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Rheological properties of resin composite [Review Article]

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Abstract

Dental ceramic materials can provide aesthetic realism. Ceramics cause regular & diffuse light transmission and both specular and diffuse light reflection. Therefore, it has the potential to reproduce the depth of translucency, depth of color and surface texture of natural teeth. The following reviews highlight the mechanical and surface properties of the ceramic materials.

Keywords;Ceramic;Mechanical properties;Surface properties.

Introduction:

Rheology is a branch of physics that deals with the deformation and flow of materials, both solids and liquids. The word rheology is derived from the Greek word (rhéō) meaning flow and (logia) meaning study[1].

Studying the rheological properties of is of a prime importance for adequate handling and performance of dental materials. Since resin composite restorations were developed as an esthetic and more conservative alternative to dental amalgam, many efforts have been made to improve their physical and mechanical properties. The handling and flow characteristics are one of the major parameters that affect the final quality, success rate and life span of composite restorations[2].

Basic concepts of rheological properties:

Rheology is the study of the deformation and flow characteristics of matter, whether liquid or solid.

Although a liquid at rest cannot support a shear stress, most liquids when placed in motion (e.g. between two plates) are subjected to shear stresses (figure 1).

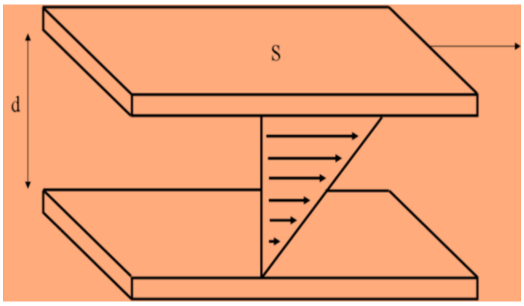

Figure1: Laminar shear of fluid between two plates. The friction between the fluid and the moving plates causes the fluid to shear[3].

The shear stress (τ) that is necessary to generate the movement is expressed as:

$\underline{\tau = F/A}$;

Where F is the force that is applied, and A is the surface area of the plates.

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The resulting shear rate (rate of change of deformation) is determined by:

$\boldsymbol{\varepsilon = V/d}$;

Where V is the velocity of the moving surface and d the distance between the plates.

The viscous behavior of fluids is represented by curves illustrating shear stress values versus shear strain rate.

According to the rheologic behaviors, three types of fluids can be identified:

1) **An ideal or Newtonian fluid**: They are fluids in which shear stress values are directly proportional to the strain rate. The viscosity of a Newtonian fluid is constant and independent of shear rate. The plot is a straight line and resembles the elastic portion of a stress-strain curve, with viscosity the analog of the elastic modulus (figure 2). Some dental cements and impression materials are Newtonian [4,5].

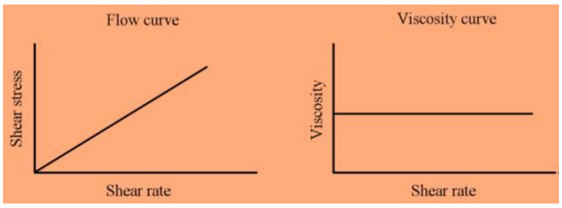

Figure2: Flow curve and viscosity curve of a Newtonian fluid [3].

2) **Dilatant fluids**: Shear-thickening fluids or dilatants (figure 3) are fluids that show a viscosity that increases with an increased shear rate; similar o starch. The faster the dilatant fluids are stirred or forced through a syringe, the more viscous and more resistant to flow they become. One examples of dilatant fluids in dentistry is the fluid denture base resins [4,5]
3)

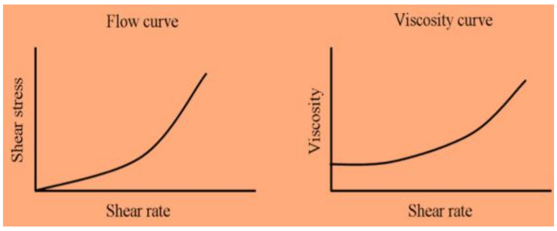

Figure 1: Flow curve and viscosity curve of a dilatant fluid [3].

4) **Pseudoplastic fluids**: Pseudoplastic or shear thinning fluids give a viscosity that decreases with increasing shear rate i.e., opposite behavior from dilatant fluids (figure 4). Thus, the more rapidly the pseudoplatic fluids are stirred or forced through a syringe, the more easily they flow [4,5].

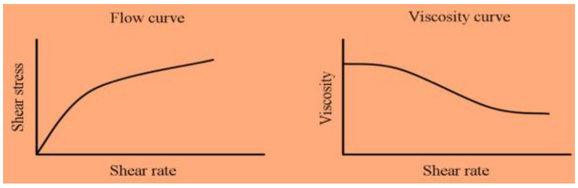

Figure 2: Flow curve and viscosity curve of a pseudoplastic (shear-thinning) fluid [3].

Some pseudoplasic (shear-thinning) fluids show a time-dependent change in viscosity. The longer the fluid undergoes a shear stress, the lower is the viscosity. This phenomenon is called thixotropy. A thixotropic fluid shows a decrease in viscosity over time at a constant shear rate while a simple shear-thinning fluid displays a decrease in viscosity with increasing shear rate[3].

I. Measuring the rheological properties of materials:

Rheometers are instruments that study the particular flow properties of fluids. Dynamic oscillatory rheometers are the most commonly used devices that measure the dynamic rheological properties of materials. They are designed with various geometries, usually cone and plate or parallel plates[3].

Dynamic oscillatory rheometers may work either in **strain controlled or stress-controlled modes**. Strain controlled rheometers induce a given strain in the samples and record the stress response. On the other hand, stress controlled rheometers induce a given stress and record the resulting strain[3].

Cone and plate dynamic oscillatory rheometers:

The cone and plate geometry are illustrated in (figure 5). The sample is placed between a plate and a cone of a low angle which tip virtually touches the plate at the center. The lower plate is coupled with a motor that makes the plate oscillate and a mathematical processor calculates the dynamic moduli and viscosity parameters. The advantage of the cone and plate geometry is that the shear rate is constant throughout the sample, which simplifies the mathematical analysis. But its drawback is that it is not suitable for filled or highly viscous materials[3].

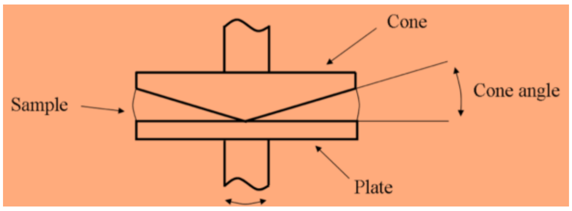

Figure 3: Cone and plate geometry for dynamic oscillatory rheometers [3]

Parallel plates dynamic oscillatory rheometers:

The parallel plates' geometry (figure 6) works on the same principles as for the cone and plate geometry, except that the mathematical analysis is a bit more complex because the shear rate inside the material is not constant. The shear rate is maximal at the edges and close to zero near the center. It can be used with highly viscous and filled materials[3].

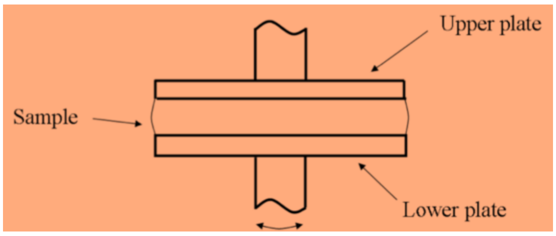

Figure 4: Parallel plates geometry for dynamic oscillatory rheometers [3].

II. Dental significance of rheological properties:

5) Dental materials have different viscosities depending on their intended clinical applications. Many dental materials are manipulated in a fluid state so that they can be placed and shaped as required; then they undergo transformation to a solid state, in which they are durable and perform their function. Following are some dental examples[4,5]:

1) Cements and impression materials undergo a fluid to solid transformation inside the patient's mouth.
2) Gypsum products are transformed extra-orally from fluid slurries into solids.
3) Monophase elastomeric impression materials are pseudoplastic. They can be used in a syringe because at the higher shear rates (encountered as they pass through the syringe tip), the viscosity decreases by as much as ten-fold so that they can record the fine details of the patient's mouth.

4) The rheological properties of resin composites have a direct impact on the handling characteristics of the material. Rheological properties affect the ability of the material to adhere to the tooth structure (and not to the operating instruments) , allow adequate shaping of the material within the restored site, reduce the operation time and enhance the quality of the restoration [2,6].

III. Rheological properties of resin composites:

Since resin composite restorations were developed as an esthetic and more conservative alternative to dental amalgam, many efforts have been made to improve their physical and mechanical properties. Throughout the years, many studies focused on the mechanical and physical properties of resin composites. However, there are only very scarce studies dealing with their rheological properties.

The handling and flow characteristics are one of the major parameters that affect the final quality, success rate and life span of composite restorations[2]. Although classification of dental resin composites has often been based on filler particle size, nowadays dental composites can also be classified according to their flow characteristics or rheological properties into flowable, medium viscosity and packable composites[2,6].

Dental resin composites are considered highly filled suspensions of inorganic particles in an organic matrix, which provides these materials viscoelastic nature, i.e. they have both liquid-like and solid-like behavior. Such suspensions also usually exhibit complex rheological properties such as shear-thinning (pseudoplasticity) and thixotropy[7].

Thixotropic nature of dental composites:

The exact explanation of the thixotropic nature of dental resin composites is still unknown. Two hypotheses have been suggested and both of them rely on the presence of microfiller particles:

The first hypothesis was based on **the spatial organization of the microfiller.** It was assumed that the decrease of the viscosity was the consequence of the destruction of the 3D network of microparticles formerly linked together via hydrogen bond and that recovery of the initial viscosity was the sign of the secondary reconstruction of that network[3]. **However,** TEM microphotographs that were performed on destructured and non-destructured sample did not show any difference in the dispersion of the microfiller (figure 7).

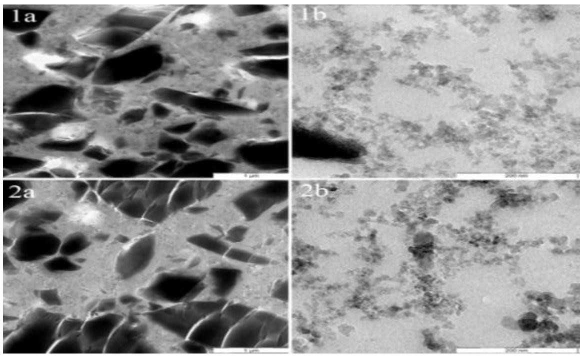

Figure 7: Dispersion of the fillers by transmission electron microscopy immediately after complete destructuration at 5000 x (1a) and 40,000 x (1b) magnifications and without any destructuration at 5000 x (2a) and 40,000 x (2b) magnifications [3].

1) The alternative explanation is that due to the **large contact area generated by the microfiller**, a very important part of the monomer interacts with the fillers surface. Accordingly, the monomer layer that surrounds the particles shows **greater restriction of the monomer mobility** resulting in a significant local increase of the viscosity. Although this hypothesis seems convenient for the explanation of viscosity increase, it is not sufficient to totally explain the time dependence of the viscosity after deformation[3]

IV. Factors affecting rheological properties of dental composites:

1) Matrix phase:

Dental composites are pseudoplastic materials and their fluidity is strongly dependent on the resin matrix phase[6,7].

Composite viscosity is greatly affected by monomer composition of the matrix phase. Studies revealed that composite viscosity decreases dramatically as the Bis-GMA/TEGDMA ratio decreases[7]. BisGMA, with its two hydroxyl radicals per molecule, increases the viscosity of monomer mixtures, promoting the formation of hydrogen bonds between the monomers. Conversely, TEGDMA, a small molecule with no aromatic cycle or hydroxyl radicals, helps lower the viscosity of composite matrix[8].

The polymerization rate of the matrix phase of resin composites is indicative of the viscoelastic behavior during curing: the higher the polymerization rate, the higher the stiffness and viscosity development of the cured material.

2) Filler phase:

Studies revealed that composites viscosity exponentially increased as the filler volume fraction was increased and vice versa [7]. Flowable resin composite is a clear example. They were created mainly by retaining the same small particle size of traditional hybrid composites, but reducing the filler content and consequently the viscosity of the mixture[2].

For identical filler volumes, composite viscosity increased as the filler size was decreased.

Microfillers are the major determinant of the final rheological properties of resin composites. The more the microfiller content increases, the more shear-thinning is observed, and the materials viscosity increases dramatically. On the other hand, as much as 60 % of macrofiller content alone does not have a major influence on the viscoelastic properties, except that it increases the Newtonian viscosity and that a slight shear-thinning behavior appears.

No direct correlation could be made between the morphology of the filler particles and the viscosity of the materials. However, filler morphology may affect the filler loading (e.g., spherical shape particles allow an increased filler loading) and thus indirectly affect the material's viscosity.

3) Effect of temperature:

As temperature increases, the viscosity of the composite decreases. This is understood in terms of the Arrhenius equation which shows the relationship between the temperature and fluid viscosity:

$$\eta = Ae^{(-Ea/RT)}$$

Where η is the viscosity; A: proportional coefficient; Ea:activation energy for flow; R: gas coefficient; T: temperature)

This explains why composite pastes with high filler loadings are normally hard and stiff at room temperature when they are squeezed out the syringe, but they become more readily adaptable in the oral cavity and can be molded into the prepared tooth cavity. Studies revealed that temperature increases from 25◦C to 37◦C significantly reduced viscosity of composite samples by between40% and 90%[6,7].

References:

1) Schümmer P. Mechanics of Non-Newtonian Fluids. Von W. R. Schowalter. Pergamon Press, Oxford–Frankfurt 1978.; 1979.
2) Beun S, Bailly C, Devaux J, Leloup G. Rheological properties of flowable resin composites and pit and fissure sealants. Dent Mater. 2008;24(4):548-555. doi:10.1016/j.dental.2007.05.019
3) Sébastien Beun. Rheological characterization of dental resin composites – fundamental study and clinical applications. Thesis Published online 2009.
4) Greig V. Craig's Restorative Dental Materials, 13th Edition. Vol 213.; 2012. doi:10.1038/sj.bdj.2012.659
5) Anusavice KJ, Shen C, Rawls HR. Phillip's Science of Dental Materials. :721-724, 94-108.
6) Al-Ahdal K, Silikas N, Watts DC. Rheological properties of resin composites according to variations in composition and temperature. Dent Mater. 2014;30(5):517-524. doi:10.1016/j.dental.2014.02.005
7) Lee JH, Um CM, Lee I bog. Rheological properties of resin composites according to variations in monomer and filler composition. Dent Mater. 2006;22(6):515-526. doi:10.1016/j.dental.2005.05.008
8) Jager S, Balthazard R, Dahoun A, Mortier E. Filler content, surface microhardness, and rheological properties of various flowable resin composites. Oper Dent. 2016;41(6):655-665. doi:10.2341/16-031-L