Features of acetone dynamic effects induced to acrylic teeth superficial layer: a time domain C Scan (En Face) OCT new approach.

Adelina Elena Stoia, Cosmin Sinescu, Mihai Rominu, Adrian Gheorghe Podoleanu.

Abstract—The main reason of this study is mainly represented by the C Scan (En Face) OCT time domain investigation of acetone dynamic effects induced to the superficial layer of acrylic teeth. One of the organic solvents used in order to improve the adhesion of acrylic teeth to denture base resin is acetone.
The ridge lap area of 20 acrylic second upper molars (Spofa Dental complete denture kit) was milled to flat. Afterwards the molars with the milled ridge lap area were cut in two halves. The artificial teeth were randomly assigned in 2 groups. : Group 1. (control) (without treatment), Group 2. Acetone treatment. The both sample groups were submitted to OCT C Scan (En Face) investigation for 200 seconds. The both sample groups were also submitted to SEM (Scanning Electron Microscopy) nondestructive investigation.
The dynamical changes of acrylic teeth superficial layer induced by acetone, among which the superficial layer hardening, were captured with C Scan OCT, proving the fact that time domain C scan OCT could be used in order to investigate the dynamics of the effects of this organic solvent to the polymeric acrylic teeth substrate.

***Keywords*—** acetone, acrylic teeth, En Face (C Scan) OCT, superficial layer.

I. Introduction

FROM ancient times it was found that solids are able to adhere strongly after wetting each of the surfaces to be joined with a thin liquid layer that hardened or solidified gradually during contact. In our days, despite the advanced technology, numerous unanswered questions concerning principles underlying the mechanism of adhesion are still present. This aspect is responsible for excessive empiricism, situation still common in current application techniques.
The adhesion is influenced by important factors including: the relation between adhesion and friction, the effects of non matching the physical properties of adhesive and adherent, the effect of voids or occlusions on the development of stress concentrations, and mostly the role of adsorbed films and inappropriate wetting on joint strength.
In other words the role of chemical constitution of adherents and adhesives on adhesion is of great importance.
Among the known methods used to bond plastics it could be mentioned: the adhesive bonding, the welding, the mechanical fastening and last but not least the solvent cementing known also as solvent welding.
The solvent welding requires a few principles regarding the design of the adherent surfaces and the selection of the solvent cement.
The plastic material surfaces that will be bonded are brought to a fluid, tacky condition after the application of a solvent for the plastic. In some cases, the solvent is represented by a catalyzed monomer, or, could contain a dissolved polymer, the same with one from the plastic component.
A cohesive joint will result, with joint properties similar to the properties of a homogeneous piece. This process is suitable for amorphous and soluble thermoplastics, such as acrylic resins, cellulosic resins and polystyrenes.
Dissimilar thermoplastics may be solvent cemented, providing the fact that they are compatible with each other in solution and also in molten condition.
Selection of the solvent cement must be guided by the type of solvent.
There are three principal types of solvent cements used for thermoplastics. Those are: simple solvents, solvents containing polymers (dope cements) and solvents containing monomer (polymerizable cements).
The simple solvents, or blends of solvents, must be carefully selected for the specific plastic to be bonded. In other words, they must have an appropriate solvency to soften the plastic surfaces to such a depth that when pressure is applied, a slight flow occurs at every point in the softened area. The solvent must dry completely without bloom and without leaving residues that will plasticize and weaken the plastic.
Whereas the low-boiling solvents are inexpensive and able to generate the fastest setting action, they can cause frequently crazing of the plastic, lowering the optical clarity in the bond.

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The fast evaporation of the above mentioned low-boiling solvents leaves the joint in a state of stress or crazing, so that the formation of many tiny cracks is a process, through which these stresses relieve themselves, particularly, in brittle, low-impact-strength plastics.
Polymer containing solvents are represented by bonding solvents which contain in solution a quantity of the same polymer that is being bonded.
Solvents containing monomers are made from a reactive monomer, which is compatible or even identical with the one to be bonded.
The selection of the best solvent for solvent cementing procedure is directly dependent to the solubility parameter of the materials. The solubility parameter is defined as the square root of the cohesive-energy density, this being the amount of energy required to vaporize one cubic centimeter of the hypothesized liquid. Basically a non polar molecule will require less energy for evaporation, so it will have as a consequence a lower solubility parameter than the highly polar associated molecules. Each plastic material dissolves best in solvents whose solubility parameters are almost equal to its own.
The adhesion of acrylic teeth to denture base resin, is responsible for the longevity of a complete denture, but even so, still remains a common problem in dental laboratory practice according to numerous authors among which Patil et al. P [1] and Darbar et al. [2].
Even if the two main components of the complete denture, the artificial acrylic teeth and the denture base resin have almost a similar composition from chemical point of view, the detachment of acrylic teeth from the resin of the denture base reaches levels of almost 30%, as it was mentioned by authors such as Huggett et al [3], Fig. No.1.
The causes of the decreased adhesion between acrylic teeth and the resin of the denture base are numerous, varying from many different types of impurities [4], [5] to manufacturing technology steps, mechanical or micromechanical treatment such as micro-sandblasting realized with 50 μm Al_2O_3 particles [6],[7],[8],[9].
Chemical treatment of acrylic teeth ridge lap area represents also an important factor of influence regarding the adhesion between acrylic teeth and denture base resin, the improvement of the adhesion being proved after chemical treatment with methylene chloride [10].
Other organic solvents were used also in order to improve the bond strength between acrylic teeth and denture base resin: methyl methacrylate, ethylene chloride, ethyl acetate and also acetone.
Acetone is a solvent used successfully for cellulose nitrate cementing.
This study purpose is focused around the need to capture with nondestructive investigations methods aspects of the depth changes of the superficial layer of acrylic teeth after acetone chemical treatment, aspects that could explain the tensile strength lower values of the acetone treated samples group compared to the control group (without treatment) obtained after tensile strength testing [11].
The chemical treatment of acrylic teeth with organic solvents is realized in order to enhance the bond strength of acrylic teeth to denture base resin.

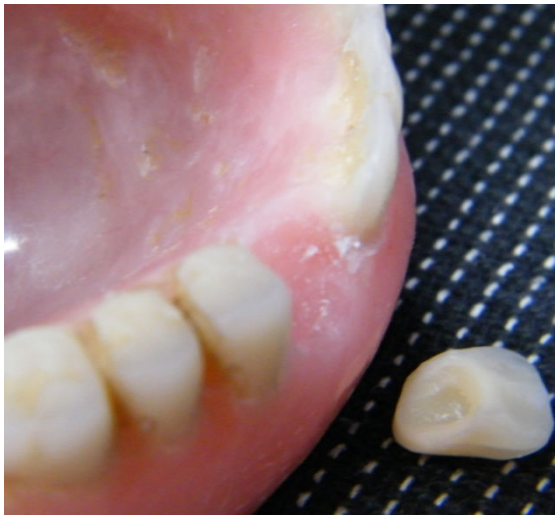

Fig.No.1. Dethachment of acrylic teeth from denture base resin

According to [11], the bond strength between acrylic teeth and denture base resin, after acrylic teeth acetone treatment is lower, compared to control group (no treatment). Because the tensile strength testing is a invasive investigation method used to demonstrate the bond strength also between acrylic teeth and denture base resin, but because it is not able to explain the reason why the bond strength tests obtained values, are lower or higher than the ones pertaining to control group, it was chosen to investigate the superficial layer assumed depth changes of acrylic teeth treated with acetone, in C Scan Time Domain Optical Coherence Tomography.
Beginning with the early years of 1980, three basic approaches of optical tomography were developed: diffraction tomography, diffuse optical tomography and optical coherence tomography (OCT). Those optical techniques are safe, not extremely expensive and they offer in addition a substantial therapeutic potential.
The advances in OCT technology since 1990 until now are responsible for a large variety of applications, especially in the medical applications field.
Among the advantages of OCT, we could mention: the high probing depth in scattering media, the so called contact-free, the non invasive operation, the ability to realize different various function image dependent contrasting method, the high depth and the transversal resolution.
The depth resolution is separated in OCT from the transverse resolution.
OCT is able to synthesis cross-sectional images from a multitude of laterally adjacent depth-scans. OCT is used in three different fields of optical imaging: in macroscopic imaging of structures seen by the naked eye or using weak magnifications, in microscopic imaging using magnifications up to the classical limit of microscopic resolution and also in endoscopic imaging, where low and medium magnifications are used.
The reflectometry technique and the dual beam technique of OCT were initially based on time-domain low coherence interferometry depth-scans.

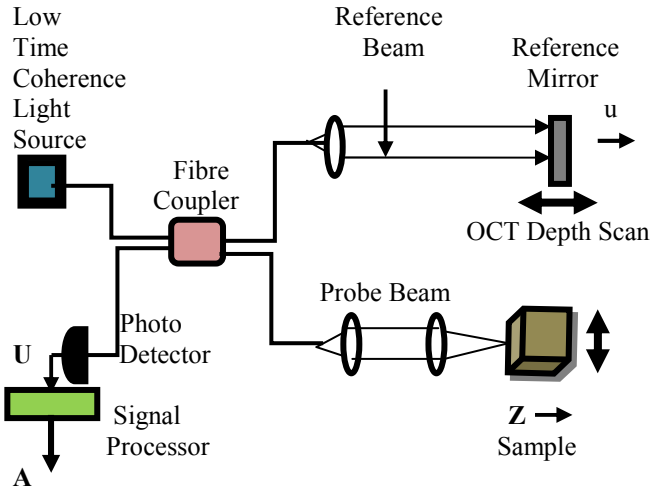

Fig.No.2. Time domain reflectometer LCI in fibre optics technology. U-U_m =U_G (τ) = LCI [12].

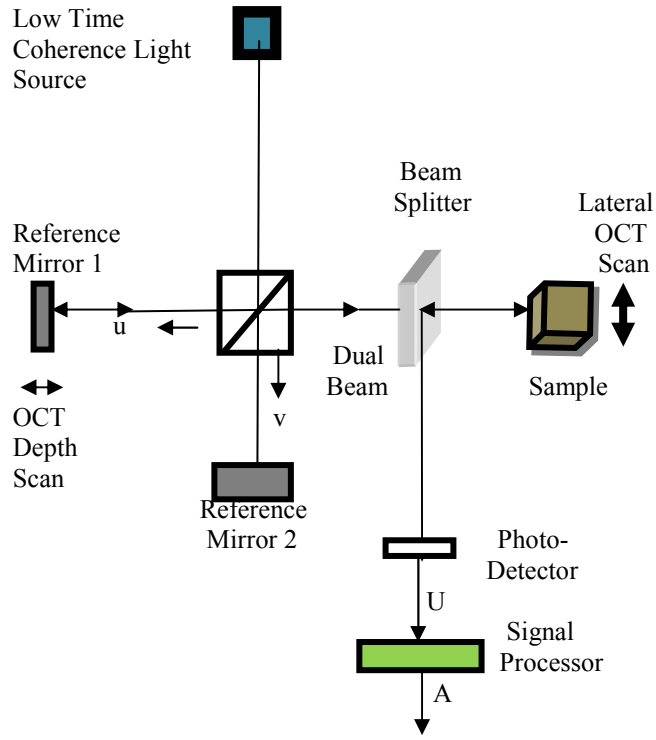

Fig.No.3 Dual beam LCI in free space optics technology [12].

The expression of low coherence interferometry in OCT is time domain, investigation mode used also in order to visualize at microscopic scale the effect of acetone to the superficial layer of acrylic teeth. So, in standard OCT, two scans must be able to perform: the lateral OCT scan addresses laterally adjacent sample positions whereas the OCT depth-scan uses time-domain LCI to detect depth positions of light re-emitting sites in the sample. There are two basic low coherence interferometry techniques in the time-domain and both of them are using the two-beam interferometry.

One of them is the reflectometer technique, in this case the sample is placed inside the interferometer and illuminated by the sample beam only. (Fig.No.2)
The other one is the dual beam technique; the sample is localized outside the interferometer and illuminated by both interferometer beams (Fig. No.3) [12].

II. MATERIAL AND METHODS

The null hypothesis is regarding the fact that (En Face) C Scan OCT could not capture the changes induced by acetone into the depth and at the surface of the superficial layer of acrylic teeth.

A. Sample Preparation

In order to be able to visualize the effects of acetone on acrylic teeth under En Face C Scan OCT investigation, as a first step, 20 acrylic second upper molars ridge lap area was milled to flat and afterwards the molars were cut in two halves so that the samples have two flat surfaces: the ridge lap area milled to flat and perpendicular to that area, the also flat surface resulted after cutting the sample in two halves.

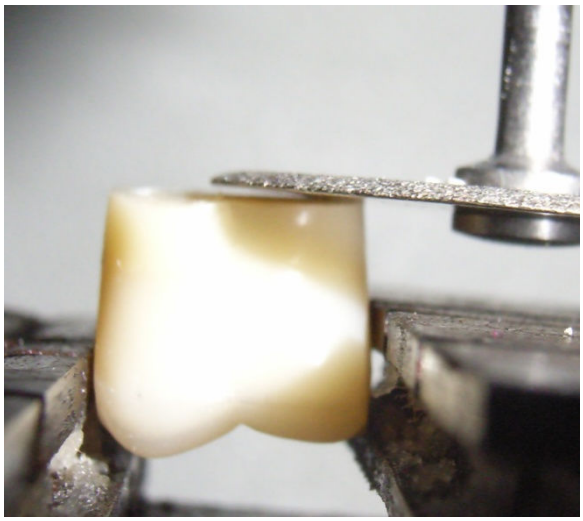

Fig.No.4. Surface "I" rezulted after the ridge lap area was milled to flat.

In order to understand the shape of the samples we considered to name the ridge lap area milled to flat, surface "I", the milled to flat surface "I" is showed in Fig. No.4. With a diamond disc the samples were cut in two halves so that the other flat surface was obtained. This surface was named surface"II". Surface "I'' is perpendicular to surface "II", in other words surfaces "I" and "II" are perpendicular one to each other.
The milling was realized with a disc attached to Dakar Alexandro Altun milling keys device.
According to [13] it is esential that the surface trough which the optical beam used in OCT C Scan reaches the sample, is pefectly flat, without any convex areas, in order to evoid optical artefacts in captured C Scan OCT images.
This is the reason for which the samples were cut in two halves.

In this study the surface trough which the optical beam reaches and traveles in to the depth of the sample is surface"II".

B. En Face (C Scan) OCT time domain noninvasive investigation

After the geometry of the samples was realized, the samples were randomly assigned in 2 groups. : Group 1. (control) (without treatment), Group 2.Acetone treatment. The both sample groups were submitted to Time Domain OCT C Scan (En Face) investigation.

As a first step the samples of the control group were submitted to C Scan OCT investigation, afterwards, as a second step, the acetone treated samples were investigated in Time Domain C Scan OCT as it can be seen in Fig.No.5. and in Fig. No.6.

Fig.No.5. Time Domain OCT device used to investigate the effect of acetone to acrylic teeth.

The flat milled surface of the samples is the surface submitted to chemical treatment with acetone. Both falat surfaces are perpendicular one to each other so that the optical beam direction along his travel trough the dept of the sample, in order to realize C Scan OCT time domain images, is perpendicular to the surface "II", basiccally to the XY plane.

OCT is able to provide cross-sectional images of the structures situated underneath the tissue surface, similar to histopathology abilities.

The maximum imaging depth in almost all types of tissues, except the transparent tissues (the eye tissues for example) is limited by scattering and optical attenuation to 2-3 mm [14] [15].

Even though the OCT depth is shallow compared to other clinical imaging techniques, the image resolution of OCT is from 10 to 100 times finer compared to conventional ultrasound imaging, to computed tomography and also to magnetic resonance imaging.

According to Fujimoto [16] OCT is able to provide resolutions similar to the ones used in conventional histopathology, can be operated in situ, in real time also, allowing from this point of view even the investigation of the response to therapeutic agents. OCT also is able to perform functional imaging among which spectroscopic imaging of tissue properties.

Fig.No.6. One of the acrylic samples in front of the OCT device scanning head durring acetone treatment.

Last but not least, the imaging processing techniques and intelligent algorithms must be used in order to asses OCT images and quantitatively and extract diagnostic information.

OCT can operate in different modes. [17]

In the transverse mode, one galvo-scanner is driven with a ramp at 700 Hz and the other galvo-scanner with a ramp at 2 Hz. In this way, a C-scan image, perpendicular to the optic axis is generated at constant depth [18].

En Face C Scans OCT are realized using a collection of T scans, lying in the same transverse XY plane of the probed object, collected at a constant dept. The acquisition is performed at the slower rate determining in this way the image frame rate.

Optical Coherence Tomography (OCT) according to Huang et al [19] is known to be a powerful and very sensitive tool used in order to characterize the optical properties and to realize imaging data of superficial tissue. OCT achieves micrometer depth resolution and allows in vivo measurement of thickness, area and volume in the tissue. In OCT, the depth dimension is explored after scanning the optical path difference (OPD) between the object path and reference path in an interferometer illuminated from a low coherence source.

The maximum interference signal is obtained if OPD = 0.

The achievable depth resolution in OCT is given by the optical source line width. OCT is a remarkable method for high resolution imaging of superficial tissue, with penetration depths of up to 2–3 mm, depending on the scattering and absorption properties of the tissue.

A super luminescent diode (SLD) [20] generates a depth resolution of OCT better than15 μm and a larger band width source allows a resolution depth of 2 μm [21].

C-Scans are made from numerous T-scans along either of X, Y, ρ or θ coordinates, repeated for different values of the other transverse coordinate, Y, X, θ or ρ, respectively, in the transverse plane. The repetition of T-scans along the other transverse coordinate is performed at a slower rate than that of the T-scans, called the frame rate, so that a complete raster

will be generated in this manner [22]. Different transversal slices can be collected at different depths "Z" [23] or at the same depth in the Z plane.
The optical scheme of OCT C Scan (En Face) device is represented in Fig. No.7

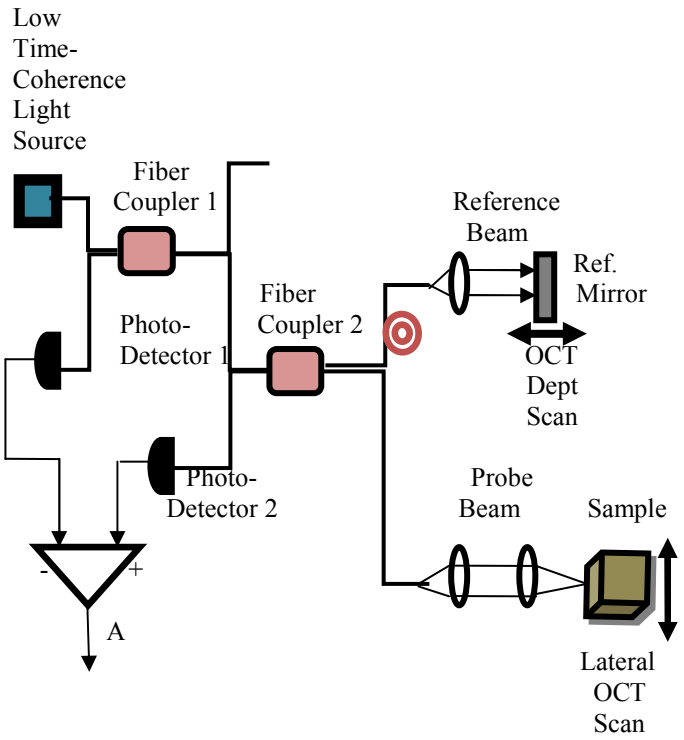

Fig.No.7 En Face (C Scan) OCT fiber optics technology with dual balanced detection (photodetectors 1 and 2) for intensity fluctuation compensation [24], were " " represents a piezoelectric fiber stretcher.

Comparing the Fig.No.7 with Fig. No.2 and also with Fig No.3, differences and similarities between OCT's time domain two basic low coherence interferometry based on two-beam interferometry techniques and En Face, C Scan OCT fibber optics technology can be understood.
En Face OCT is a technique that has been introduced by Izatt et al [24] in the field of microscopy in order to yield transversal sections of the sample.
A fast lateral scan is performed by the sample or by the probe beam. The referrence mirror is used in order to adjust the depth of these scans.
Since there is no depth-scan-generated heterodyne frequency, a separate phase modulation is introduced either to the reference beam, either tho the sample beam.
Izatt et al [24] have demonstrated that the coherence gate can substantially improve the probing depth of microscopy. Confocal microscopy can be enhanced when the collected signal at the focal plane is dominated by light scattered from other planes.
Podoleanu et al [25], later in 1998, used the en-face technique to generate OCT images of different types of objects such as human retina in vivo.
As a extension of that technique stacks of transversal OCT images were generated so thath three dimensional profiles of the tissue were , in this manner constructed.
In other words longitudinal images could be generated by software at any transversal position in the stack according to Podoleanu et al [26].
Further advancement research investigations in this field were made by Rogers et al [27].
Standard time domain OCT as well as en face OCT are single point detection techniques. These techiques have already been used in order to generate two dimensional OCT images up to video rate. Rollins et al [28] recordet the beating heart of a Xenopus laevis embrio with an image acquisition rate of up to 32 frames per second and 125 depth-scans per frame.
Podoleanu et al [29], in 2000, generated 112 en-face OCT images of a human optical nerve head at a rate of two frames per second. The captured imaging data were mounted to a three dimensional data set, in order to vizualise the tissue volume from different viewing angles and also to show slices with different orientations.
Durring the last 10 years, the reaserch of Prof. A.G.Podoleanu team, in the medical field, was not limited only to ophthalmology, it was extended also in many areas of the dentistry among which we could mention prosthodontics, orthodonthics, endodontics, odontology, implantology [30], [31], [32], [33].
Among the working parametres of this study, at which the images of each one of the samples, control and acetone treated samples, were captured, we could mention the $\lambda = 1300$ nm.
The investigation time for acetone treated samples and for the control group samples was establised as 200 seconds.
The frames of all the samples submitted to C Scan OCT investigation were captured at a rate of 1 frame/ second.
So, bassically, the frame rate of the C Scan OCT captured imaging data regarding the effect of acetone to the superficial layer of acrylic teeth, was established at 1 frame/second, and, because the investigation time was 200 seconds, a complete number of 200 En Face (C Scan) OCT imaging data frames was obtained.

C. SEM nondestructive investigation process

The same samples of the Group 1. (control) (without treatment), and Group 2.Acetone treated were both submitted to SEM nondestructive investigation, after C Scan OCT investigations were realized.
The investigations were realized using the variable pressure Hitachi TM-3000 Tabletop Scanning Electron Microscope. The imaging mode of SEM Hitachi TM3000 Table Top Scanning Electron Microscope used in this study is Topo Mode, a function based on four back scattered electrons detection sections. Higher or lower areas of the sample are observed in this manner. Topo Mode imaging was chosen in order to investigate the aspects of the surface of the samples before and after acetone treatment. SEM Hitachi TM3000 does not require technical skills or sample preparation. The observed area of the samples submitted to SEM TM3000 investigation reaches 35 mm square. It was chosen to work under BSE TOPO Signal Name, at 5000 Volt (5KeV) Accelerating Voltage, at a Working Distance of 6000 um and at 1000 Magnification.

III. Results

The images captured before and during the chemical treatment with acetone in time domain C Scan OCT have revealed also the so well known fact that acetone is capable to produce changes at the superficial layer level of artificial acrylic teeth.
The yellow arrows from Fig.No.8, Fig.No.9, Fig.No.10 and also Fig.No.11 were used in order to indicate the surface of the acrylic samples in C Scan OCT.
The red arrows from Fig.No.9 are used in order to indicate the acetone penetration depth in to the superficial layer of acrylic teeth after 10 seconds treatment time.

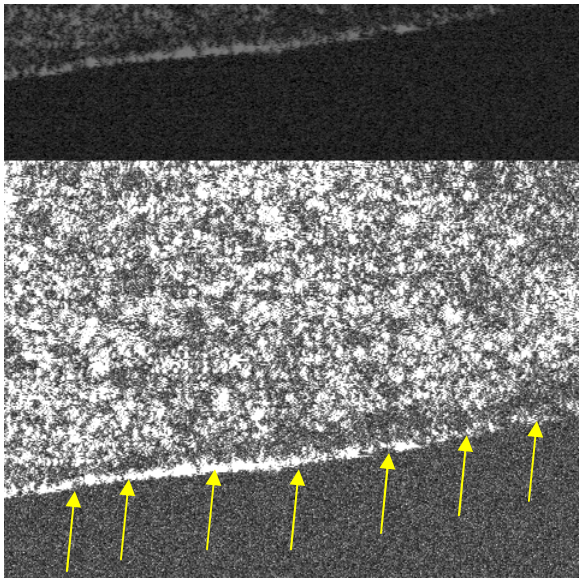

Fig.No.8. Acrylic teeth sample data imaging captured in time domain C Scan OCT before chemical treatment.

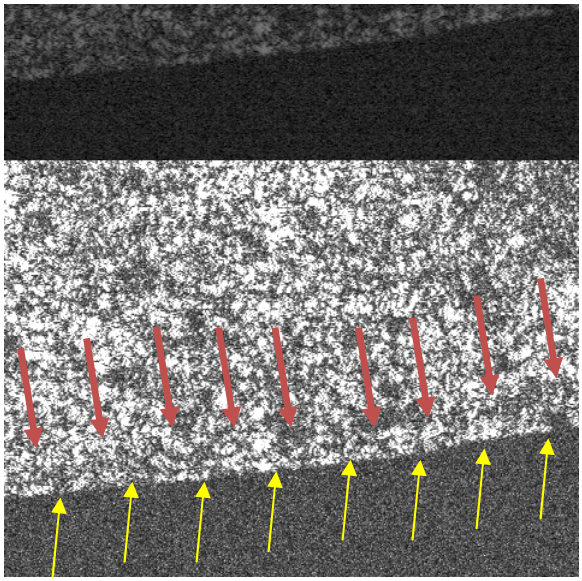

Fig.No.9. Acrylic teeth sample after 10 seconds acetone treatment in C ScanTime Domain OCT.

The same aspects are visualized in Fig. No. 10, after 1 minute (60 seconds) acetone treatment time, but in this situation the width of the strip situated between the red arrows and the yellow arrows is noticeably accentuated.
The "white" strip line with a barely noticeable width that was observed in C Scan OCT beginning with second 100 of acetone treatment, has a superior limit line represented by the surface of the acrylic teeth indicated with yellow arrows, and a lower limit line indicated with dark green arrows in Fig.No.11. Basically, this so called "white" thin strip is characterized by a distinguishable pronounced, sharp contrast difference reported to the underlying layer modified during acetone treatment.

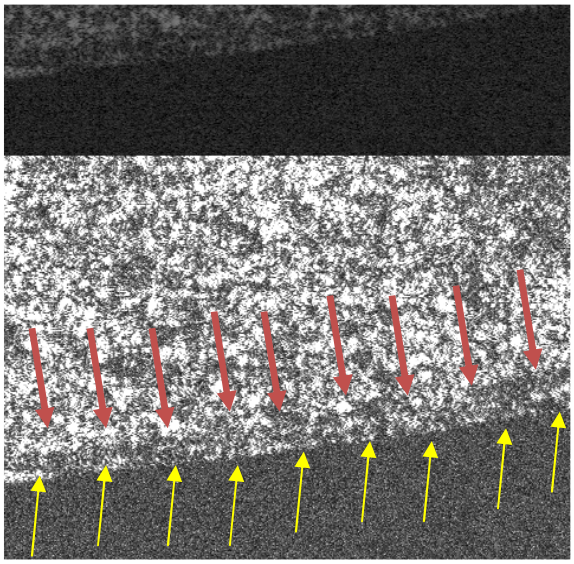

Fig.No.10. Acrylic teeth sample after 60 seconds acetone treatment in C ScanTime Domain OCT.

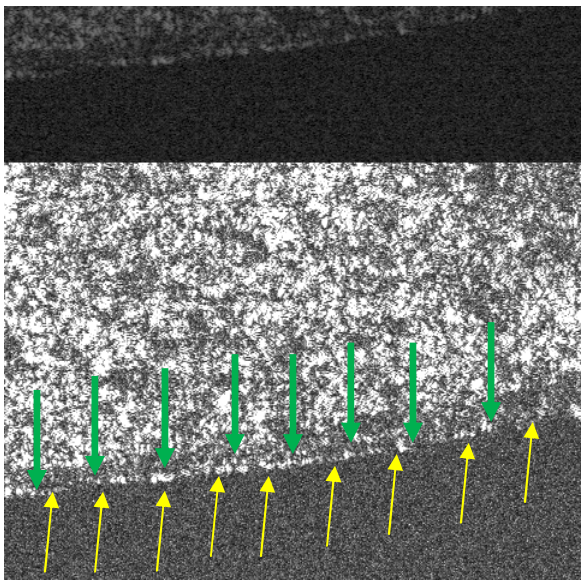

Fig.No.11 C Scan OCT time domain capture revealing a strip 'white' line at surface of the superficial layer of acrylic teeth sample after 100 seconds treatment time

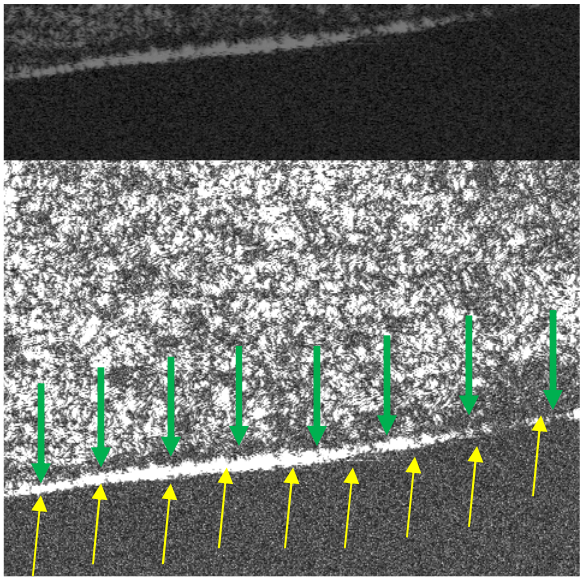

Fig.No.12. C Scan OCT time domain capture revealing a strip white line at surface of the superficial layer of acrylic teeth sample after 200 seconds treatment time.

The OCT C Scan capture regarding acetone effects on the superficial layer of acrylic teeth allows to visualize in Fig.No.12., also, the white strip line situated within the upper limit line representing the surface of the acrylic sample, and the lower limit line situated at a certain depth inside the sample, depth indicated also, as in the Fig.No.11.with dark green arrows

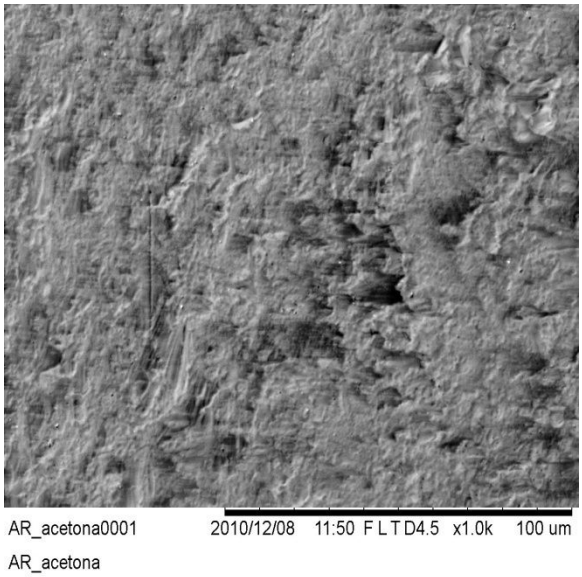

Fig.No.13 SEM Hitachi TM3000 data image of the acrylic teeth hardened superficial layer surface sample after acetone treatment.

Fig.NO.13 reveals the presence of the hardened layer at the surface of the acrylic teeth sample after 200 seconds treatment with acetone.

IV. Discutions

The wider strip width situated between the red arrows that are indicating the acetone penetration depth, and the yellow arrows that are indicating the surface of the sample, is observed in the capture showed in Fig.No.9. and in Fig. No.10 also, as an area with irregular edges characterized by a different reflectivity due to the scattering phenomenon caused by the passage of acetone trough the superficial layer of acrylic samples.

The different reflectivity, is observed because, the density of the acrylic teeth superficial layer trough whose depth acetone travels, is increased.

Basically, this area is characterized by a different contrast reported to the underlying layer unaffected by acetone after 10 seconds and also after 60 seconds treatment time

This wide strip is assumed to be determined by the swelling and softening process caused by organic solvents (including acetone) to polymeric samples.

Scattering is a physical process where some forms of radiation, such as light is in OCT, are forced to deviate from a straight trajectory by one or more localized non uniformities, known as scattering centers, (particles, bubbles, droplets, defects in monocrystalline solids, cells in organism, crystallites in polycrystalline solids and density fluctuations in fluids) in the medium through which they pass, including the deviation of a reflected radiation from the angle predicted by the law of reflection.

Comparing the images captured in Fig.No.11 at 100 seconds acetone treatment with the ones captured in Fig.No.12, at 200 seconds acetone treatment, it can be observed that the “white” irregular strip line increases its dimensions, so that the distinguishable pronounced, sharp contrast difference becomes much more obvious after 200 seconds acetone treatment time.

The explanation of the observed phenomenon could be found in the fact that some organic solvents are able to induce to the superficial layer of polymeric samples, including acrylic teeth samples, (Spofa Dental acrylic teeth used in this study have a chemical composition based on cross linked network polymers), two different effects: one regarding the softening and swelling of the superficial layer and the other effect regarding the hardening of the superficial layer.

Basically the swelling and softening are followed by the hardening process, and (En face) C Scan OCT is able to capture those effects according to the results of this study.

For this reason and based on the above explained phenomenon, captured in C Scan OCT, it can be considered that acetone induces also a hardening effect to the superficial layer of acrylic teeth, effect visualized with C Scan OCT captures, frame by frame during the 100 seconds, from second 100 of acetone treatment until second 200 of acetone treatment, practically along the 100 seconds elapsed from second 100 treatment time to second 200.

Between those 100 seconds the hard layer of the acrylic sample, represented by the white strip line, becomes thicker, fact that could explain the lower tensile test values after acetone treatment of acrylic teeth [11].

In OCT imaging, the so called “dark” to “light gray” shadows are indicating regions with a decreased density, characterized in some cases even by the lack of substance and the “white”

ones are showing the presence of areas with increased molecular density. For this reason we assumed that the white strip line situated at the surface of the superficial layer of acrylic teeth captured with Time Domain C Scan OCT is the result of the hardening process induced by acetone to the acrylic teeth samples.

Reporting from a comparative point of view, the captured data image of acetone effects induced to the superficial layer of acrylic teeth captured in C Scan (En Face) OCT with the captured data image regarding the effect of other organic solvents to the superficial layer of acrylic teeth, among which, methylene chloride, [34], and ethylene chloride [35], captured also in C Scan OCT, it can be observed that only acetone generates the hardening process at the surface of the superficial layer of acrylic teeth, the effects of methylene chloride and ethylene chloride being limited just to the softening and to the swelling process of the superficial layer of acrylic teeth.

In order to have another vision approach regarding the hardening process observed in C Scan OCT at the surface of the superficial layer of acrylic teeth after acetone treatment, SEM, a different nondestructive investigation method, was used.

In other words, because the organic chemistry reveals the fact that some organic solvents harden the surface of the polymeric samples superficial layer, and because C Scan OCT provided data imaging details regarding the presence of the highly distinguishable pronounced, sharp contrast difference at the surface of the superficial layer of acrylic teeth sample after acetone treatment, it was considered useful to investigate the surface of the acetone treated acrylic samples with a different non-destructive investigation method only to have another confirmation of the hardened superficial layer surface.

The captured SEM surface imaging data showed in Fig.No.13 reveals the presence of the hardened layer at the surface of the acrylic teeth samples after acetone treatment, those imaging data being used in this study only in order to confirm and to consolidate the hypothesis according to which C Scan (En Face) OCT is able to capture data of the hardened superficial layer surface of acrylic teeth after acetone treatment.

V. Conclusions

Within limitations of this study it can be observed that Time Domain C Scan OCT is able to capture and to allow the visualization of the swelling softening and hardening effects induced by acetone to the superficial layer of acrylic teeth

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