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Observation of shear bond strength between zirconia core and silica based composite material; a finite element analysis

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Abstract

The strength of all-ceramic restorations depends on not only properties of basic material but also used ceramic material, substructure and upper structure connection, the thickness of crown, design, and bonding technique of restoration. The purpose of this study is to analyze the shear stress between the zirconia core and silica-based ceramic by using the finite element method. Using 20-node structural solid elements, the shear stresses were calculated with the methods of shear test and Schmitz-Schulmeyer test through 3-dimensional finite element method. The commercial software Ansys (Ansys Version 11.0, ANSYS, Inc., Canonsburg, PA 15317, USA) was used to create a three-dimensional mesh. There is no significant difference between the test methods as a result of the force applied close to the bond interface. However, when moving away from the bond interface, it is understood that there is a failure in higher tensile forces. It was determined that there was no significant difference in the results when the force to be applied in both the Shear bond Test and Schmitz-Schulmeyer tests was performed the near interface of Zirconia core-Silica based veneer ceramic.

Keywords: silica based composite; finite elements analysis; shear strength; Schmitz-Schulmeyer; zirconia
Kulcsszavak: szilícium-dioxid alapú kompozit; végeselemes analízis; nyírószilárdság; Schmitz-Schulmeyer; cirkónia

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1. Introduction

Recent developments in dentistry for materials and technology have increased the aesthetic expectations. Ensuring the shade harmony between the specified shade and the natural shade of teeth is one of the most important criteria of success in the aesthetic sense. Nowadays, many ceramic materials and systems are used, and the clinical activities of these systems have been discussed in many scientific articles, and the differences between each other have been investigated [1]. Although metal-reinforced restorations are widely used, they can remain aesthetically inadequate due to their metal cores [2]. Despite the success of metal-ceramic restorations on power and impact endurance, researchers have not stopped looking for new materials [3]. All-ceramic restorations have gained great popularity in the last 10 years [4]. All-ceramic restorations are more aesthetic than metal-ceramic restorations, and this is one of the most important factors in the increase of their use [5]. In other words, all-ceramic restorations are more aesthetically superior because they have different optical properties than metal-reinforced ceramic restorations. Today, there are a large number of materials that are fully ceramic-based such as leucite-reinforced ceramics, glass-infiltrated ceramics, lithium disilicate, alumina, and zirconia [6]. In these, zirconia offers better mechanical properties. High durability, white appearance, chemical, and structural stability are the features that bring the zirconia core to the forefront. [7].

To obtain the optimum aesthetics, the zirconia cores are covered with silica based ceramic materials. Then, by adding veneer ceramics to the layer, certain restorations are provided according to the individual's optical characteristics. Zirconium substructure is resistant to damage from abrasions caused by sharp corners and internal adaptations sourced from the structure of teeth and durable to the pressures of chewing. Zirconia has a high bending resistance due to its transformation hardness characteristic, which puts itself ahead of other materials. It is biocompatible, which is also an important good feature. Covering the Zirconia core with silica based ceramic is better for its aesthetic appearance, while the weakness of fracture strengths is one of the disadvantages of zirconia-based restorations [7,8].

Different tests can be found in the literature on the determination of the shear stresses of Veneer ceramics [9]. Ozkurt et al. have applied Shear tests using the ceramics of 4 different manufacturers [10]. They also conducted a surface crack analysis to determine the errors. They found the highest shear voltage value as 40.49±8.43 MPa in the products of DC-Zirkon Company. In their study, they determined that shear stresses differ according to the type of zirconia used by the manufacturer.

Tuncel et al. investigated the effects of shading in zirconia veneering on shear stresses [11]. In the study, zirconia discs were divided into 11 groups, each of which were 12 pieces, and they used shear test method when examining the shading stress. As a result of their work, they found the lowest shear stress as 29.47 MPa and the highest shear stress as 36.40 MPa. As a result of their experiments, they determined that shadingprocesses affect the zirconia/ceramic shear stress, and the results they find showed that the study is clinically acceptable.

Teng et al. used the Schmitz-Schulmeyer test method to detect shear stresses in all-ceramic systems [12]. In the study, they used 30 zirconia core ceramics coated with veneering ceramics. They used three different surface leveling methods: surface leveling with silicon carbide disc, aluminum particles, airborne-particle abrasion and powder-coated zirconia. They used a metal-ceramic system as a control group and investigated their differences with all-ceramics in the results section. The average shear stresses of the control group were investigated with three different surface levels and was 47.02 MPa for powder-coated zirconia, 39.14 MPa for particle abrasion, 36.66 MPa for silicon carbide disc, and 46.12 MPa for the control group.

Guess et al. investigated the differences of the shear stresses between the core and veneering ceramics in all-ceramics belonging to different companies and their sensitivities to heat exchange through the Schmitz-Schulmeyer test method [13]. This study used a metal-ceramic system as a control group. The temperature range for which sensitivity is measured is 5-55 °C. They observed different shear stress values for different brands. Consequently, the shear stresses between the core ceramics and silica based ceramics are not affected by heat exchange [13].

The finite element method (FEM) is a numerical technique used by different disciplines in the field of engineering [14]. It provides cost and time savings during the modeling phase of the processes. Modeling of many materials can be done with FEM. In the application of dentistry, FEM is used in the analysis of the success of the all-ceramic restorations [15]. The calculation of shear stresses between core ceramics and veneer ceramics and the multifaceted examination can be done with FEM [16]. In this study, shear stresses between core ceramic and silica based ceramic in all-ceramic restorations were tested using shear Test and Schmitz-Schulmeyer test methods. The application was performed using FEM.

2. Materials and methods

In the present study, FEM was used for all calculations to detect shear stresses in all-ceramic restorations. Using 20-node structural solid elements, the shear stresses were calculated with the methods of shear test and Schmitz-Schulmeyer test through 3-dimensional FEM.

The commercial software Ansys (Ansys Version 11.0, ANSYS, Inc., Canonsburg, PA 15317, USA) was used to create a three-dimensional mesh which the model 1 (3D model used for shear testing, *Fig. 1*) consisting 9060 nodes with 42789 mainly tetrahedral elements and the model 2 (3D model used for Schmitz-Schulmeyer test, *Fig. 2*) consist of 12858 nodes with 8339 mainly tetrahedral elements.

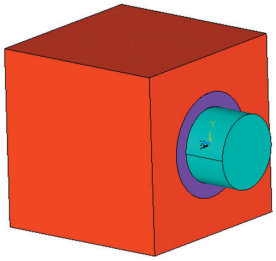


Fig. 1 3D model used for shear testing
1. ábra A nyírószilárság teszteléséhez használt 3D modell

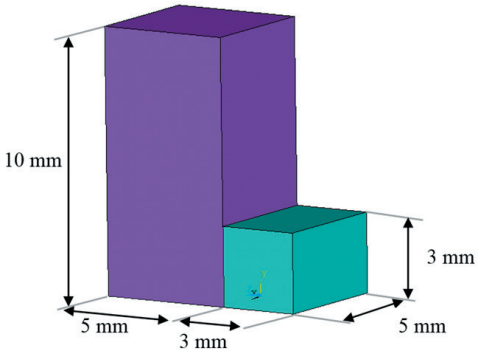


Fig. 2 3D model used for Schmitz-Schulmeyer test
2. ábra A Schmitz-Schulmeyer vizsgálathoz használt 3D modell

The Solid 92 element was divided into meshes with a 10-node tetrahedral element, which yields results closer to reality than the 4-node tetrahedral element, but with a longer solution duration.

This element has three degrees of displacement (u_x, u_y, u_z) at each node x, y, z direction, and is suitable for the solution of large displacements, large strain, slip and plasticity problems (*Fig. 3*).

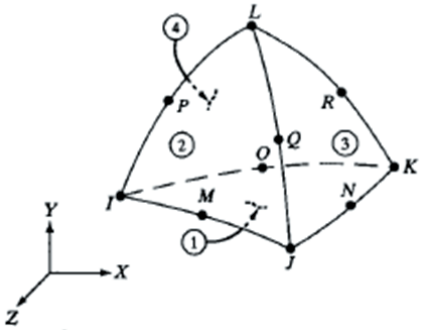


Fig. 3 10 node Solid 92 element
3. ábra 10 csomópontú Solid 92 elnevezésű végeselem

The mechanical properties of the materials used in the analysis are given (*Table 1*).

Materials	Young's Modulus (MPa)	Poisson Ratio
Acrylic resin	33×10^2	0.30
Zirconia Core Ceramic	1×10^5	0.25
Silica based Veneer Ceramic	65×10^3	0.19

Table 1 The mechanical properties of the materials used in the analysis
1. táblázat A felhasznált anyagok mechanikai tulajdonságai

2.1 Shear test

In the 3D analysis, a cylinder with a core ceramic structure with a radius of 3.5 mm was placed inside a cube made of 12 mm acrylic material for shear testing (*Fig. 1*). The silica based veneer ceramic material in cylindrical structure with radius of 2.5 mm is bonded to the core ceramic material. The cylinder height is 3 mm. Acrylic and core ceramics were divided into meshes with 3-dimensional tetra hedra elements. To apply the force to the desired location, the silica based veneer ceramic material was divided into meshes with hexahedra elements. The force was applied to 3 different regions as shown (*Fig. 4*) and the applied force is 200 N. The application area of the force is in the form of sharp knives (*Fig. 3*) but is a wider range of enforcement areas (*Fig. 3-b*).

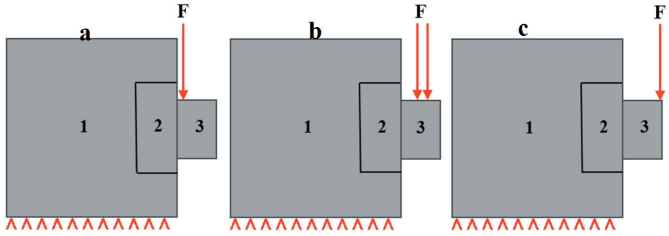


Fig. 4 *(1) Acrylic resin, (2) Zirconia Core Ceramic, (3) Silica based Veneer Ceramic, (a) Force applied to the region near the interface of Zirconia core-silica based veneer ceramic, (b) Force applied to the large surface area of silica based veneer ceramic, (c) Force applied to the end of the silica based veneer ceramic*
4. ábra *(1) akrilgyanta, (2) cirkónium-oxid kerámia, (3) szilícium-dioxid alapú furnérkerámia, (a) a cirkónium szilícium-dioxid alapú furnérkerámia határfelületéhez közeli területre kifejtett erő, (b) a szilícium-dioxid alapú furnérkerámia felületére kifejtett erő, (c) A szilícium-dioxid alapú furnérkerámia szélére alkalmazott erő*

As the boundary condition for this model, the nodes at the bottom of the acrylic resin were fixed as shown (*Fig. 3a*). It is assumed that all three materials are linear, elastic and isotropic.

2.2 Schmitz-Schulmeyer test

For Schmitz-Schulmeyer test, two rectangular prisms glued together were designed in 3D analysis as shown (*Fig. 2*). The core ceramic material was modeled with a rectangular prism of 5x5x10 mm and silica based veneer ceramic material with a rectangular prism of 3x5x3 mm. The force was applied in three different ways, as shown (*Fig. 5 a-c*), and the applied force is 200 N.

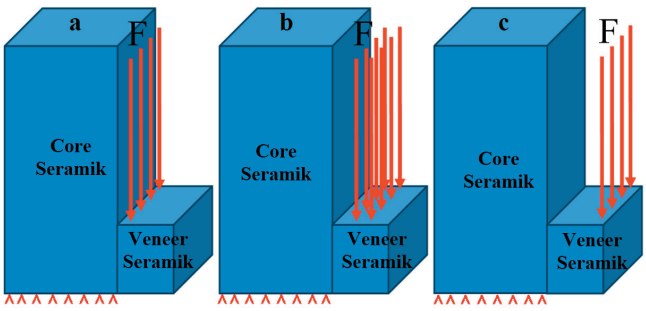


Fig. 5 *(a) Force applied to the region near the interface of Zirconia core- silica based veneer ceramic, (b) Force applied to the large surface area of silica based veneer ceramic, (c) Force applied to the end of the silica based veneer ceramic*
5. ábra *(a) A cirkónium szilícium-dioxid alapú furnérkerámia határfelületéhez közeli területre kifejtett erő, (b) A szilícium-dioxid alapú furnérkerámia felületére kifejtett erő, (c) A szilícium-dioxid alapú furnérkerámia végére kifejtett erő*

As a boundary condition for this model, the nodes at the bottom of the core ceramic material were fixed. It was assumed that the two materials are linear elastic and isotropic.

3. Results and discussion

In all-ceramic restorations, the shear bond test (*Fig. 4*) and Schmitz-Schulmeyer test (*Fig. 5*) were modeled and analyzed with finite element method to detect shear stresses between core ceramics and silica based veneer ceramics. The maximum shear stresses obtained from the analyses were given (*Table 2*).

For shear bond test, the results of shear stresses obtained as a result of forces applied to positions (Figs. 4,6).For Schmitz-Schulmeyer test, the results of shear stresses obtained as a result of forces applied to positions (*Figs. 5,7*).

	Shear Test (MPa)	Schmitz-Schulmeyer Test (MPa)
Near interface of Zirconia core-Silica based veneer ceramic	63.05	64.45
Wide surface of silica based veneer ceramics	47.04	100.58
Endpoint of silica based veneer ceramic	265.26	369.43

Table 2 *The maximum shear stresses obtained from the analyses (MPa)*
2. táblázat *A számításokból meghatározott maximális nyírófeszültség (MPa)*

The more aesthetic demands expected from dental restorations have increased the clinical use of all-ceramic restorations. With the development of zirconium oxide-based core materials, strong core and aesthetic veneer ceramic combinations have been successfully used. In order for zirconium oxide-based restorations to provide long-term functional, biological, and aesthetic requirements, the bond between reinforced core and esthetic veneer ceramic must be successful [17]. Luthardt et al. [18] indicated that failure in zirconium oxide systems mostly occurred on two porcelain interfaces.

The presence of zirconium oxide monoclinic phase on the interface of zirconium oxide-based restorations with core and veneer porcelain may result in the formation of intermediate micro-spaces[19]. Phase transformation occurring in zirconium oxide can trigger the formation of localized stresses that cause micro cracks in the veneer porcelain. The thermal expansion coefficient of the monoclonal phase in zirconium oxide ceramics is 7.5 x 106 K^{-1}, and the thermal expansion coefficient of the tetragonal phase is 10.8 x 106 K^{-1}[19]. For these reasons, it is reported that t → m transformation occurring on the surface of zirconium oxide ceramics can affect the bond strength between the core and silica based veneer porcelain [20].

Limited in vivo studies that evaluate zirconium oxide-reinforced core restorations indicate that the most common failure in such restorations is that whole or part of the veneer porcelain can separate from the core in the form of layers [21]. It is thought that many factors are involved in the occurrence of this problem. These can be sorted as a lack of proper geometry of the core, fatigue phenomenon, in-ceramic defects, insufficient core support, lack of occlusal stability, patient-dependent factors, inadequate bonding force, discrepancy between the core, and

the thermal expansion coefficients of the materials used in the core and veneer [7,22]. Although the factors affecting the bond in the interface are known, but the bond between the core and the veneer has still been not clearly explained.

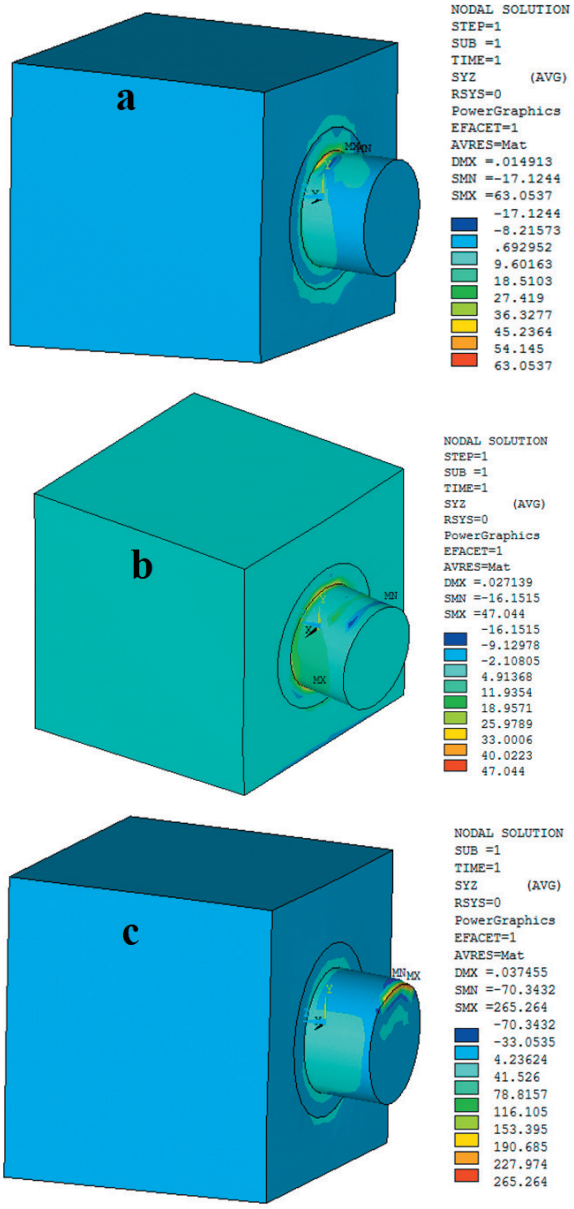


Fig. 6 According to the force applied to areas, shear stress results (a) near the interface of Zirconia core-silica based veneer ceramic, (b) the large surface area of silica based veneer ceramic, (c) the end of the silica based veneer ceramic

6. ábra Az alkalmazott terhelésekből számolt nyírófeszültség (a) a cirkónium-dioxid alapú furnérkerámia határfelülete közelében, (b) a szilícium-dioxid alapú furnérkerámia felületén, (c) a szilícium-dioxid alapú furnérkerámia szélén

In a study, which evaluated the fixed-section prostheses with 3 to 5-member zirconium oxide core in the posterior region on 45 patients during 3 years of use, the failure of the veneering to separate from the core was revealed as 13% [21]. In a prospective clinical pilot study that investigated the activities of the three-member zirconium oxide core prostheses in the posterior region, the 20 three-member zirconium oxide core prostheses with fixed-section were followed up on 16 patients during 3 years, consequently the minor fractures were observed in the veneer porcelain in the five of the fixed-section prostheses [23]. At the end of the 2-year follow-up period of 20 zirconium oxide core with 3-5 members fixed part prosthesis by using DC zirconium technique, they reported that fractures in the veneer porcelains were observed in 15% of the restorations[24].

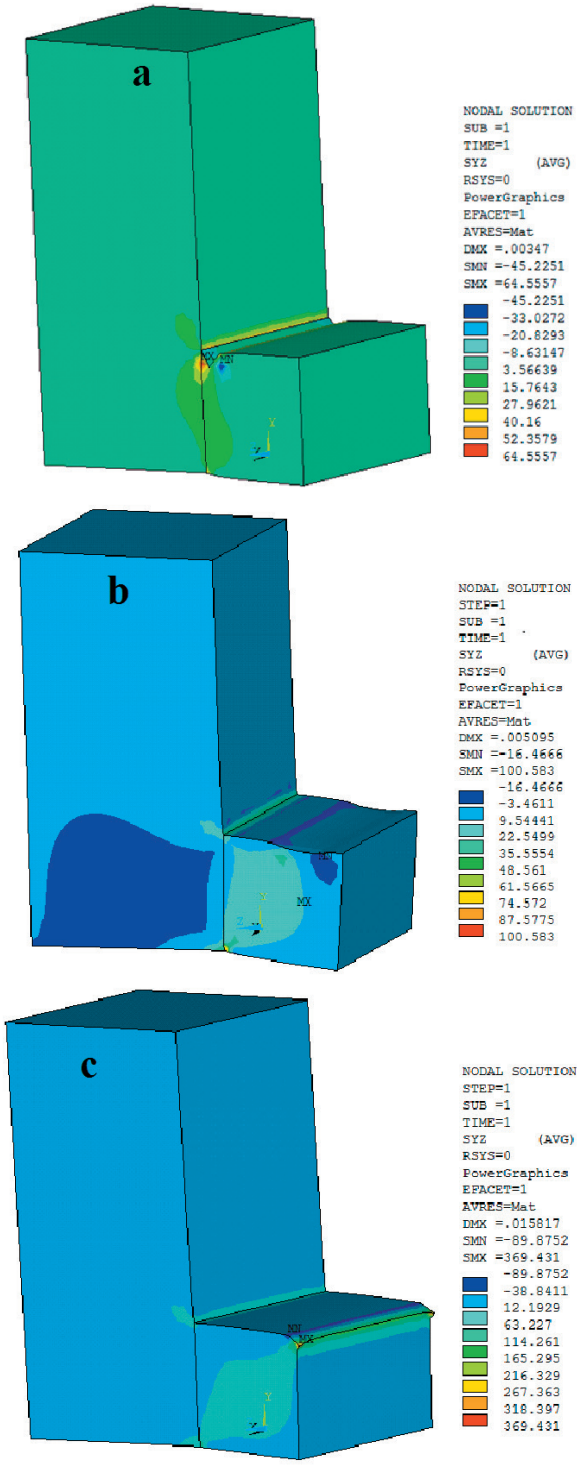


Fig. 7 According to the force applied to areas in Schmitz-Schulmeyer test, shear stress results (a) near the interface of Zirconia core-silica based veneer ceramic,(b) the large surface area of silica based veneer ceramic, (c) the end of the silica based veneer ceramic

7. ábra A Schmitz-Schulmeyer teszt során a kifejtett erő szerint a nyírófeszültség értéke (a) a cirkónium-oxid szilícium-dioxid alapú furnérkerámia határfelülete közelében, (b) a szilícium-dioxid alapú furnérkerámia felületén, (c) a szilika alapú furnérkerámia szélén

In the present study, we compared the bond strength between zirconia core and silica based porcelain by using shear bond test and Schmitz-Schulmeyer test methods with finite element analysis in both test methods and obtained a stress of 64.45 MPa with shear test and 63.05 MPa with Schmitz-Schulmeyer test for near interface of zirconia core-veneer ceramic. With the force applied to the wide surface of veneer ceramics, 47.04 and 100.58 MPa stress were obtained, respectively. In addition, with the force applied to the veneer ceramic endpoint, which is the third force application point, the stress was 265.26 MPa with shear test and 369.43 MPa with Schmitz-Schulmeyer test. *Table 2* shows that there is no significant difference between the test methods as a result of the force applied close to the bond interface. However, when moving away from the bond interface, it is understood that there is a failure in higher tensile forces. At the same time, bond strength assessment with Schmitz-Schulmeyer test application may result in failure due to higher forces.

A study, where the bond strength is tested on different core and porcelain surfaces by the Schmitz-Schulmeyer test method, reported that bone strength in zirconia core and silica based porcelain interfaces was not better than metal ceramics, and this bone strength was not affected by thermal cycles [13].

In the literature, there are studies that compare the bond strength values between different core materials and dental ceramics [4,9,10,11,13]. In the present study, both the test methods and the bond failure at different distances of the applied force to the bond interface were evaluated by finite element analysis. If the distance to the bone interface increases, we can say that the bone strength occurs as a result of applying force at higher values. We can also propose that the higher bone strength values with the Schmitz-Schulmeyer test application are due to the larger bond surface area.

One of the factors that affect the success of the treatment with complete ceramic systems is the choice of the right material. Two experimental methods used in dentistry to measure shear stresses in all-ceramic restorations are Shear bond Test and Schmitz-Schulmeyer test. In experimental tests, there is not much data available, and there is also a time and cost problem. With finite element analysis, both methods can be done using more materials at a lower cost and in less time. In addition, it is possible to analyze shear stresses in all-ceramic systems in a versatile way by finite element analysis.

4. Conclusions

As a result of our finite element analysis study, in vitro experimental studies investigating the shear bond strength of zirconia and feldspathic ceramic materials of all-ceramic restorations, it was determined that there was no significant difference in the results when the force to be applied in both the shear bond test and Schmitz-Schulmeyer tests was performed the near interface of zirconia core-Silica based veneer ceramic. However, it has been observed that the difference in test methods significantly affects the results in the case of applying a load from the wide surface or the endpoint of silica based veneer ceramic of the connection.

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Invitation to Ceramics 2022

Dear Colleagues and fellow Ceramists,
As we all know only too well, the global pandemic has had some tragic consequences as well as disrupting our personal and professional lives very significantly. Whilst many valiant efforts have been made to continue with meeting and conferences on-line, our ability to talk face-to-face with each other and enjoy each other's company has in many cases simply not been possible. However, the good news is that, hopefully, things look as if we may be able to start planning again for a world where we can meet, learn and laugh together.

The undersigned below would very much like to invite all of you to a meeting that we hope will help to re-unify the worldwide ceramics community in one place and at one time. By agreement between the European Ceramics Society, the International Ceramic Federation and the International Committee of Electroceramics, and with excellent international co-operation, it has been decided to combine three major conferences into a single major conference. We realise just how busy 2022 is likely to be as many conferences that have had to be postponed are now jostling for timeslots – and attendees' budgets. Our move will see ECerS XVII, ICC9 and Electroceramics XVIII all held simultaneously in Krakow, Poland, 10-14 July 2022. A single registration fee will provide access to all three conferences, which are being hosted under the common title Ceramics in Europe 2022.

We truly hope that you will let this wonderful and ancient city with an old university and scientific tradition become the background for a tremendously fruitful meeting, which will give us all a much-needed boost for achieving progress again in our professional lives for the benefit of our world.

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