Dental Visible-light Curing Units : Intensity Characteristics and Photopolymerization

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ABSTRACT

Nine visible-light (VL) curing units which were fibre type (F1, F2, F3, F4, F5) and gun type (G1, G2, G3, G4) available in dental service were used to clarify the intensity characteristics of illuminating power and spectral irradiance and also to examine the related properties of Knoop hardness and curing rate in visible light-cured (VLC) composite resin. VL units were classified into three types by the magnitudes of their intensity values which showed lower illumination intensity (the maximum value; L_m) and greater spectral irradiance (the maximum value; E_m) (Type I), greater L_m and lower E_m (Type III) and the intermediate one (Type II). Electric power of bulb affected the magnitude of integrated spectral irradiance of VL units and also the use of light conductor attached to VL unit increased the integrated magnitude. In the case of VLC composite resin cured by two of VL units (F1, F3), Knoop hardness and curing rate were examined at irradiation times of 20, 40 and 60 sec. The results suggest that an increased Em exhibits deeper depth of cure as indicated in F3 unit with larger value of the maximum spectral intensity than F1 unit.

INTRODUCTION

VL curing unit is used to polymerize VLC resins containing alpha diketone of camphorquinone (CQ; photosensitizer) and reducing agent which produced ion radicals of resin matrix[1,2]. Because CQ was activated in the range of the wavelength 400 to 500 nm[3,4], the spectra wavelength emitted by VL units was measured in the range of 400 to 550 nm[5]. The depth of cure depends on the intensity of the visible light radiation in the VLC resins[3,6]. VL curing unit was fixed along the direction normal to the end of the light conductor in VL curing unit[5,7,8]. Cook reported that VL curing units as a waveguide type of photopolymerization unit were types of fiber-optic cable, fiber-optic rod and glass rod[5]. Both a gun type with a rigid light tube and a fiber type with a flexible light tube were classified by the design of VL units[9]. The maximum radiant output range was found between 450 and 485 nm for the units[5]. VL units were influenced by the variation in the input voltage or electric power[10] and light intensity characteristics[11]. The depth of cure of dental composite resins was due to their intensity value of VL units[12,13].

Our study examined illumination intensity and spectral irradiance of dental VL curing unit and the Knoop hardness and curing rate (curing efficiency) of a VLC compositre resin with changing irradiation time (20, 40, 60 sec) by two of VL units investigated.

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MATERIALS AND METHODS

1. VL units and intensity measurement

Nine VL curing units investigated were listed in Table 1. The standard light source for the VL units was a tungsten halogen lamp fitted with an integral reflector. A VLC dental composite resin tested was a commercial one, Occulsin (ICI, Cheshire, England; serial No. LH06). The resin was constituted from hybrid filler type, and CQ was 1.03±0.03 wt% in the resin phase and dimethylami-

Table 1 Nine visible light curing units investigated: Fibre type (F1 to F5) and gun type (G1 to G4).

Brand name	Manufacturer	Serial No.	Conductor type	Code
Suncure Light	Sanei electric MFG. Co.	1083	fiber	F1
Daylight Lamp	Osaka optical Ind. Co.	1180818	fiber	F2
Luxor	ICI Co.	06497	fiber	F3
Davlight Lamp	Shofu Inc.	0285741	fiber	F4
Quick Light	J. Morita Co.	1012	fiber	F5
Fotofil Activator Light	Johnson & Johnson	1395	gun	G1
Grip Light	Sansha electric Co.	05850902	gun	G2
Wite Lite	Takara belmont	510186	gun	G3
Optilux	Demetoron Co.	03280	gun	G4

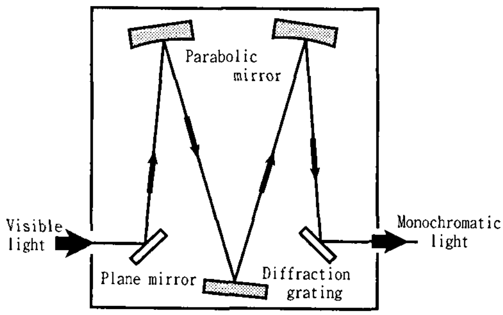

Figure 1 Schematic figure to measure monochromatic light (monochrometer) and calculate illumination power and spectral irradiance.

noethyl methacrylate (DMAEMA) 0.86±0.02 wt%[14].

Fig. 1 (schematic figure) shows the spectrum produced by each VL curing unit, which was passing the light through monochrometer (Nikon G-250, Tokyo, Japan). The fiber-optic tip or tip of glass rod attached to light guide was set perpendicular to the detector window of the monochrometer. The tip was positioned on an adjustable stage in order to give the maximum output. The spectral radiant flux was calculated by tabulated spectral efficiency.

Irradiance measurement was done for electric power of lamp of 50 W for G2, 75 W for G1, G3 and G4, 150 W for F1 to F6 (see Table 1 for key). Both illumination power (lux) and spectral irradiance (mW/cm^2·nm) was measured by the spectral VL through the monochrometer with illuminating meter (Toshiba Co, Tokyo, Japan; SPI-Type) and optical digital powermeter (Anritsu Co, Tokyo,Japan; ML93A).

Their measurements were repeated three times at each test.

2. Knoop hardness and curing rate

Both the Knoop hardness and the curing rate in VLC resin were evaluated when irradiated for 20, 40 and 60 sec by two VL curing units (F1, F3). The VL unit (F3) is recommended for polymerizing a VLC composite resin (Occlusin). At a longitudinal section of the cylinder-like specimen (5 mm diameter) which was cut with a low-speed saw ISOMET (Buehler Co, Chicago, USA), Knoop hardness was measured three times at each depth every 1 mm. Thin polyethylene films with a 0.05 mm thickness were set at the positions of the upper and lower surfaces in a 2 mm thickness teflon block with a cavity of 5 mm diameter and 2 mm long. The other block with a cavity (5 mm diameter and 1 mm long) was set to the bottom of the first block. VL was then irradiated to resin paste within the cavity from the upper surface of the first teflon block by setting two teflon blocks.

For example, the curing rate ($(m_d/m_b)\times 100$) at a 3 mm depth was calculated using cylinder-like specimen between 2.05 and 3.05 mm thickness from the surface which was weighed before immersing (m_b). It was immersed for 1 day into 5 mL methanol and then dried for 2 days in a desiccator and re-weighed (m_d).

RESULTS

1. Intensity characteristics (classification)

Fig. 2 shows attenuation percentage in the wavelength range of 400 to 650 nm using fibre (F1 to F6) and gun types (G1, G2) of VL curing units. Fig. 3 shows the illumination power and spectral irradiance in the wavelength of three types of VL curing units (Table 1), representing that the wavelength component below 400 nm was not measured, because no biological hazard is suggested below 390 nm and the measuring range was used for the

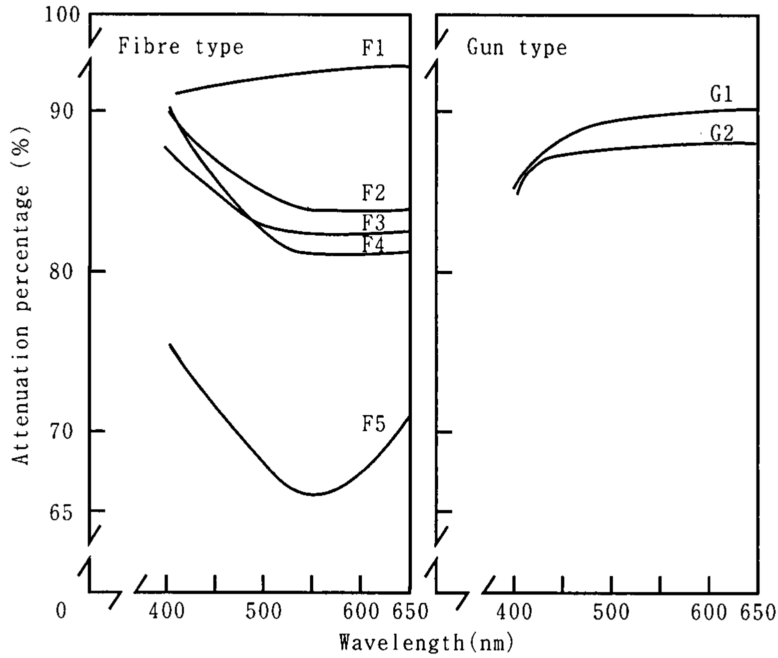

Figure 2 Attenuation percentage at the wavelength of fibre (F1 to F5; left) and gun type VL units (G1, G2; right).

wavelength between 400 and 650 nm[3]. The peak wavelength was found for 470 and 530 nm with five of the VL curing units and the values of the other VL units were ranged between 470 and 530 nm. VL units were classified into three types from the characteristics of spectral distributions and peak wavelength, as described as Type I, Type II and Type III. The peak wavelength was about 470 nm and the spectral distribution above 550 nm was found a little (Type I). The peak wavelength was found to be about 500 nm and the spectral distributions were also ranged to above 550 nm (Type III). The VL units indicated as Type II were VL units which were not classified only as Type I or Type III. Fig. 4 shows the relation between Lm (the maximum value of illumination power) and Em (the maximum of spectral irradiance) of VL units investigated. VL units had different linear relation for each one. Fig. 5 shows Em value at each electric power of bulb (50, 75 and 150 W), which was irradiated by VL units with light conductor (left) and without light conductor (right), representing that there appearred different Em values among them.

2. Knoop hardness and curing rate (VLC resin)

Fig. 6 shows F1 and F3 VL units to polymerize dental VLC composite resin (Occlusin), and the intensity characteristics were completely different between them when used with and without light conductor attached to VL unit. Figs. 7 and 8 shows the apparent features of light fibres in F1 and F3 VL units, and the occupied area was 17.6% (F1) and 14.2% (F3).

Dental VLC composite resin (Occulsin) was measured at different irradiation times using different VL units, as shown in Fig. 9 (Knoop hardness) and Fig. 10 (curing rate). The maximum hardness of the VL cured resin occurred at certain depth and the value of the maximum hardness varied at different irradiation times (20, 40 and 60 sec). At the depth of 5 mm the Knoop hardness varied among different irradiation times. Considering curing efficiciency of the VL cured resin, the larger irradiation time, the larger the curing rate at deeper depth from the top surface. The maximum values of hardness after longer irradiation time (40 and 60 sec) were larger than that after polymerized for 20 sec.

DISCUSSION

We examined a profile of the spectral distributions which were normally to a 1-cm^2 area of the tip, because VL unit varied significantly in the cross-sectional area of

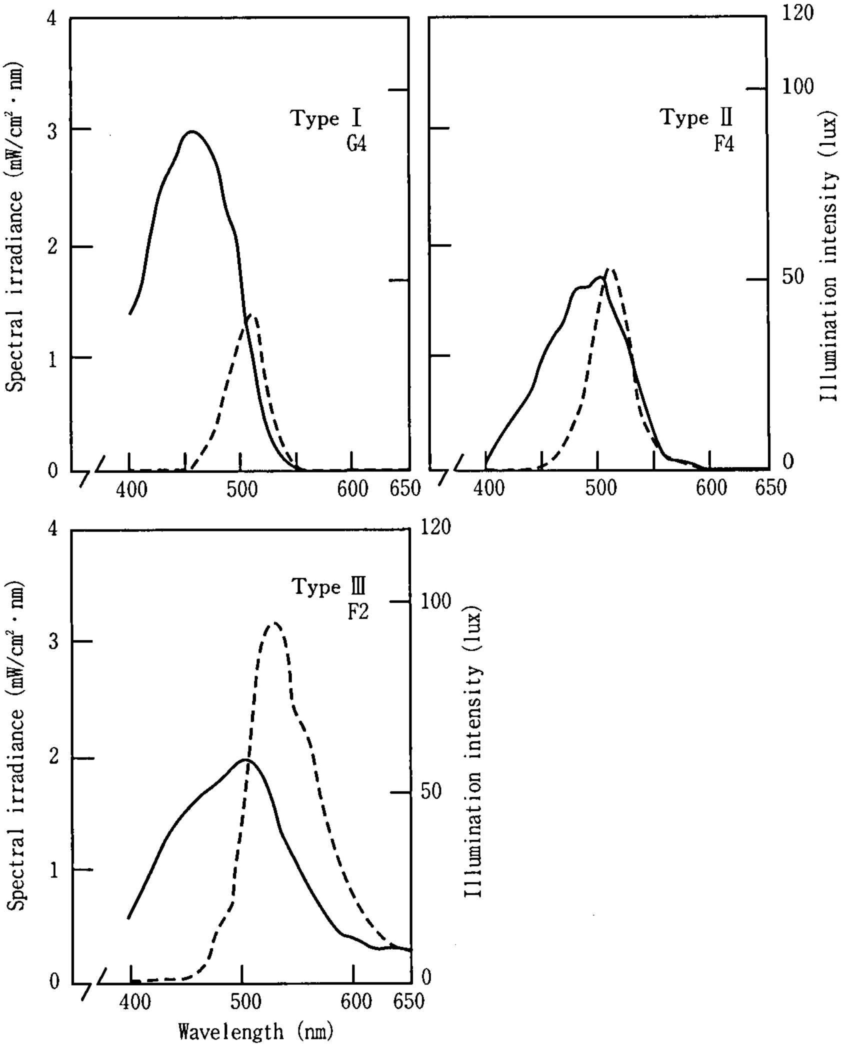

Figure 3 Spectral irradiance (—) and illumination power (---) when emitted by VL curing units; Type I (G4), Type II (F4) and Type III (F2).

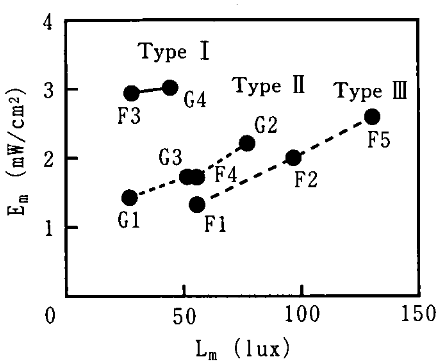

Figure 4 The relation between the integrated values of illuminating power (the maximum; L_m) and spectral irradiance (the maximum; E_m). See Table 1 for key.

fiber-optic tip of the light-guide[7] and also the area and size of occupied fibre were different between them (Figs. 7, 8). The peak wavelength of VL curing units was detected between about 460 nm and about 500 nm in a spectroscopical analysis[4,12], and the peak of the spectral irradiance was within the wavelength region in spite of the spectral irradiance/wavelength profile measured in terms of different VL units (Table 1; Fig. 2). Our study exhibited that there were remarkable differences in the peak wavelength, ranging from 480 nm to 535 nm (Fig. 3). Distinct differences were found in the integral value of irradiance (E_i) at 480 to 535 nm when the VL units were operated at 50 to 150 W input, ranging from 111.8 to

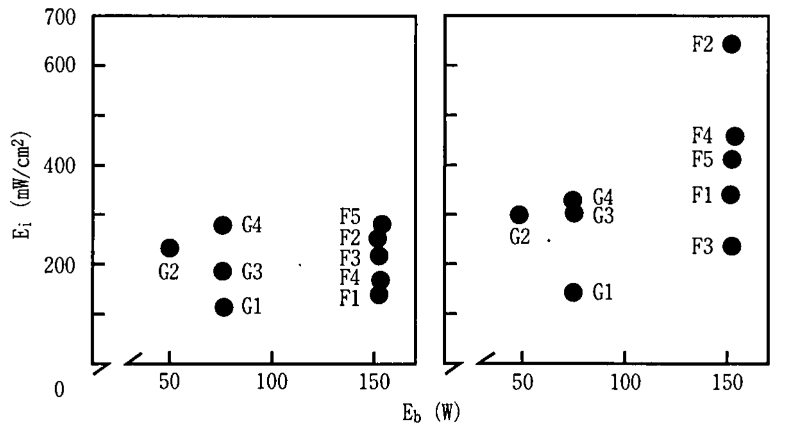

Figure 5 Integrated spectral irradiance (E_i) at electric power of 50,75 and 150 W (E_b) when irradiated by VL unit with light conductor (left) and without light conductor (right).

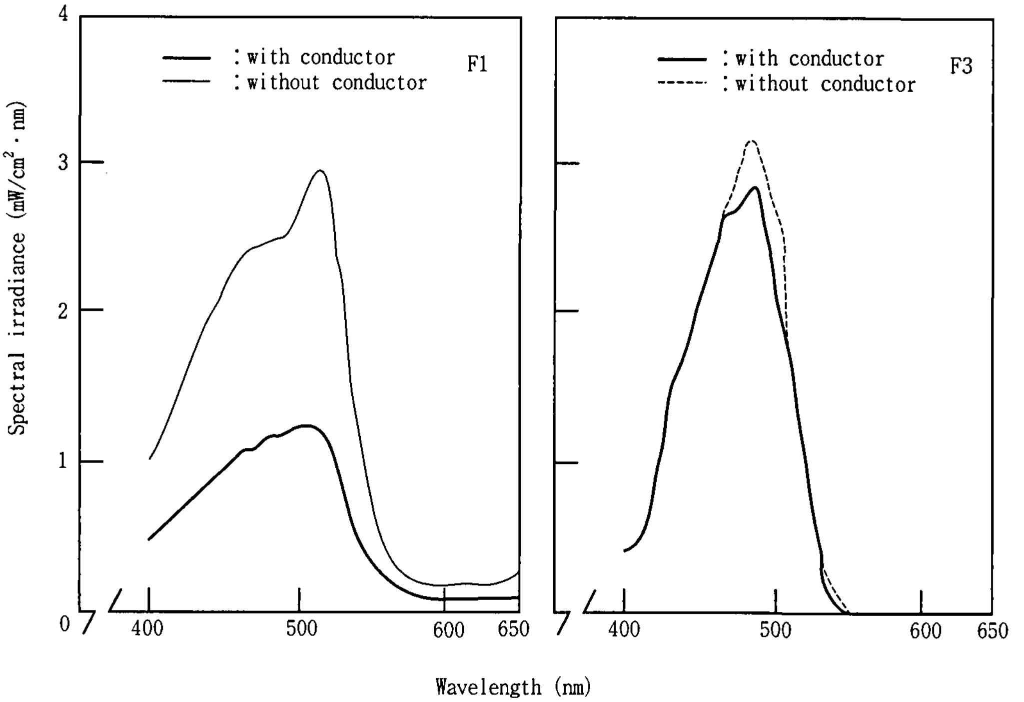

Figure 6 Spectral irradiance in the wavelength range when irradiated by F1 (left) and F3 (right), with light conductor and without light conductor.

270.9 (mW/cm^2) (Fig. 5).

Knoop hardness at each depth was improved by longer irradiation times in polymerizing VLC resins with each VL unit[7,15]. The VL units were classified into Type I, Type II and Type III VL units (Figs. 3 and 4), and the intensity characteristics of VL units were more complicated than the other studies[10,11]. Because the illumination power might be an important factor to consider the cure of a VL cured resin and to the eye, VL units (F1, F3) with the lower illuminating power were selected in our study (Fig. 4; Fig. 6). Namely, the VL curing unit of F3 (Type I) had the lower illuminating power and higher irradiance (Fig.

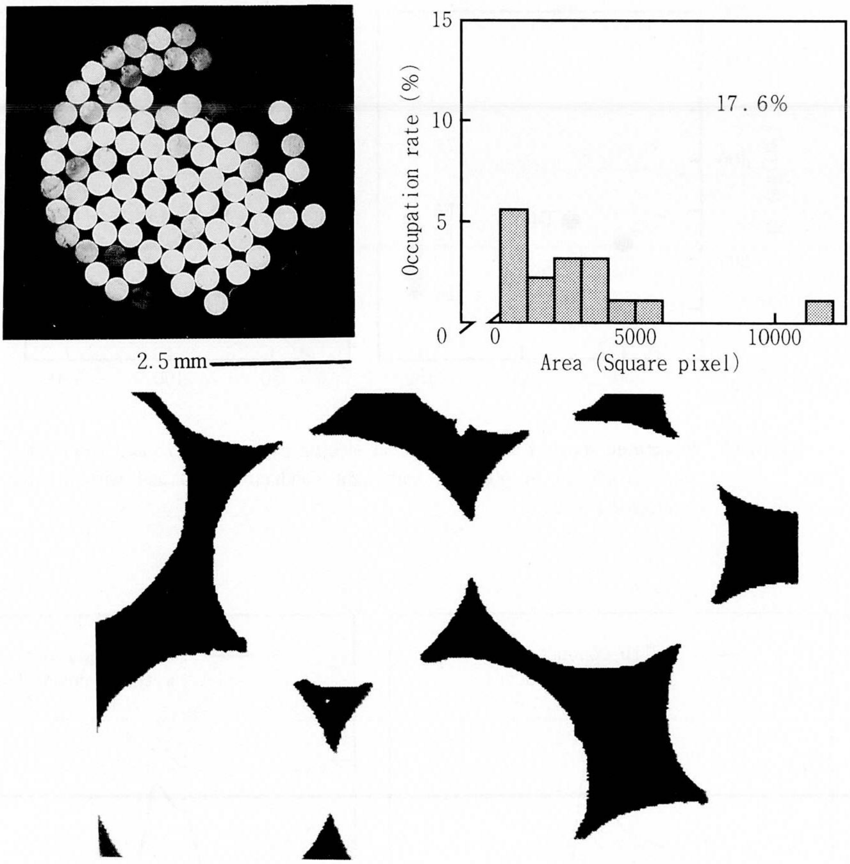

Figure 7 F1 VL unit; the apparent feature and occupied area of fibre.

4), whereas F1 the lowest illuminating power and irradiance of the Type III VL units (F1, F2, F5). The irradiance in the wavelength region of 450 to 500 nm was a better indication of the effectiveness in photopolymerization (Fig. 3). The photosensitizer's absorption peak at 470 nm is constituted by both a steep slope to 500 nm and a gradual trailing to 410 nm, using a 0.5 wt% solution of camphorquinone in methyl methacrylate[2]. Hirose et al reported that the relation between depth of cure and the characteristics of two VL units was plotted in the wavelength region (460 to 480 nm) to indicate the influence of the narrow wavelength[16]. With better VL units to choose larger depth of cure which showed the 460–480 nm wavelength, a dental VLC composite resin was irradiated. In the VLC composite resins, reducing agents (dimethyl-para-toluidine, Michler'ketone, etc.)[17] and resin matrix[18] will be examined to effect of their chemical composition on cure performance when irradiated by different types of VL curing units.

CONCLUSION

Dental VL curing units to polymerize VLC resins were examined by measuring the intensity characteristics (illumination power and spectral irradiance) and the selected mechanical properties (Knoop hardness value and curing rate). VL units were classified into three types by the magnitudes of illumination power and spectral irradiance, and also the magnitude changed by light conductor attached to it. In a VLC composite resin which was cured by two of VL units investigated (F1, F3), Knoop hardness at each cured layer from the top surface decreased with deeper layer and curing rate had the same tendency as Knoop hardness. The results suggest that VL unit with larger spectral irradiance gave the increased selected mechanical properties.

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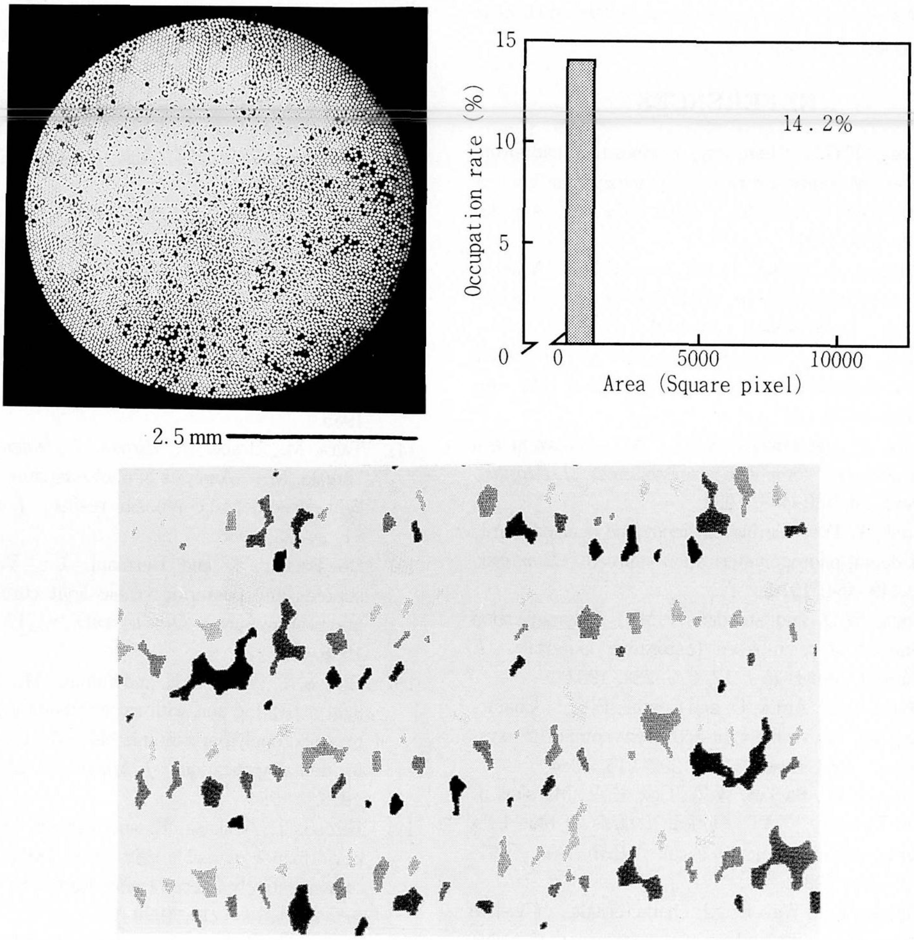

Figure 8 F3 VL unit.

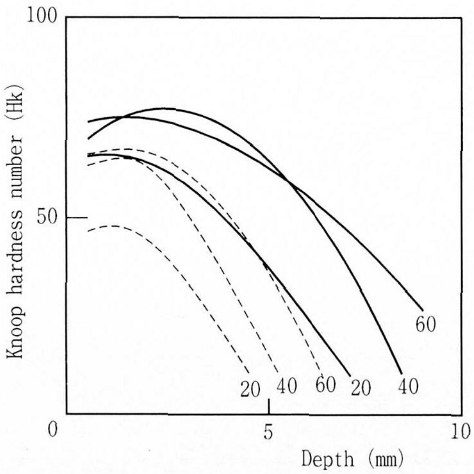

Figure 9 Knoop hardness number at cured layer (---(F1), — (F3)) when irradiated for 20, 40 and 60 sec.

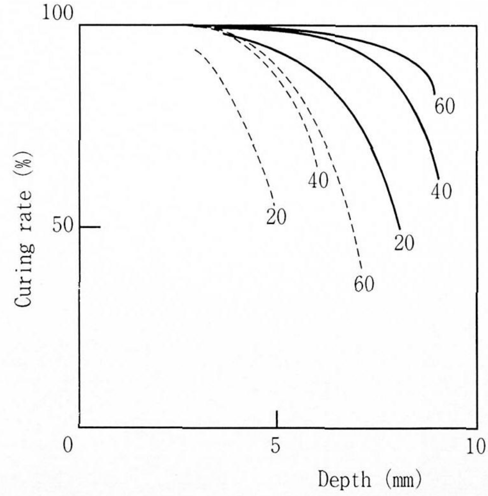

Figure 10 Curing rate at cured layer (---(F1), — (F3)) when irradiated for 20, 40 and 60 sec.

use of "*Biomaterial Combined Analysis System*" at Hiroshima University Graduate School.

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