Agar-Based Adaptable DIY Materials

Hajra S Zuberi
Researcher
İzmir University of Economics
Design Studies Master's Program
İzmir,
Turkey

Murat Bengisu
Professor
İzmir University of Economics
Department of Industrial Design
İzmir,
Turkey

Several types of agar-based polymeric materials were developed for the use of designers, engineers, makers, and do-it-yourself (DIY) enthusiasts. Simple recipes and procedures were determined for the adaptation and use by anyone who is interested to use sustainable, non-toxic, and even edible plastic-like materials without the need for a scientific background. The recipes and procedures were developed by controlled laboratory experiments. The main recipes contain different combinations of agar strips, water, glycerine, and vinegar. A variety of films with different sensorial properties (soft, hard, flexible, stiff, clear, coloured, textured, with or without spicy odour, etc.) were prepared by heating the ingredients in a saucepan, mixing, pouring on a flat surface, and drying for a few days. These were evaluated by tinkering and user studies that involved students from design, food engineering, culinary arts, and other fields. Based on these studies, several applications were suggested for product, fashion, service, and food design.

Keywords: *agar, DIY materials, edible films, organic materials, sustainable polymers.*

1. INTRODUCTION

Plastics were among the most amazing inventions during the first half of the 20th century. Designers were inspired by the ease of forming, choice of colour, and useful properties of plastics such as bakelite, cellop–hane, nylon, or PVC [1]. Their low cost and versatility caused a boom in production and applications. How–ever, the widespread use of plastics caused environ–mental pollution and health hazards. Environmental concerns caused by fossil-based synthetic polymers have been the major driving forces behind the invention, development, and production of sustainable polymers since the 1970s [2]. Two of the most important biopo–lymers derived from organic materials and commer–cialized as a result of massive R&D efforts include thermoplastic starch and polylactic acid (PLA). Biopo–lymers such as cellulose, chitin, chitosan, and their deri–vatives have found many important uses, although most of these substances are infusible. Starch, cellulose, and chitin are three most abundant polymers synthesized by natural organisms. They are purified and derivatized by various chemical, mechanical, and thermal processes in order to be used in scientific and industrial applications [3, 4]. Biopolymers are increasingly being used as engineering materials in pure, blend, or composite forms, depending on the stress, strain, and other mechanical requirements [5]. One such candidate is agar.

Agar is a biopolymer derived from red seaweed, two main species of which are Gelidium and Gracilaria. Agar derived from Gelidium species are preferred due to their higher gelling strength. Similar to starch, cellulose, and chitin, agar is also a polysaccharide. In chemical terms, unlike the former three substances, agar is a sulfated polysaccharide and falls into the group of linear polymers called galactans [6, 7]. The majority of agar (~90%) is used for its gel forming ability in the food industry and the rest is used for biotechnological, bacteriological, and pharmaceutical applications. Agar is also used in Asian kitchens as a gelling agent and as a substitute for animal-based gelatine for vegetarian meals. Agar-based thermoreversible gels have a higher melting point (60-97°C) compared to animal-based gelatine (~37°C) [8, 9]. Recent studies focus on the antimicrobial, antioxidant, anticoagulant, and anticancer properties of agar and other galactans [9-11]. Although the film-forming properties of agar are known in the scientific community, agar is not considered as a strong candidate to substitute fossil-based polymers. Due to the lack of thermoplastic characteristics, necessitating solu-tion-based processes. However, agar could be an att-ractive material for designers and the do-it-yourself (DIY) community since it is widely available, cheap, adaptable, and very easy to work with.

DIY material development is a relatively new con-cept suggested by Rognoli et al. [12]. DIY materials are usually derived from recycled materials or from sources that are not mainstream, e.g. vegetable and fruit shells, demolition waste, minerals, and unused parts of plants or animals [5, 13]. A DIY material should be easy to use, non-toxic, harmless, and easy to transform. Typi-cally designers are restricted with commercially available materials which may have certain disadvan-tages in terms of cost, access, ease of manufacturing, variety, and need for technical/scientific knowledge. DIY materials eliminate most of these disadvantages and provide opportunities for experimentation. Such materials can be designed through the creative use of natural substances. They can be a source of richness concerning perception and aesthetics in design [13]. Furthermore, they can contribute to the solution of ever-growing environmental problems by the use of simpler, less hazardous processes. Selection of natural, bio-based

Received: August 2018, Accepted: March 2019
Correspondence to: Professor Murat Bengisu, İzmir University of Economics, Department of Industrial Design, Izmir, Turkey
E-mail: muratbengisu@gmail.com
doi: 10.5937/fmet1903442H

and biodegradable materials reduces overall energy consumption and transportation costs. Innovative and environmentally conscious use of bio-based materials have the potential to eliminate toxic additives in products and processes [14]. DIY materials highlight craftsmanship, design, self-production, and customization. New tools such as 3D printing, fablabs, open source software, and open source electronic platforms such as Arduino enrich the DIY material movement.

Some reviews of DIY material projects can be found in the literature [5, 12, 15]. Some of these projects propose new materials while others find new identities for conventional materials [12]. For example, Green Plastics is a website for students and hobbyists to share information on biodegradable plastics. Sweeney's video on this website shows how to make simple bioplastics at home from starch, vinegar, glycerine, and water [16]. Parmar, in his project named A Peel, used materials from dried citrus peel, blended and fused with natural binders. This material can be processed into flexible sheet or bulk forms [17]. Precious plastics [18] is a project that focuses on a process to recycle materials rather than suggesting a new material. This project features many elements of the DIY-maker culture. It provides all the necessary instructions and technical drawings to build a low budget, mini plastic recycling 'factory' to turn waste plastic parts into more valuable objects. These and similar projects help designers and makers to explore new ideas, make their own prototypes or products, and challenge the idea of a passive consumer that must purchase mass produced items.

The present study is a design-led development and exploration of agar-based DIY materials. The aim is to develop a formula that can be customized by designers and become easily accessible to them. The concept is influenced by DIY and open design philosophies to provide an easy-to-use formula and method that interest amateurs, students, and young designers. The sensorial qualities and design potential of agar-based DIY materials are investigated through the lens of the Material-Driven Design (MDD) method [19]. Laboratory experiments were conducted to optimize variables and obtain adaptable agar-based films for designers and makers. Time-dependent changes of the films were determined. Based on optimized films, some modifications were made in colour, texture, and composition. MDD guides the designer through the process of discovering added value, meaning, user experience and how a material can support user practices. User experience was investigated by MDD conducted with design, culinary art, food engineering, and other university students to understand the aesthetical and practical usage of the new material in the design field.

2. METHODS

2.1 Pilot Study

Several experiments were done with various organic materials on a trial and error basis to develop an organic material. The primary purpose of pilot studies was to create a material with the help of existing natural substances from our surrounding which are accessible and affordable. During this phase, common food grade materials such as flour, rice flour, raw rice, corn starch, and agar were selected and used as key ingredients in experiments. Other substances were also selected from daily kitchen materials like sugar, tea and tea waste, coffee ground, and vinegar to develop a composite material. Experiments were conducted through a simple procedure by combining dry ingredients and water and cooking that mixture on a stove at medium heat. After the mixture became thick like a paste, it was spread on baking sheet and left for a week or two to dry. Some experiments also involved baking the paste in an oven for about half an hour. Glycerine was incorporated as an additive to yield more elasticity [20, 21]. Through pilot studies, two basic types of samples were developed: hard samples and soft, flexible samples. Hard samples were obtained in the absence of glycerine whereas soft and flexible samples were obtained by the addition of glycerine. These pilot studies yielded some encouraging results, thus new experiments were planned in a more precise way with better-controlled procedures. Based on the experiments, agar and corn starch were selected as key components to develop DIY materials.

2.2 Laboratory Experiments

After the pilot experiments, agar was selected as the base material while other substances were water, glycerine, sugar and vinegar. Corn starch was selected as a comparative material to agar. During the second phase, experiments were done to determine procedures to make agar based materials and to observe their interactions with other substances. Three types of commonly accessible agar were selected to perform experiments;

• Bacto™ Agar (agar powder) by Becton, Dickinson and company used for bacterial growth and as a solidifying agent in laboratories (agar type 1).

• Food grade agar powder used in the food industry as vegetarian gelatine substitute for animal-based gelatine (agar type 2). Two types of powder were used: food grade agar powder bought in Italy (type 2a) and agar powder bought in Turkey, named as Agar Agar by Tito with E code E-406 (type 2b).

• Food grade white agar flakes/strips also used as vegetarian gelatine as well as a food ingredient in Japanese and Chinese cuisines (agar type 3). The food grade agar strips were bought from Chinatown, Italy.

Food grade synthetic or white vinegar, corn starch and sugar (both brown and white sugar) were bought from the local grocery store. Laboratory grade glycerine (glycerol for analysis by EMSURE®) was used in the experiments.

Experiments were performed in a precise manner to minimise errors and calculate ratios with proper units instead of spoons and cup measurements in the pilot study. To maintain accuracy, temperature, quantity (in grams or millimetres), and shape were kept constant through the second phase of experiments. Simple tools were used in all of the experiments; a standard saucepan to cook, a hot plate for heating, and a stirrer or spoon to stir the mixture. A measuring scale was used to measure

Table 1. Compositions of solutions used for base materials.

Material combination	Sample No.	Agar type	Agar (g)	Glycerine (ml)	Sugar (g)	Vinegar (ml)	Starch (g)
agar	2, 3, 13, 24	3, 2a, 1, 2b	2				
starch	4						2
agar + starch	5, 6, 14, 25	3, 2a, 1, 2b	2				2
agar+ starch + glycerine	12, 11, 10, 27	3, 2a, 1, 2b	2	2			2
starch + glycerine	7			2			2
agar + glycerine	8, 9, 15, 26	3, 2a, 1, 2b	2	2			
agar+ glycerine + sugar	16, 17, 18, 19	3	2	2	2 - 0.5		
agar+ glycerine + sugar	20, 21, 22, 23	2a	2	2	2 - 0.5		
agar+ glycerine + sugar	29, 30, 31	2b	2	2	2 - 1		
agar + glycerine + vinegar	41, 32	3, 2b	2	2		2	
agar + vinegar	43, 34	3	2			2	
agar + vinegar + sugar	45, 33	3, 2b	2		2 -1.5	2	
agar + starch+ vinegar	40, 38	3, 2b	2			2	2
agar + starch+ sugar	42, 39	Type 3	2		2 - 1.5		2
agar + sugar	44, 28	Type 3, 2b	2		2		

* Each solution contains 50 ml water; agar type has a same order of sample number

the dry ingredients accurately and a measuring cylinder was used for liquids. To maintain the shape and quantity of the sample and to observe the shrinkage in terms of diameter and thickness during the drying period, Petri dishes were used. Our basic procedure to develop a DIY material consisted of four main steps:

- precise measurement of ingredient weights,
- combining dry and liquid ingredients in a saucepan,
- placing the saucepan on a hot plate at 240- 260°C and heating the mixture until it becomes homogeneous and thick in consistency like honey,
- pouring the mixture into the Petri dish (93 mm x 7 mm) and drying at room temperature for a week.

For the basic recipe, 2 g of agar or corn starch, 2 ml glycerine, and 50 ml of water was used. This recipe remained constant through the whole period of experiments of the second phase. Bioplastics based on corn starch are available and edible films are in the process of practical development [20, 22, 23]. To compare and understand properties of samples containing corn starch, a series of experiments were done using corn starch and different types of agar. Detailed compositions of basic experiments are given in Table 1.

2.3 Coloured Samples

After the basic experiments with different types of agar, agar flake (type 3) was selected as a preferable raw material to continue the new phase of experiments. This phase consisted of coloured and textured samples using natural and organic additives. Coloured samples were developed using food colours, fruit peels and juice, and spices (cinnamon, red chilli and turmeric) from an Asian kitchen. Different types of herbal teas and coffee ground were also used to give colour and texture to samples. For coloured and textured samples, two types of combinations were adopted to perform experiments;

- Agar + water + colour,
- Agar + water + colour + glycerine.

Agar, water, and colouring material were used to obtain hard, coloured samples while glycerine was used to get flexible, softer coloured, and textured samples. The ratio and quantity of ingredients remained constant as in the basic experiments. Samples 2 and 8 were selected to include colorants. The quantity of colorants varied in experiments depending on the shade of colour and texture required. 0.5 g of dry colorants were used whereas for liquids colorants like food colour, few drops were used depending on the required colour.

2.4 Evaluation

The approach used to evaluate material samples is the Material Driven Design (MDD) method [19]. It enables the designer to understand, analyse and create a material experience. It helps to understand material-specific and design related qualities and application possibilities. The MDD method is based on four main steps;
(1) understanding the material: technical and experimential characterization,
(2) creating materials experience vision,
(3) manifesting materials experience patterns,
(4) designing material/product.

In the case of agar-based materials, they are further analysed, evaluated, and possible application proposals were achieved through different steps inspired by the MDD method. Agar-based material properties were explored through experimentation (tinkering), observation of time-dependent changes, user material experiences and possible material applications through user studies. User experience was investigated by surveys conducted with three groups respectively; design (industrial, textile and interior), culinary art and food engineering students as well as random university students. This step aimed to understand the aesthetical and practical usage of the DIY material in the design field. Although the survey groups were selected carefully in order to get the most useful data, we acknowledge the fact that the opinions are limited to a sample group located at our present institution and studies with other survey groups will probably lead to different results with regard to user experience. However, this is only a small part of the research and design research is typically subjective when dealing with people and opinions.

3. SENSORIAL PROPERTIES AND TIME DEPENDENT CHANGES

During and after the experiments, some noticeable changes have been observed over a certain period. Changes observed in agar based polymer films during and after the experiments are discussed below.

3.1 Pilot Study

Different materials and processes were tested to obtain an appropriate DIY material sample. Sensorial properties such as softness, roughness, dryness, stickiness, odour, etc. were evaluated by one of the authors at this stage. Varied sensorial properties and time-dependent changes were observed during the pilot study, which led to the selection of an appropriate sample with favourable features to further explore its possible characteristics through systematic and precise experiments. It has been observed that by adding glycerine; agar becomes flexible and stretchable. In contrast, vinegar makes it hard and brittle.

3.2 Laboratory Experiments

These main experiments consisted of several compositions with agar as the key ingredient and corn starch as a comparative material. Sensorial properties varied considerably upon the use of different types of agar and additives. Though ratios remained constant (agar 2 gm + additive 2 gm/2 ml+ water 50 ml) throughout the second phase of experiments, time-dependent changes were different even within agar types. Major changes were observed depending on agar type and use of the different additives. Prominent time dependent changes are:

- shrinkage and thickness differences,
- shape changes and deformation during the week of drying,
- colour changes, and colour differences,
- broken or torn samples,
- contaminated samples, mould or fungus-like spots,
- short term and long term changes of sensorial properties.

3.3 Shrinkage, Shape and Colour Changes Based on Agar Types

Prominent differences in the amount of shrinkage, colour, thickness and flexibility were observed depending on the agar type. Figure 1 compares the as-prepared samples (left) and samples dried for one week. It has been observed that samples made from agar flake are white, whereas those prepared from other agar types are yellowish. Food grade agar powders type 2a (bought in Italy) and 2b (bought in Turkey) also have some differences in terms of shrinkage, colour and deformation. Sample 2 (type 3) is hard and flexible whereas other samples are non-flexible, less transparent and brittle with higher shrinkage ratios (Fig. 1). Since the percentage of agar is the same for all four samples in Fig. 1, we come to conclude that the type of agar is responsible for the observed differences.

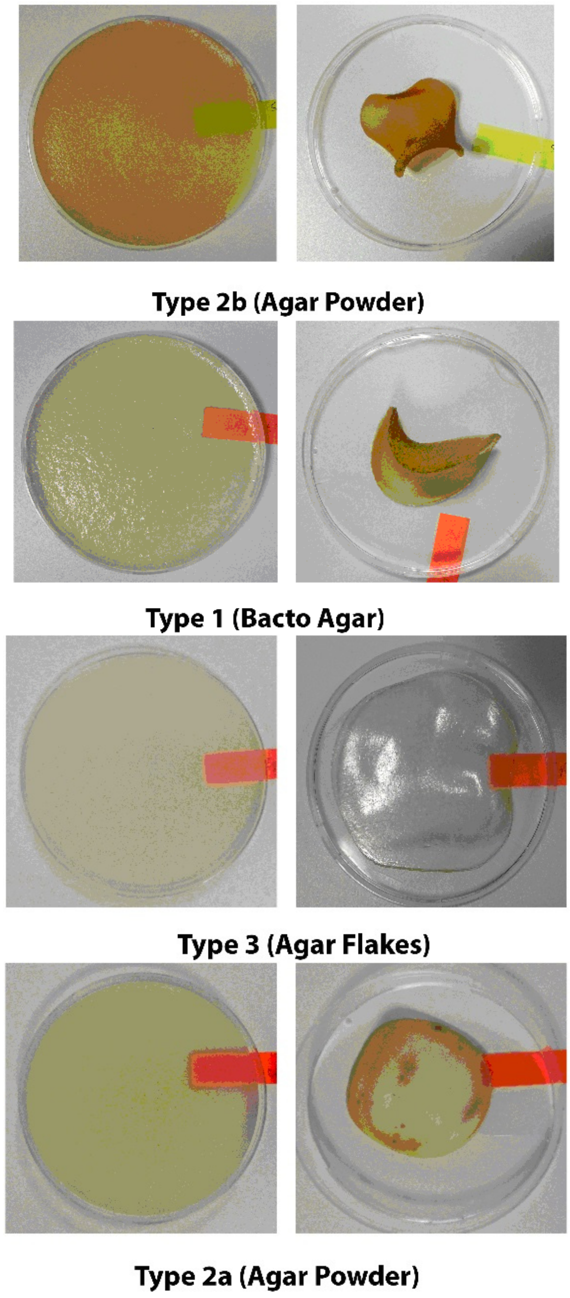

Figure 1. Observed Changes with Different Agar Types for the Basic Recipe Agar + Water; As-Prepared (Left) and Dried Samples (Right)

Glycerine was used as a plasticiser to give flexibility to materials. Samples containing glycerine are strong, flexible, and stretchable. Without glycerine, samples become usually hard and brittle.

3.4 Broken, Torn, and Contaminated Samples

Even though the second phase of experiments were well-controlled in ratio, not all samples came out perfect; some unsatisfactory samples were also observed like contaminated, cracked and porous samples. Combination of agar and starch resulted in hard and thick samples. Samples containing starch got contaminated with black and greenish fungus like spots. To control contamination of samples, vinegar was added later into the samples containing corn starch. Vinegar (acetic acid) is used in the food industry and home cooked products (like jam and marmalade) as a natural preservative against spoilage. Samples 5 and 25 containing starch and agar without vinegar contained black spots but adding vinegar to the mixture suppressed these spots. Similarly, adding glycerine or sugar also prevented contamination in the samples.

Samples based on agar flakes are flexible in nature with hard surfaces. Interestingly samples containing agar flakes, water, vinegar, and sugar resulted in hard yet relatively flexible samples. Replacing agar flakes with starch made the samples brittle.

3.5 Short-Term and Long-Term Changes

For the purpose of this article, we define short-term as 1-2 weeks and long-term as 3-6 months. Most of the dried samples remained the same after several months. However, sugar-containing samples have shown some interesting short- and long-term time dependent changes. It has been observed that sugar-containing samples get misty and their transparency is reduced in the long term. The level of mistiness depends on the of presence glycerine. It has also been observed that combination of agar, glycerine, and sugar gives more strength than agar and sugar alone. Sugar acted as a plasticizer in the start and gave flexibility to agar, but it worked differently towards type 2b (powder) and type 3 (flakes). After a period of around 6 months, the sample changes into hard and brittle form with a misty surface.

3.6 Categorization of Samples

Samples prepared in this study can be categorised based on flexibility and hardness into three characteristic grades: soft and flexible (SF), hard and flexible (HF), and hard and brittle (HB). These three grades depend on agar type, use of glycerine, sugar, vinegar and starch. Materials containing glycerine fall into the category of soft and flexible samples (Grade SF), whereas without glycerine materials based on agar type 1 or 2 are hard and brittle (Grade HB). Samples based on agar flakes without glycerine are hard yet somewhat flexible (Grade HF).

Type 3 agar was selected to conduct further studies with coloured and textured samples because of its strong, flexible character. Two basic combinations (*agar + water* and *agar + glycerine + water*) with colorant or textured additives were selected to conduct further experiments. Spices, food colours, fruit peels, herbal tea and coffee were used as colorant and textured additives (Figs.2-4). Spices such as cinnamon and turmeric, known to act as antimicrobial agents, were used [20]. Adding food colour to the base material did not change sensorial properties (other than colour) or time dependent changes. Cinnamon and coffee gave strength and a rough fabric- like feel to Grade SF samples.

3.7 Tinkering

To determine technical and sensorial characteristics, tinkering with agar-based materials were performed. Tinkering aims to extract data, recognise material potentialities, and understand material properties and constraints. Sample 8 (agar + water + glycerine) and sample 2 (agar + water) were selected to perform a set of experiments in order to explore their technical properties and constraints.

Cutting, tearing, heating, burning, stretching, bending, dyeing, and water resistance tests were performed with samples (Fig. 5). These simple experiments provided considerable insight into agar-based materials.

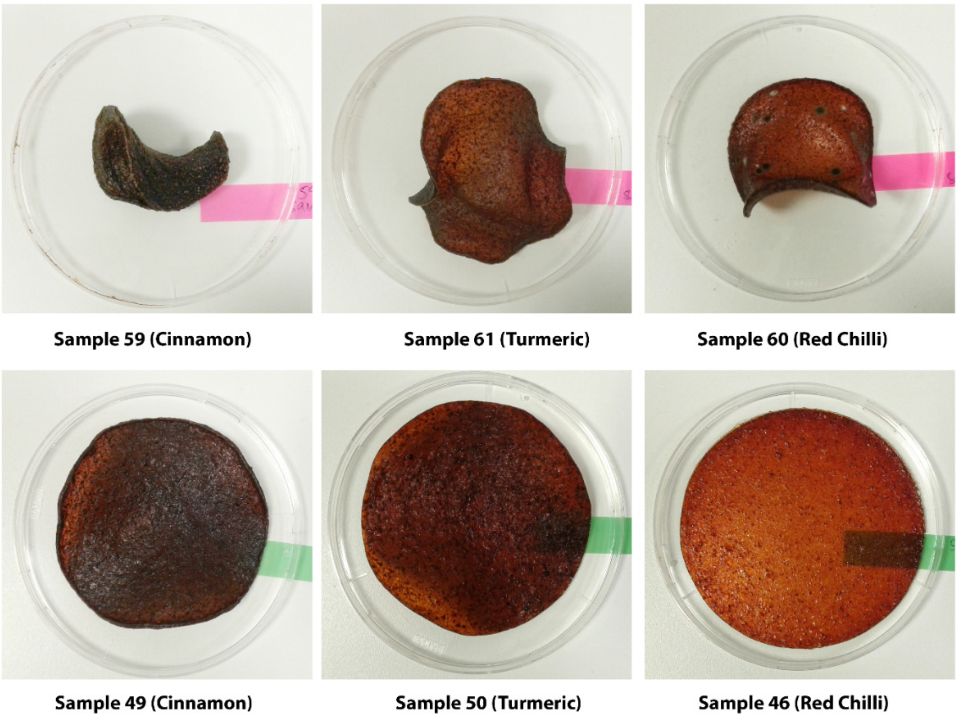

Figure 2. Coloured samples containing spices; agar+ spice (top row) and agar + spice + glycerine (bottom row) – all samples dried for a week.

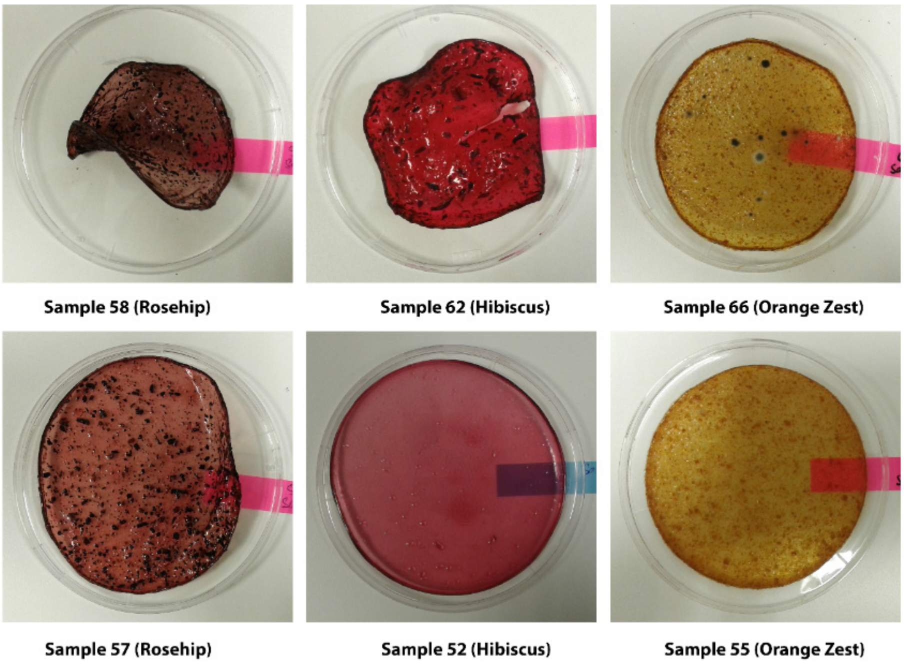

Figure 3. Coloured samples containing teas and fruit peels; agar+ colorant (top row) and agar + colorant + glycerine (bottom row) – all samples dried for a week.

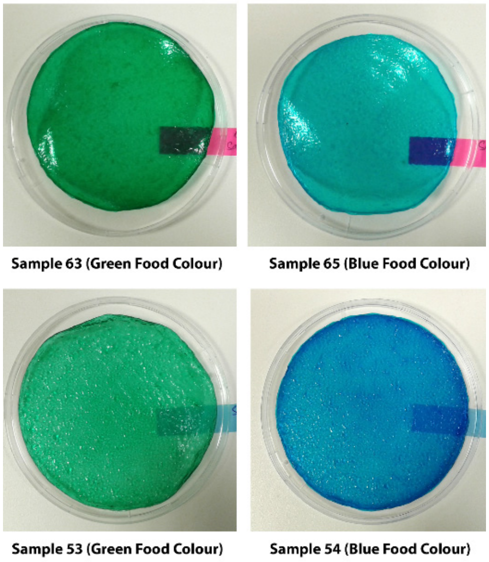

Figure 4. Coloured samples containing food colours; agar+ colourant (top row) and agar + colourant + glycerine (bottom row) – all samples dried for a week

Both samples can be easily cut with a pair of scissors. Sample 8 is more elastic; it can be stretched and torn while sample 2 is more resistant to tearing or stretching by hand. Both samples turn black and burn when exposed to flame. They become soft when immersed in water for extended times (30 minutes) but sample 2 recovers its original stiffness when dried. Some useful properties of agar-based films are their edible quality (they have no taste), the possibility of shaping with heat and light pressure (sample 8, ironing) and the ability to dye them with fabric dye. These experiments suggest that agar-based materials are adaptable to different uses while more experimental testing is needed to obtain quantitative data about material properties including heat and fire resistance, colour absorption capability, water absorption, and mechanical properties.

3.8 User Studies

To explore material qualities through sensorial and emotional experiences, user studies are a suggested step in the MDD method. In order to understand how people perceive the material regarding senses, emotions, meanings, inspirations, and how they interact with it, user studies were conducted with 45 university students. Participants were students from Design (Industrial Design, Interior Architecture and Environmental Design, and Fashion and Textile Design), Food (Culinary Arts and Management; Food Engineering) and other departments at İzmir University of Economics, Turkey. User studies were conducted through a questionnaire consisting of open- and close-ended questions about the material, its sensorial properties and possible uses in design fields. The questionnaire was designed and evaluated based on the MDD approach. Questions were designed to achieve qualitative and quantitative data about the selected material samples. Each user was asked to evaluate samples from two categories, named as category A (soft samples) and category B (hard samples). Category A includes grade SF samples while category B includes both HF and HB grade samples. Each category consisted of 4 samples; basic sample A(i) (agar + water + glycerine) and B(i) (agar + water) with their coloured counterparts A (ii, iii, iv) and B (ii, ii, iv). Qualitative data was collected by adding open-ended questions to investigate the material experience. The users were asked to evaluate material samples about their key ingredients, similar materials and possible applications. To obtain quantitative information, a sensorial evaluation chart was used. The sensorial chart is a combined form of Expressive-Sensorial Atlas [25] and Meaning Driven Material Selection (MDMS) Tool [26]. The sensorial evaluation aims to sense relevant characteristic like smell and tactile features and physical properties like hardness and transparency [26].

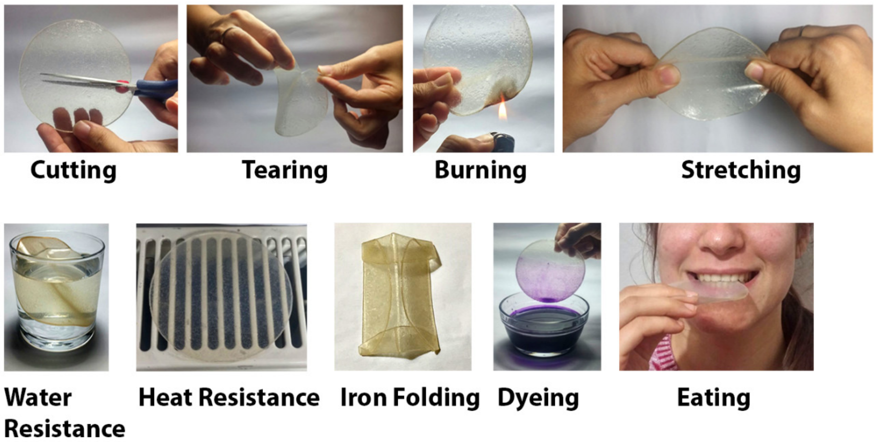

Figure 5. Different tinkering steps on sample 8 (agar + water + glycerine).

Selected samples from A (soft) and B (hard) categories were;

- sample A (i) and B (i) (the basic samples),
- sample A (ii) and B (ii) with green food colour,
- sample A (iii) and B (iii) with cinnamon powder,
- sample A (iv) and B (iv) with turmeric powder.

The first question of the questionnaire asked the participants to guess the *key ingredient* of samples from respected categories. Interestingly, only some Culinary Arts and Food Engineering student guessed agar as the main ingredient. Other students perceived the source material as plastic, rubber or silicone in case of soft samples. However, for category B (hard samples) most of students perceived the samples as plastic. Some organic materials were also named by the students as the main ingredient of samples like starch, organic powder, and gelatine.

In the second question, students were asked to name a *similar material* that they know with respect to each sample. For category A, the mostly mentioned similar materials were silicone and plastic. However, Culinary Arts and Food Engineering students most frequently mentioned gelatine and agar as one of the most similar materials. Other groups mentioned silicone, plastic, rubber and even jelly-like similarities. Particularly for sample A (iii) and A (iv) some of the students also mentioned some spices. Culinary Arts and Food Engineering students have mentioned cinnamon as the most similar material for sample A (iii). Fruit leather or dried fruit pulp were also mentioned as similar to sample A (iii) and A (iv).

For category B samples, the most frequently mentioned material was plastic as a similar material. Interestingly Design, Culinary Arts, and Food Engineering students mentioned PET as the second most similar material to sample B (i) and sometimes B(ii). Most of the random students and even design students mentioned chips for samples B (iii) and B(iv), probably because they look like potato chips. However, instead of chips, Culinary Arts and Food Engineering students specifically mentioned cinnamon chips for sample B (iii).

For both categories, the most frequently mentioned similar materials was plastic. Some of the students have also mentioned soft and hard plastic with respect to category A (soft samples) and category B (hard samples). For category A, many students have mentioned silicone because of its similar nature (soft, flexible, and translucent) while in case of category B a big number of students have mentioned PET or some as hard plastic. These answers give some insight on possible uses of those samples based on similarities to existing materials.

The third question was on the *possible usage* of the given samples. Students were asked to suggest suitable and possible applications based on their evaluation. Students responded with respect to their fields. Culinary Arts and Food Engineering students suggested possible applications in food applications such as food décor, edible packaging, disposable plates, cutlery, biodegradable grocery bags, and placemats, while design students suggested more design and product based uses including textiles, fashion accessories, soft toys, cups, plates, bottles, disposable kitchen utensils, jewellery, and undergarments. In case of random students, answers were based on available products made from similar materials such as bags, jewellery, plates, grocery bags, food containers, decoration, and table covers.

Students were asked to evaluate samples depending on the given *sensorial chart*. They were asked to grade each sample between seven scales from -3 to 3 including 0 from two opposite characteristics like opaque and transparent. The sensorial chart is based on physical and sensorial characteristics, ranging from hardness to pleasant smell of the material.

Sensorial evaluation of samples was done separately for each sample. For category A it has been observed that sample A (i) and sample A (ii) resulted in similar results except for the subtle colour. According to participants, both are glossy, flexible, resistant, and soft with transparent fibrous textures. In contrast sample, A(iii) and A(iv) are matte, opaque, rough with vivid coloured samples. All samples from category A are soft, flexible and resistant to nature according to participants. According to some students, samples A(iii) and A(iv) had a pleasant smell and according to others, they had a disgusting smell. However, most of the students remained neutral.

In case of B category, all samples were marked as hard and rough. First two samples, B(i) and B(ii), were evaluated as transparent, glossy, flexible, and resistant while the other two were seen as opaque, matte, rough, fragile and inflexible. With regard to smell, overall students remained neutral in all samples of grade B.

Material driven design is based on four action steps. The first step (understanding material) is followed by creating material experience vision and manifesting material experience patterns. Instead of following each step of MDD separately, in the case of agar-based materials, the second and third steps were combined into an overall material experience. In this part overall results were combined from tinkering to user studies with the help of Karana's Meanings of Materials (MoM) Tool [24]. MoM tool is suggested in the MDD method for manifesting material experience. In this case, this tool is used to summarise the evaluation (user studies and tinkering) for category A and B samples. Through this tool, information is summarised into meaning, users (demographic information), material properties (technical and sensorial properties from tinkering and user studies), and product regarding novel material (manufacturing process, finishes, function, and shape). User details, sensorial and technical properties, and possible uses are summarized with the help of the MoM tool. This tool shows an *overall evaluation* of samples based on their grade. Therefore, in properties, finishes and emotions (similar material question) conflicting features such as rough and smooth, matte and glossy, opaque and transparent are found. The shape of the material defines the visual qualities of the end product. As some of the samples were not flat or linear, they come in the 'curves' category because of non-linear appearance. With the help of the MoM tool, overall material experience based on user studies, tinkering and sensorial evaluation of agar based materials are visualized.

4. CONCLUSION AND REMARKS

Exploration of agar based materials through user studies and controlled laboratory experiments indicated that they are versatile, adaptive materials suitable to transform in terms of form, colour, thickness, transparency, and additives. Their hardness, stiffness, smell, and visual qualities can be easily changed. Furthermore, their preparation is easy, inexpensive, and does not require sophisticated equipment. All these features make them a suitable medium for DIY practices, prototyping, design research, and sustainable products. One disadvantage is the solution-based nature of the process required for preparation of agar based films. Unlike thermoplastic materials, they cannot be shaped by melting and molding or deformation while hot. Solution-based processes require sufficient time for drying which ranges from several days at room temperature to several hours when heating in an oven.

Two main categories of agar films were developed in this study. These are category A (grade SF - soft and flexible) and category B (grade HB - hard and brittle and HF - hard and flexible). Category A materials have certain advantages over category B: their shape remains stable during drying and they have more attractive aesthetic features including transparency, colour (when added), and tactile qualities. On the other hand, category B materials tend to deform during drying. However, the drying and shaping of these materials can be improved by further studies.

Table 2. Product Groups With Possible Products of Agar Based Materials.

Product Group	Possible Uses	Products	Design Fields	Suggested Material category
Food Products	Packaging	Food pouches, wrappers & coatings	Service Design	A
		Product coatings	Service Design	A
	Cutlery& Crockery	Spoons, fork, knife, chopsticks, plates, cups, bowls	Product or Service Design	B
	Mats	Food & Serving mats, Foldable plates	Product or Service Design	A
	Food Storage Items	Packaging & storage, boxes, shopping bags	Product or Service Design	B
	Culinary	Food décor&3D printed food ingredient	Culinary art & Food Design	A & B
Fashion & Textiles	Clothing	Jackets, 3D printed clothing	Fashion Design	A
	Accessories	Undergarments	Fashion Design	A
		Bags, belts, jewellery, shoes & sandals	Fashion & Product Design	A & B
		Jewellery	Fashion Design	A & B
	Furniture & Accessories	Furniture upholstery, cushion covers & throws	Interior & Product Design	A
Home Décor	Decorative Use	Decorative products like vase	Product Design	B
Baby Products	Food Products	Feeding bottles	Product Design	B
		Baby cutlery & crockery	Product Design	B
	Toys	Building blocks	Product Design	B
		Stuffed toys	Product Design	A
		Rattles, teeters	Product Design	A & B

Tinkering with agar-based films provided some very interesting results. Although they are not thermoplastic materials, it was found that category A films can be shaped permanently by ironing. Thus, there is the possibility to shape the films by heating and deforming them. Furthermore, both category A and B films can be coloured with fabric dye. It is also remarkable that these films are edible and tasteless, so they are suitable candidates for food design, food packaging, and food engineering.

User studies indicated that agar-based films have similarities to plastic, silicone, or rubber. Such results are encouraging since they suggest that agar-based materials, which are organic and sustainable, can be developed with similar sensorial qualities to different types of polymers. Additional studies with these materials are worthwhile. Suggested studies include exploration of new forms, addition of different organic materials, experiments with shaping, and development of innovative applications.

In the present study, only films were analysed. Solution based processes can also be tried to obtain solid blocks, thick sheets, plates, fibres, or porous media. The suitability of other processes can be investigated, especially thermoforming (heating and deformation) and 3D printing (which can be solution based).We have envisioned various potential applications for agar based materials. General categories include food industries, culinary arts, fashion and textile, home décor, healthcare, baby care, and disposable products. Agar based films and bulk materials could be further developed as alternative elastomeric materials used in mechanical components such as seals, valves, tubing, or wheels. The biodegradability of agar based polymers could be a disadvantage in certain components but they can also open interesting possibilities for niche products such as biodegradable tubing for disposable applications. Furthermore, certain additives and processes may well increase the durability of these materials, which requires further research and analysis. Table 2 lists the possible range of applications based on the advantages highlighted in the discussions. This table shows only a small window of opportunities that are relatively easy to think of. However, the interactive and collaborative nature of makers, young designers, and other actors that aim to contribute to sustainable projects may lead to many other innovative ideas and develop these materials for a wider variety of applications.

ACKNOWLEDGEMENT

Prof. Valentina Rognoli (Politecnico di Milano), Prof. Nazan Turhan (IUE Dept. of Food Engineering), Sıla Canpolat (IUE Engineering Labs), faculty members and students of Culinary Arts and Faculty of Fine Arts and Design (IUE) are kindly acknowledged for their help and support during this study.

REFERENCES

[1] Ashby, M.F., Johnson, K.: *Materials and design: the art and science of material selection in product design*, Butterworth-Heinemann, Oxford, 2013.

[2] Sivasubramanian, V. (Ed.): *Environmental sustainability using green technologies*, CRC Press, Boca Raton, 2016.

[3] Yilmaz, E.: Chitosan: a versatile biomaterial, in: Hasırcı, N, Hasırcı, V. (Eds.) *Biomaterials: From Molecules to Engineered Tissues*, Springer, Boston, 2004, pp. 59-68.

[4] Jiang, L. and Zhang, J.: Biodegradable polymers and polymer blends, in: Ebnesajjad, S. (Ed.) *Handbook of Biopolymers and Biodegradable Plastics*, Elsevier, Oxford, 2013, pp. 109-128.

[5] Troiano, M., Santulli, C., Roselli, G., Di, G.G., Cinaglia, P., Gkrilla, A.: DIY bioplastics from peanut hulls waste in a starch-milk based matrix, FME Transactions, Vol.46, No. 4, pp. 503-512, 2018.

[6] Usov, A.I.: Structural analysis of red seaweed galactans of agar and carrageenan groups, Food Hydrocolloids, Vol. 12, No.3, pp.301-308, 1998.

[7] Smidsrød, O. and Størker, T.M.: *Biopolymer chemistry*, Tapir Academic Press, Trondheim, 2008.

[8] McHugh, D.J.: *A guide to the seaweed industry*, Food and Agriculture Organization of the United Nations, Rome, 2003.

[9] Pierre. G., Delattre, C., Laroche, C. and Michaud, P.: Galactans and its applications, in: Ramawat, K.G. and Mérillon, J.M. (Eds.), *Polysaccharides: Bioactivity and Biotechnology*, Springer, pp. 753-794, 2015.

[10] De Lacey, A.M., Lopez, M., López-Caballero, E. and Pilar Montero, M.: Agar films containing green tea extract and probiotic bacteria for extending fish shelf-life, LWT: Food Science and Technology, Vol. 55, No. 2, pp. 559-564, 2014.

[11] Kanmani, P., Rhim, J.W. Antimicrobial and physical-mechanical properties of agar-based films incorporated with grapefruit seed extract, Carbohydrate Polymers, Vol. 102, pp.708-716, 2014.

[12] Rognoli, V., Bianchini, M., Maffei, S. and Karana, E.: DIY materials, Materials & Design, Vol. 86; pp. 692-702, 2015.

[13] Ayala-Garcia C., Rognoli, V. The new aesthetic of DIY-materials, The Design Journal, Vol. 20, No. Sup 1, pp. S375-S389, 2017.

[14] Nunes, R.L.C., Santacruz, G., Arcaro, S., Koop, A.A. and Pérez, B.C.: Glass foams produced from glass and yerba mate (Ilex paraguarinensis) waste. FME Transactions, Vol. 46, No.1, pp. 70-79, 2018.

[15] Ayala-Garcia, C., Rognoli, V. and Karana, E.: Five Kingdoms of DIY Materials for Design, in: *Proceedings of the International Conference 2017 of the Design Research Society Special Interest Group on Experiential Knowledge (EKSIG)*, TU Delft Open, pp. 222-234, 2017.

[16] Green Plastics: Make your own bioplastics, YouTube video, 03:30, Posted November 17, 2008, https://www.youtube.com/user/greenplasticsnet

[17] Karana. E., Pedgley, O. and Rognoli, V. (Eds.), *Materials experience: fundamentals of materials and design*, Butterworth-Heinemann, Oxford, 2014.

[18] Hakkens, D.: Precious plastics, https://precious plastic.com, 2013.

[19] Karana, E., Barati, B., Rognoli, V., Der Laan, V. and Zeeuw, A.: Material driven design (MDD): a method to design for material experiences, International Journal of Design, Vol. 9, No. 2, pp. 35-54, 2015.

[20] Palviainen, P., Heinämäki, J., Myllärinen, P., Lahtinen, R., Yliruusi, J. and Forssell, P.: Corn Starches as Film Formers in Aqueous-Based Film Coating, Pharmaceutical Development and Technology, Vol. 6, No. 3, pp. 353-361, 2001.

[21] Wang, L.F., Rhim, J.W.: Preparation and application of agar/alginate/collagen ternary blend functional food packaging films, International Journal of Biological Macromolecules, Vol. 80, pp. 460-468, 2015.

[22] Valencia-Chamorro, S.A. et al.: Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: a review, Critical Reviews in Food Science and Nutrition, Vol. 51, No. 9, pp.:872-900, 2011.

[23] Khoramnejadian, S., et al.: Bio-based plastic a way for reduce municipal solid waste, Procedia Engineering, Vol. 21, pp. 489-495, 2011.

[24] Rognoli, V.: A broad survey on expressive-sensorial characterization of materials for design education, METU Journal of the Faculty of Architecture, Vol. 27, No. 2, pp. 287-300, 2010.

[25] Karana, E., Hekkert, P. and Kandachar, P.: A Tool for Meaning Driven Materials Selection, Materials & Design, Vol. 31, No. 6, pp. 2932-2941, 2010.

[26] Parisi, S., Rognoli, V., Ayala, C.: Designing Materials Experiences Through Passing of Time Material Driven Design Method Applied to Mycelium–Based Composites, in: *Proceedings of 10th International Conference on Design & Emotion*, Amsterdam, Netherlands, pp. 239-255, 2016.

ПРИЛАГОДЉИВИ КРЕАТИВНИ МАТЕРИЈАЛИ БАЗИРАНИ НА АГАРУ

Х.С. Зубери, М. Бенгису

Развили смо неколико врста полимерних материјала базираних на агару које могу да користе дизајнери, инжењери, произвођачи и креативни ентузијасти. Направили смо једноставне рецепте и поступке које могу да прилагоде и користе сви зинтересовани за употребу одрживих, нетоксичних, па чак и јестивих материјала који имају особине пластике, а да при томе не морају да поседују научна знања. Рецепте и поступке смо развили у контролисаним лабораторијским условима. Главни рецепти се састоје од комбинације трака агара, воде, глицерина и сирћета. Различити филмови са различитим сензорним својствима (мекан, тврд, савитљив, крут, провидан, у боји, са текстуром, са и без мириса итд.) су припремљени загревањем састојака у посуди, мешани, расути на равну површину и остављени да се суше неколико дана. Затим је извршена непрофесионална евалуација материјала и процена њихове корисности од стране студената дизајна, прехрамбене технологије, кулинарства и др. Дато је више предлога за њихову примену у области дизајна производа, моде, услуга и хране.