisation and mass production.

This made the new products cheap, numerous, always available. Though good design was involved already at an early stage, many disposable, throw-away products have not been ‘good in form’.

As with glass, a lot of toxic products have been added to plastics, such as toxic monomers, plasticisers, dyes etc. However, once realised and identified, they have been avoided and banned, at least in countries with an environmental consciousness.

Toxic products and littering cause tremendous environmental problems. We have heard of the Great Pacific garbage patch, also described as the Pacific trash vortex. [76] However, this seems not to be a problem of materiality but that of human attitude and awareness of environmental protection.

11. Plastics: rating

In summary:

- Natural plastics have been in existence for a very long time. Their use is as old or even older than other material like ceramics, metal, or glass.
- Semisynthetic or synthetic plastics were produced very late in history, which resulted in their partial use as cheap and simple daily products. On the other hand, very specialised high-tech properties can be achieved only with plastics. With them, the modern way of life e.g. in medicine, sport, traffic and a lot of technical applications became possible.
- Initially, plastics could partially be used for imitation and ‘ersatz’, but new properties enabled very early industrial innovations.
- Plastics are mass produced by numerous different techniques.
- Plastics can cause environmental problems when containing toxic products or littered.

With respect to plastics, most of these factors lead to special sentiments and prejudices

Henry van de Velde (1863-1957), architect and early interior designer, already wrote in 1902 (translated): *"As soon as a new material was found or discovered, people asked instantly which of the already existing materials could be imitated by the new ones: ....Celluloid, Linoleum etc. ... one would ask on the contrary, if the already existing forms could not be enriched by not yet exiting ones... The material chosen for imitation is a priori not ugly, each contains the traces of beauty in itself"*,[77] a lot of opposing statements are more typical of the time.

In an exhibition catalogue of the State Museum Stuttgart from 1909 with the title (translated) "Taste aberrations in Applied Arts", *Celluloid* and *Galalith* are labelled as materials, which *"irritate"* the spectator. They are included in the special catalogue category *"Materials error"*, sub chapter *"Material surrogates"*.[78]

And the famous French philosopher Roland Barthes still wrote in 1957 (translated): *"Despite its Greek shepherd names (polystyrene, phenoplastics, polyvinyl, polyethylene, the plastic is ...essentially an alchemistic matter. ...Plastics keep a flocculent appearance, something opaque, creamy and curdled, something powerless ever to achieve the triumphant smoothness of Nature. ... Plastic is barely a matter but more the idea of its endless transformation. ...ceaseless, the matter presents itself to the spirit as a picture puzzle"*.[79] These statements have influenced legions of contemporaries with their 'angst', ignorance and lack of understanding of scientific facts up until today.

So it is not especially remarkable that some years ago, grounds for a judgement of the District Court at Munich were published as follows: *"Plastic windows may have numerous advantages, especially with respect to maintenance and service – wood has the advantage not to be plastic".*

12. Plastics: comparison with glass

The comparison of both polymeric kinds of material - glass and plastics - shows indeed that in principle only few differences exist. Beside the length of the period of use by mankind, the mechanical and solubility behaviour, there are characteristic temperature ranges. Glass as an amorphous inorganic polymeric material has high transition temperatures: at 700 - 1000 °C. Common thermosets are thermally stable up to ~140 °C. Common amorphous thermoplastics like polystyrene exhibit glass transition temperatures at T_g ~100 °C, polyethylene crystallites have a melting temperature T_m = up to ~135 °C.[80] Only organic high temperature polymer mixtures with e.g. polybenzimidazoles, exhibiting glass transition temperatures of ~430 °C and melting temperatures of 760 °C, gradually approach their inorganic relatives.[81]

With respect to material history, glass had a sufficient length of time to find its way as a highly innovative material, made by artisans as precious, luxury goods for the aristocracy and the upper class, similar to the much younger European porcelain. Only since the beginning of the 20th century have glass objects been produced as machine-made mass products.

Imitation played a role in both material classes.

Environmental problems were found likewise with glass materials, as later on with some toxic additives in plastics from different countries and with plastics littering. Nevertheless, the materiality of glass did not lose in principle its time-honoured, original value and reputation in applied arts and society.

Plastics as the youngest, innovative material group could not benefit from a comparatively long production and usage time. There was no chance to "ennoble" it very early on by the arts and crafts. The development and time of production of the first examples coincide in Europe directly with the Industrial Age and its mass production. From the beginning, this situation created the image of a cheap and inferior bulk material and objects made from it. The terms substitutes, surrogates and imitations, i.e. 'ersatz' played a strongly overemphasised role.[82] Beside an indifference with respect to industrial developments, herein are also reflected to a considerable extent the objection, suspiciousness and fear towards a new material, which, on a popular level, linger on until today. If we wanted, we could say that plastics are subjected to the "disgrace of a late birth". [83]

Though polymeric materials are now present in all areas of life, the assessments mentioned are still alive and influential in popular opinion. Only products of high-tech polymers and composites in sport, traffic and medicine, as well as special functional materials like e.g. light emitting polymers or new biopolymers have begun to change public opinion.

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