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Selected bending properties of mineral-acrylic solid surface material for furniture construction purposes

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Abstract: *Selected bending properties of mineral-acrylic solid surface material for furniture construction purposes*. The aim of this work was to characterize the bending properties of selected, commercially available panels made with the use of mineral acrylic fillers and thermoplastic matrix (trade names Corian and Staron), with regard to thermal forming. The research showed that when the temperature of the tested materials rises from 20 to 160°C, there is a significant reduction in the value of bending strength (by over 90% for Corian and about 80% for Staron) and the modulus of elasticity (by almost 99% for Corian and by 97% for Staron), which should definitely improve the thermoformability of these materials. Among the two tested materials, Staron is a material that is more susceptible to shape modification at elevated temperatures.

Keywords: mineral-acrylic material, bending, temperature, furniture

INTRODUCTION

In line with the prevailing trends, also furniture construction industry attempts to produce and use materials with the highest possible mechanical strength and high resistance to damage. Most often, there are needs to apply such materials for public use. Additional advantages of such materials is the possibility of recycling. At the end of the twentieth century, a mineral acrylic material was created to meet the above requirements, but currently the same structure is sold under different names. Despite a great similarity, there is a discrepancy between individual materials, which translates into their mechanical and physical properties.

Du Pont™ Corian is a high-tech modern solid surface. It is an alternative to traditional surface materials, used in many utility rooms. One of the main features of this material is its high durability. The life cycle of Corian is long and it rarely needs changing, which means extraordinary cost efficiency and less waste. Corian material can also be easily restored to its original appearance. Another advantage is its non-toxicity; DuPont Corian is chemically inert and non-toxic. At typical household temperatures, it does not emit any gases, because it consists of 1/3 polimethyl methacrylate (PMMA) and 2/3 of natural minerals. During combustion, it releases mainly carbon oxides, which form smoke that is optically light and does not contain toxic halogenated gases. Based on their research, Jackson *et al*. (1990) determined the density of Corian – about 1800 kg/m^3, chemical composition which consists of Al_2O_3 ($3H_2O$) and PMMA, particle size – 20 µm and has been determined Young's modulus – 10 000 MPa. Flexural strength was also tested and amounted to 60 MPa. Examples of Corian's applications can be found practically everywhere; for example, it is used in cash desks, food service solutions, display systems, information hubs and decorative wall cladding (Andriievska and Marchuk 2017).

According to Taurino *et al*. (2013), materials with properties identical to Corian's can be found on the market under different names. An example can be Staron, produced by Samsung. Staron board (solid surface) is a mineral-acrylic plastic used by designers also in the furniture industry. A Staron board is made in 2/3 of mineral filler and in 1/3 of acrylate. Staron is a material which keep all of its original characteristics for very long time of use, so even after many years of use it looks satisfactory. Staron boards are available in the richest and most advanced colour range The solid surface mass may feature various embedded decorative features. Staron is used in the furnishing of hotels, in reception halls and lounges and in hospitals, pharmacies and clinics. In the houses, it can be found in kitchen and bathroom counters. The manufacturer assures about many of its advantages, such as its total resistance to discolouration, uniform structure throughout the entire volume, ease in machining, use with all joinery techniques, e.g. sawing, grinding, planing, etc., that it is very easy to clean, and resistant to stains and many chemical agents, and that it assumes the ambient temperature. It can be used in many processes, including cementing, cutting, sawing, grinding, heat forming, milling and due to the ease of cutting and milling, the material can be overworked with tools for hardwood processing (https://tuplex.rs).

Kerrock is also a solid surface material, and, similar to Corian, it is composed of PMMA (40%) and of alumina trihydrate (ATH) (60%) with silane, which was confirmed by Vovk *et al*. (2017). The authors compared Kerrock with wood with regard to processing methods. Kerrock is thermoplastic, so it's easy to mold it under the influence of temperature. The authors mentioned the wide range of Kerrock applications, among others, for work surfaces and cladding. According to the manufacturer, Kerrock can be used in the production of kitchen equipment, bathrooms, in hotels as well as boats or other business premises. Often, sinks, bathtubs, shower trays and sinks are made of it (http://www.kerrock.pl/intro). This material is also renewable, but this process is very expensive.

A widely-used, durable, layered material used in furniture upholstery, and even as structural material, is high-pressure laminate (HPL). On the HPL manufacturer's website, is available a lot of information about the uses of this composite. HPL boards for external applications are duroplastic, high pressure laminates in accordance with EN 438, produced in laminate presses under high pressure and temperature. Hardened polyurethane-acrylic resins form a highly resistant surface layer on both sides, protecting against external influences and allowing the use of panels as permanent elements of balcony railings and facade cladding. Thanks to their properties, HPL boards for indoor applications are widely used in the interior design and the furniture industries. They are used for the production of office, hotel, shop and laboratory equipment, kitchen furniture, hospital beds and pool cabinets (https://tuplex.pl). A research by Jivkov and Elenska-Valchanova (2020) , showed that HPL laminated MDF boards have better mechanical properties, compare to boards without laminate. Thanks to their relatively low cost and low thickness, they can be used in thin furniture constructions. MDF laminated with HPL has much better strength properties at a relatively low thickness and price. Acrylic-based solid surface materials also show satisfactory mechanical properties at low thickness. In another publication (Philbin and Gordon 2005), the chemical composition of HPL was determined by ashing procedure. Scientists have concluded that HPL consists of 1% mineral, 6.7% moisture, and 92.3% organic material. During HPL machining, abrasive blade destruction is less common. Due to the high hardness of the material, catastrophic blade damage can be seen most often. HPL belongs to the same group of materials as Kerrock or Corian, so their processing can give similar effects. Compared to other materials for surface finishing, HPL seems to be very favourably due to its high scratch resistance (Nemli 2005).

Due to a lack of research in the field of mineral acrylic materials applied in furniture construction and a lack of current knowledge, the aim of this work was to characterize the bending properties of selected, commercially available panels made with the use of mineral acrylic fillers and thermoplastic matrix, with regard to thermal forming.

MATERIALS AND METHODS

Tested materials

The tested materials were acquired from the Polish market, in the form of 6 and 12 mm-thick boards, Corian and Staron, respectively. The density of Corian was 1710 kg/m^3, whereas Staron density was 1755 kg/m^3. These have been cut into nominal width of 14 and 16 mm, Corian and Staron, respectively.

All the tested samples were conditioned prior to testing in a heating chamber at the following temperatures: 20, 50, 100, 120, 140 and 160°C. The conditioning time was not less than 3 hours. The maximum applied temperature was in line with tested materials producers' recommendation when thermoforming these.

Modulus of rupture and modulus of elasticity testing

The modulus of rupture (MOR) and the modulus of elasticity (MOE) of the produced samples were measured using a computer-controlled, standard universal testing machine; the samples were loaded by three point bending to be broken within 60±30 s, and strain, MOR and MOE [N/mm^2] were registered and/or calculated in accordance with EN 310:1993. The bending tests were completed on 12 samples at the aforementioned 6 different temperatures. The constant span of the supports was 80 mm. During bending, the tested samples' ambient temperature was assumed as the test temperature. The samples were brought to the test temperature using a blow heater. Since the difference between the density of both tested materials was less than 3%, no influence of the density on the achieved results has been analysed.

Statistical assessment

The achieved results of all the tested features were evaluated statistically by applying Fisher's exact test with a probability level p=0.05, to establish whether the achieved average values are statistically different. Where applicable, the mean values of the investigated features and the standard deviation, indicated as error bars, have been presented on the plots as error bars.

RESULTS

The results of modulus of rupture and modulus of elasticity testing of Corian samples are presented in Figure 1. In comparison, the same tested properties for Staron are presented on Figure 2. The highest MOE value – 9374 N/mm^2 – was found for Corian. This value is comparable to the literature data (Braileanu 2017). As it is shown, in case of MOE, the established values for room temperature are about 227% higher for Corian. This value decreased with a temperature increase, and the highest differences between the tested materials (5119 and 1010 N/mm^2, Corian and Staron, respectively), are under a temperature of 100°C, i.e. about 407% difference. When analyzing the MOE values of the tested materials in the entire test temperature range, it can be concluded that in case of Corian the most significant decrease with temperature raise can be found between 100 and 120°C, where the MOE reduction is by about 40% with regard to the initial (room temperature) MOE value. This gives the MOE reduction ratio (MOE decrease in regard to temperature change) of about 2.01%/°C. In case of Staron, the most significant MOE decrease (almost 20%) was found between 120 and 140°C, where the reduction ratio was 0.98%/°C. It is worth adding that the

Staron MOE reduction in the tested temperature range was almost linear. When 160°C temperature was reached, 1.5% and 3% of the initial MOE was stored for Corian and Staron, respectively.

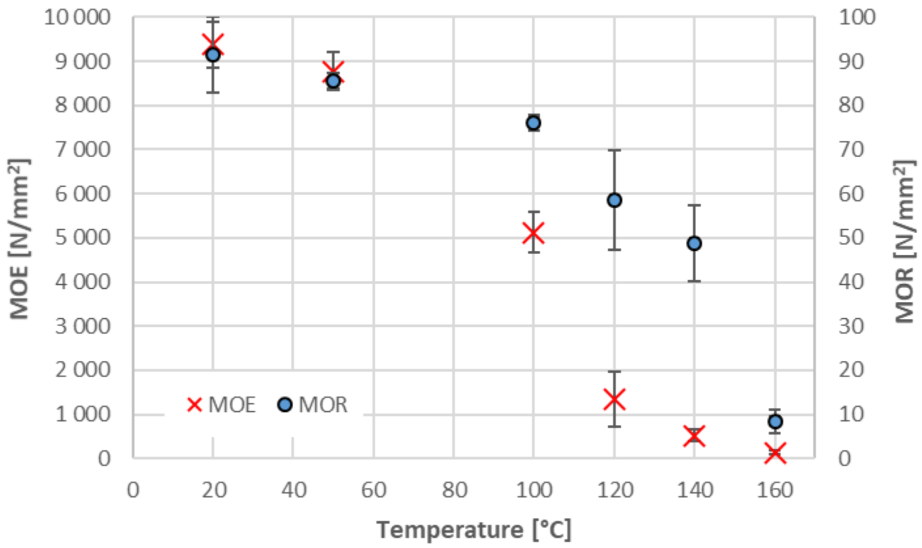

Figure 1. Corian modulus of elasticity and modulus of rupture at various temperatures

When comparing the MOE values at a room temperature with the requirements of selected wood-based composites for furniture production, it can be observed that the values reached for Corian and Staron are significantly higher than for wood-based composites. For instance, the minimum required MOE value for P2 13–20 mm thick particleboards (according to EN 312:2010 standard) is 1600 N/mm^2, and for 12–19 mm thick MDF – 2200 N/mm^2 (according to EN 622-5:2006 standard). When analyzing the statistically significant differences between the achieved MOE results for Corian, it can be noticed that there is no difference between MOE values for 20 and 50°C.

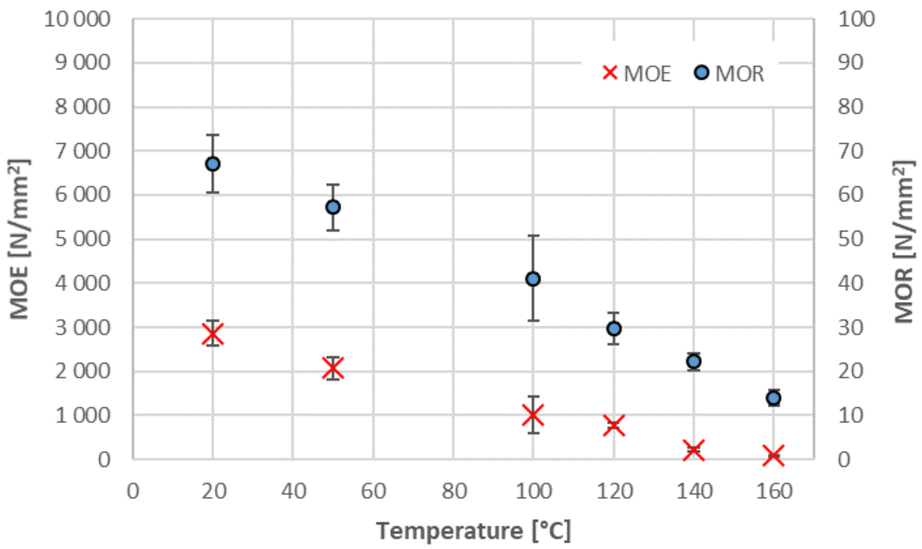

Figure 2. Staron modulus of elasticity and modulus of rupture at various temperatures

In case of Staron, no differences were found for 100°C and 120°C MOE values. The achieved MOR values for the tested Corian and Staron samples at various temperatures are presented in Figures 1 and 2. As it is shown, the highest MOR value (91.4 N/mm^2) at a room temperature (20°C) was noted for Corian. The MOR value for Staron in the same conditions was 67.1 N/mm^2, what means about 36% less. The most intensive reduction of MOR for Corian was between 140 and 160°C (over 44%, 2.21%/°C), while for Staron – between 100 and 120°C (17%, 0.85%/°C). It is worth adding that MOR reduction for Staron at temperatures between 20 and 160°C was almost linear.

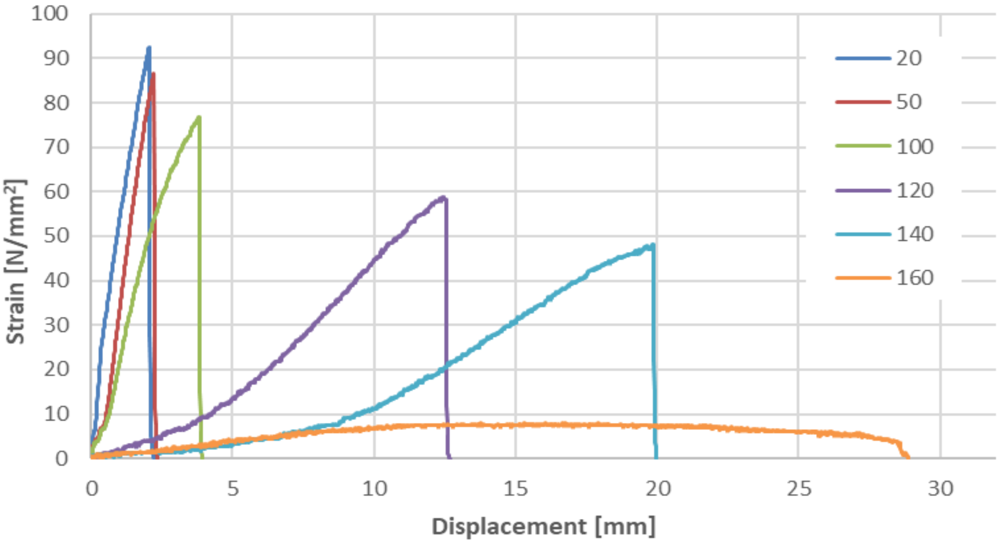

Figure 3. Strain-displacement relation when bending Corian at various temperatures

Under the highest test temperature, the stored MOR was 8.47 and 13.89 N/mm^2, what means 9.3 and 20.7% of initial MOR values, for Corian and Staron, respectively. When analyzing the statistically significant differences between the achieved MOR results, it can be found that there are no differences between Corian MOR values for 20 and 50°C, and 120 and 140°C, and the same relation is observed for Staron.

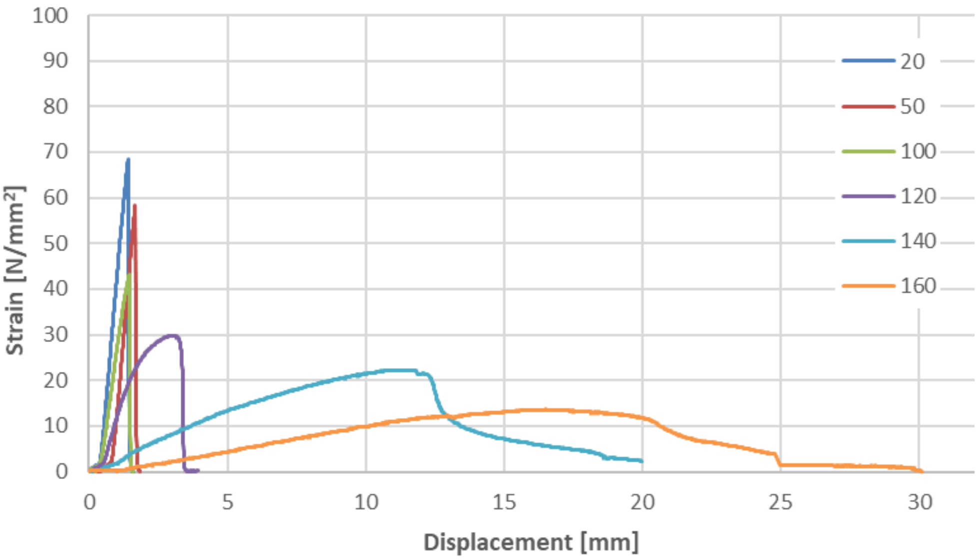

Figure 4. Strain-displacement relation when bending Staron at various temperatures

According to Vovk *et al*. (2017), the reduction of PMMA-ATH composite, formerly named Kerrock, when the temperature changes, is from about 47 N/mm^2 for 24°C to less than 30 N/mm^2 for 75°C. This gives the MOR reduction ratio of about 0.7%/°C, which is higher than for the tested Corian and Staron (0.2 and 0.4%/°C between 20 and 100°C for Corian and Staron, respectively). However, the materials tested by Vovk *et al*. (2017) had an adhesion promoting additive incorporated in the structure. The achieved MOR results for Corian and Staron materials tested under various temperatures are significantly higher than the required minimal values typically used for furniture production. For example, the minimum required MOR values for P2 13–20 mm thick particleboards (according to EN 312:2010 standard) is 11 N/mm^2, and for 12–19 mm thick MDF – 20 N/mm^2 (according to EN 622-5:2006 standard).

Figures 3. and 4. present the relation between strains and displacements of the bended samples of various temperatures. As it is shown, a significantly higher load, represented by the area under strain-displacement plots, must be applied to deform Corian. This material is also better for shaping by bending thanks to a higher displacement available.

CONCLUSIONS

According to the conducted research and the analysis of the achieved results, the following conclusions and remarks can be drawn:

1. The modulus of elasticity and the modulus of rupture for Corian and Staron decrease significantly when the temperature of these materials rises.
2. At the temperature ranged of 20–160°C, the MOE average change ratio is 0.7%/°C for Corian and for Staron, while in case of MOR it is 0.6%/°C.
3. The most intensive changes of Corian bending properties are at temperatures from 100°C to 160°C and from 100°C to 140°C for Staron.
4. When raise the bended material temperature from 20 to 160°C, Staron represents about twice higher storage of initial MOR and MOE values.
5. Due to its lower strain-displacement relation, Staron is a material characterised by easier thermal shape modification.

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Streszczenie: *Wybrane właściwości przy zginaniu materiałów mineralno-akrylowych o zwartej powierzchni do zastosowań przy wytwarzaniu mebli.* Celem badań było scharakteryzowanie właściwości podczas zginania wybranych, dostępnych w handlu płyt wykonanych z wykorzystaniem mineralnych wypełniaczy akrylowych i matrycy termoplastycznej (nazwy handlowe Corian i Staron), w kontekście formowania termicznego. Badania wykazały, że przy wzroście temperatury badanych materiałów od 20 do 160°C następuje istotne zmniejszenie wartości wytrzymałości na zginanie (o ponad 90% dla Corianu i około 80% dla Staronu) oraz modułu sprężystości przy zginaniu (o niemal 99% dla Corianu oraz o 97% dla Staronu), co powinno zdecydowanie poprawiać podatność na termoformowanie tych materiałów. Spośród dwóch przebadanych materiałów, Staron jest materiałem charakteryzującym się większą podatnością na modyfikację kształtu w podwyższonej temperaturze.

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