J. Civil Eng. Mater.App. 2020 (September); 4(3): 155-160

Journal of Civil Engineering and Materials Application

Journal home page: http://jcema.com

Received: 16 June 2020 • Accepted: 29 August 2020

Research

doi: 10.22034/jcema.2020.237399.1029

Fourier Transform Infrared Characterization of Construction Joint Sealants

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ABSTRACT

This paper presents the results of the FTIR (Fourier-Transform Infrared) spectroscopy study of commercially available silicone-based sealant materials commonly used for sealing voids, cracks, and joints in non-structural building components of commercial and residential buildings. The sealants prevent moisture leakage through the parts, making the building envelope air and water-tight, sustainable, and energy-efficient. FTIR spectroscopy is a widely used technique in characterizing pharmaceutical products, mineralogical compositions, forensic analysis, food, chemical, semiconductor, petroleum, and agro-industries. This work demonstrates the application of FTIR analysis in the study of construction materials. It reports the IR (Infrared) spectral signatures of the selected building joint sealants used in the construction industry. It is found that several IR bands are common to most of the samples, suggesting that there is a reasonable similarity in the molecular composition of the three different manufacturer brands, including DAP (Dicks-Armstrong-Pontius), GE (General Electric), and HDX (Home Depot Product). Despite the multiple similarities in the IR bands of the samples studied, the FTIR techniques provided enough evidence to distinguish the samples and suggest that the composition and molecular structures of most of the silicone brands possess unique IR signatures.

Keywords: FTIR analysis of building materials, Silicone joint sealant, Characterization of construction materials, FTIR bands of building sealants, Characterization of silicone sealants, FTIR spectroscopy.

1. INTRODUCTION

Silicone is produced in the form of elastomers, fluids, gels, and fluids. These products have been used for various purposes in different sectors, including construction, automotive, electrical and electronics, pharmaceutical, and other industries [1-4]. The hydrophobic nature of silicone rubber also makes it one of the primary materials of choice for coating materials and parts exposed to varying environmental conditions [4]. In 2018, the construction industry was the major consumer of silicone, followed by transportation (aerospace and automotive) and electrical and electronics industries. In the coming years, the market share of silicone in the construction sector is projected to grow globally [5]. Despite its gradual aging and degradation, in building construction, silicone is a widely used hydrophobic polymer having excellent weathering resistance and durability [1]. The applications include sealing voids, cracks, and joints in non-structural building components (windows and door frames, between panels), which prevents moisture leakage through the parts, making the building envelope air and water-tight, sustainable and energy-efficient construction [1,2]. Sealed joints and cracks in building envelope also minimize smoke leakage to adjacent rooms and buildings [6], retain heat within the building envelope, and reduce energy use and utility cost [1].

Silicone sealants contain thermally stable rubber called polydimethylsiloxane (PDMS), which possesses very stable chemical bonds of –Si-O-, -Si-C- and –Si-H [7]. Crosslinking, which is a formation of a molecular bond between silicone sealant polymer chains, starts when the sealant is squeezed out and interacts with the atmospheric moisture and the moisture on the joint or the building's surface components [1]. These materials' benefits include their reasonable resistance to UV, chemical and high-temperature degradation, color stability, and flexibility. The unpleasant odor and poor adhesion of paints on the silicone surfaces are some of the shortcomings [7]. Research works demonstrated the wide range of FTIR spectroscopy applications for the characterization of construction materials [7-15]. Some of the benefits of using this technique include the reliability of the analytical results collected in a short time with a relatively inexpensive system, and the simple sample preparation required [7-12]. A combination of infrared spectroscopy, x-ray diffraction, and scanning electron microscopy was also used to identify mineralogical compositions of construction materials used for plastering and foundations of ancient buildings [8]. The use of IR spectroscopy in the study, and spectral assignment of cementitious materials including ordinary Portland cement, calcium aluminate cement primarily used to resist sulfate attack, and calcium sulfoaluminate cement used where fast setting and high early strength of concrete is desired, is presented elsewhere [9]. FTIR spectroscopy is a valuable tool to detect the presence of asbestos and quantify the amount present in building materials with a detection limit of 1% w/w [10,11]. Its application as a potential technique for mapping and evaluating fire damage in buildings and as a non-destructive tool for assessing the extent of thermal damage and concrete degradation was also demonstrated [12]. One of the various applications of silicone sealants as a construction material in civil infrastructure is as an expansion joint in railway construction [16]. Li et al. (2018) used FTIR to study ultraviolet light's effect on the degradation of silicone sealant used for railway-track expansion joints. To study the effect of Al2O3 fibers on silicone's thermal stability for aerospace application, Yao et al. (2014) used FTIR to verify the hydroxyl content of the Al2O3 fiber loadings [17]. The FT-IR investigation results indicate that hydroxyl content on Al2O3 surface is reduced at 900 0C compared with the samples dehydrated at 500 0C and as-received. FTIR has also been used as a valuable non-destructive tool to evaluate the extent of thermal damage and degradation of concrete, with a potential application for forensic analysis of building's fire damage [12]. In this study, the spectral signatures of three different brands of a dozen commercially available silicone building sealants are characterized using Fourier-Transform Infrared Spectroscopy.

The use of the FTIR technique in the study of construction materials has been primarily focused on the study of Portland cement [12-15] and asbestos materials [10,11]. With the wide range of benefits, the FTIR technique to offer to the construction materials research and industry, the application of this technique in the study and analysis of other construction materials is limited. This study demonstrates the FTIR system's suitability and sensitivity for analyzing materials used in the construction industry. We believe that the present work will inspire the use of FTIR spectroscopic technique for qualitative analysis of building materials including in quality control, verifying the materials' compliance with the required specification on-site, identification of counterfeit products, and evaluation of the gradual degradation of construction materials due to aging and environmental factors. To this end, the work presented in this article corroborates the significance of this technically sound approach for construction materials research and contribute to the body of knowledge in the study of building materials.

2. MATERIALS AND METHODS

Table 1 summarizes the details of the three brands of the commercially available silicone sealants commonly used for sealing voids, cracks, and joints for indoor and outdoor surfaces in commercial and residential buildings, making the building envelope air and water-tight. The sealants fill the spaces between non-structural building components such as windows and doorframes, between panels, sidings, kitchen, bath, and plumbing fixtures. Per the manufacturer's description of the sealants' principal ingredients, sample S1 contains titanium dioxide, ethylene glycol, and calcium carbonate and meets latex sealant ASTM C-834, standard specification [18]. Sample S2, with the same manufacturer as S1, contains titanium dioxide, propylene glycol, acrylic polymer mixture, calcium carbonate, diisononyl phthalate, and other additives, and meets the ASTM C-920 standard specification for elastomeric joint sealants [19]. Sample S3 contains titanium dioxide, quartz, 50-70 percent by weight of limestone, diethylene glycol dibenzoate, and petroleum distillates [20]. Similarly, sample S4 contains titanium dioxide, quartz, 50-70 percent by weight of limestone, Diethylene glycol dibenzoate, petroleum distillates, and carbon [21]. A typical picture showing the various silicone-based joint sealant applications in construction is provided elsewhere [22]. FTIR spectra of the silicone samples were acquired using Nicolet™ iS™ 10 FTIR Spectrometer (Thermo Scientific Inc., Madison, WI, U.S.A.) at room temperature in the frequency range of 4,000 to 400 cm−1 using 32 scans at a 4 cm−1 resolution. The FTIR system is equipped with KBr/Ge coated beam splitter and Deuterated Triglicine Sulfate detector and OMNICTM standard spectroscopy software to collect and process the spectral data. The twelve different types of joint sealants identified for the study are representative of the three manufacturer brands widely used in the residential and commercial building construction industries. The 2 x 2 x 1 cm size specimen of the products described in Table 1 was prepared and allowed to be cured at room temperature. The dried samples were loaded to ensure adequate contact between the specimen and the crystal. The incident beam interacts with the specimen molecules, and the frequency of the beam matching with the molecular vibration is absorbed. The intensity of the IR bands is dependent on the rate of change of the dipole moment, with the larger the change in the dipole moment of the bond resulting in a considerable vibration of the bonds and larger IR band intensity [23].

Table 1. Description of the samples.

*Description of the Samples	Sample #	Brand Name	ASTM Standarad
Latex plus silicone caulk	S1	HDX	Meets ASTM C-834
Premium elastomeric plus silicone caulk	S2		Meets ASTM C-920
Alex Fast dry acrylic latex caulk plus silicone	S3	¥DAP	Exceeds ASTM C-834
Alex plus acrylic latex caulk plus silicone	S4		Exceeds ASTM C-834
Silicone max, 100% silicone	S5		Meets ASTM C920
Kiwi seal ultra-premium siliconized sealant	S6		
Kiwik seal plus	S7		
UV resistant, 100% silicone sealant,	S8	GE	
Silicone 2^+ , 100 % silicone	S9		
Silicone 1^+ , 100 % silicone	S10		Meets ASTM C-920
GE paintable and waterproof	S11		Meets ASTM C-920
GE Paintable quick dry	S12		Exceeds ASTM C-834

3. RESULTS AND DISCUSSION

The FTIR spectra of the three brands of the silicone sealant studies are shown in Figure 1, and the complete IR-bands of silicone-based building sealants are summarized in Table 2. In general, the IR bands located at about 890-860 cm-1 and 1100-1000 cm-1 indicate the presence of Si-H bending [24] and Si-O-Si stretching modes [24], respectively. The IR spectra of the HDX brands of the sealants labeled as samples S1 and S2 shown in Figure 1(a) have characteristic prominent IR bands located at 1727 cm-1, 1154 cm-1, 871 cm-1, 711 cm-1. The three IR bands which exist in sample S1 but not in sample S2 are the bands located at 1394 cm-1, 2024 cm-1, and 2962 cm-1. Samples S1 and S2 possess a strong IR band at 711 cm-1 region, indicating the presence of CH3 asymmetric rocking and Si-C asymmetric modes, and the IR band at 2163 cm-1 of the sample S1 suggests the presence of CH3 asymmetric stretching mode, and the IR band at 1024 cm-1 in sample S2 indicates the presence of Si-O-Si symmetric stretching in the sealant sample [25]. As described in Section 2 above, the ingredients of samples S2 are slightly different from sample S1, which resulted in more IR bands in sample S2 than in sample S1, including 745 cm-1, 962 cm-1, 1111 cm-1, 1241 cm-1, 1341 cm-1, 1379 cm-1, 1417 cm-1, and 2874 cm-1.

Figure 1 (b) shows the FTIR spectra of five different samples (S3-S7) of the DAP brand silicone-based construction sealants studied. As shown in Table 2, The IR bands located at 2922 cm^{-1}, 1727 cm^{-1}, 1154 cm^{-1}, 871 cm^{-1}, and 711 cm^{-1} are common to samples S3, S4, and S7. Again the 711 cm^{-1} band in samples S1, S2, S3, S4, and S7 confirms the presence of CH_3 asymmetric rocking and Si-C asymmetric modes. Samples S5 and S6 appeared to have different characteristic IR bands among each other and the other samples within the same brands. The three prominent IR bands of sample S5 are located around 1258 cm^{-1}, 1008 cm^{-1}, and 785 cm^{-1}, and the other three weak Ir bands are at 2962 cm^{-1}, 700 cm^{-1}, and 472 cm^{-1}. The IR bands at 700 cm^{-1} and 2962 cm^{-1} regions indicate the presence of Si-C symmetric stretching and CH_3 asymmetric stretching mode in sample S5 of the silicone sealant [25]. As shown in Table 2, sample S6 has several IR bands with a peak at 1723 cm^{-1} being very strong and sharp.

Figure 1(c) shows the IR spectra of five samples (S8-S12) selected from silicone-based GE brand construction joint sealants. As can be seen, samples S8, S9, and S10 appeared to have similar IR bands located at 2963 cm-1, 1258 cm-1, 1008 cm-1, and 785 cm-1. The weak IR band at 2963 cm-1 indicates the presence of CH3 asymmetric stretching mode in these samples. On the other hand, samples S11 and S12 possess characteristic IR bands located around 1411 cm-1, 1099 cm-1, 872 cm-1, and 711 cm-1. The bands at 1411 cm-1, 1099 cm-1, and 711 cm-1 indicate the presence of CH3 asymmetric bending, Si-O-Si asymmetric stretching, and Si-C asymmetric modes, respectively. The IR bands located at 863 cm-1 and 685 cm-1 are also common to samples S9 and S10, indicating the presence of CH3 symmetric rocking mode in these samples. The IR band located at 2963 cm-1 exists in Samples S1, S5, S6, S8, S9, and S10, indicating the presence of CH3 asymmetric stretching mode in these samples. The IR band located at 1728 cm-1 is common to some of the samples across the three different brands of the joint sealants, including samples S1, S2, S3, S4, S7, and S12. Similarly, the bands located at 711 cm-1, 872 cm-1, and 1024 cm-1 also exist in some of the samples across the construction sealant's three brands. The appearance of these characteristic IR bands in HDX, DAP, and GE brand silicone-based construction sealants indicates common ingredients in the joint sealants' production across the three manufacturers considered.

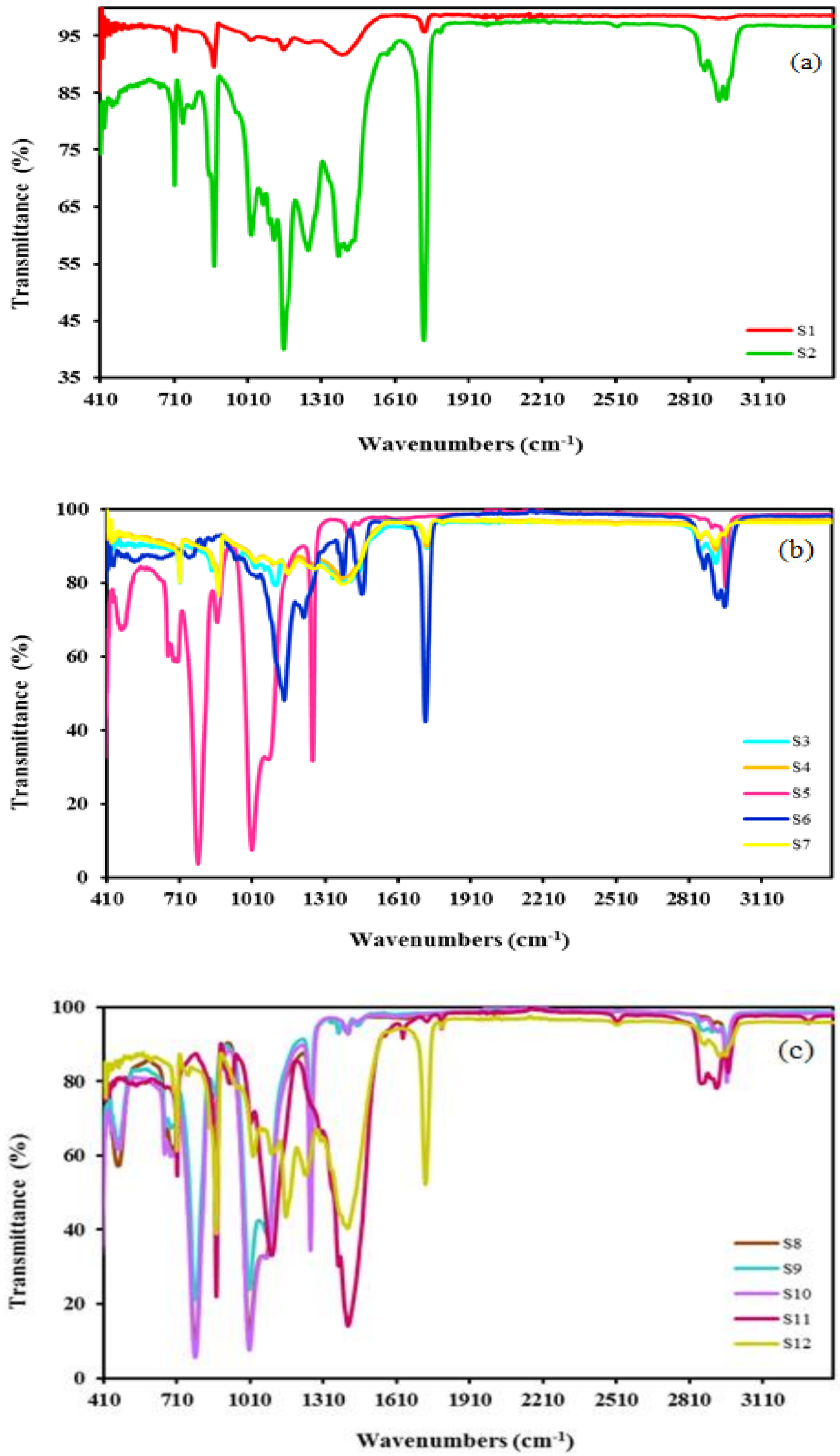

Figure 1. FTIR spectra of HDX (a), DAP (b), and GE (c) brands of silicone sealants used in residential and commercial buildings.

Table 2. IR-bands of silicone-based building sealants.

	IR Absorption Bands, cm^{-1}										
S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
711	711	711	599	472	1141	711	468	468	472	711	711
872	745	872	711	700	1222	872	700	685	685	872	872
1021	873	962	872	785	1382	1022	785	785	787	927	1024
1156	962	1024	1023	1008	1462	1156	1008	863	863	1099	1097
1394	1024	1106	1095	1258	1723	1263	1258	1008	1008	1372	1157
1730	1111	1155	1155	2962	2873	1376	2962	1079	1258	1412	1237
2024	1155	1273	1267		2928	1728		1258	2962	2921	1410
2163	1241	1341	1377		2957	2852		2963			1729
2960	1341	1407	1728			2922					2933
	1379	1728	2853								
	1417	2923	2922								
	1727										
	2874										

4. CONCLUSION

The study used FTIR spectroscopy to characterize silicone-based construction joint sealants used in commercial and residential buildings. The samples studied include a dozen commercially available HDX, DAP, and GE brands silicone-based sealants. As shown in Figure 1 and Table 2, most of the samples have characteristic IR bands suggesting some level of similarity in composition and molecular structures of the joint sealants produced by different companies. However, a detailed analysis of the IR spectral signatures of each sample indicates that there is a clear distinction between the samples, and none of the samples is identical to each other. The results shown in Figure 1 reveal a wide range of IR band intensity variations ranging from a very broad and weak to very strong and sharp IR peaks. The observed band intensities are proportional to the amount of the constituent material available [24] in the sample. In general, the IR bands located at about 890-860 cm^{-1} indicates the presence of Si-H bending vibrational mode in the sample [24]. Accordingly, except in the DAP brand samples S5, S6, and S8, and GE brand sample S11, Si-H bending mode appeared in the remaining eight samples. Similarly, the IR bands located at about 1100-1000 cm^{-1} indicates Si-O-Si stretching mode [23], which appeared in all samples except S6. The IR band located at about 871 cm^{-1} is observed to be the strongest and very sharp across most of the samples, including S1, S3, S7, S11, and S12. For samples S2 and S12, there is a strong and sharp peak at around 1727 cm^{-1}. For samples S5, S8, S9, and S10, the prominent IR band is located at around 785cm^{-1}.

FUNDING/SUPPORT

This work is supported by the Department of Homeland Security-Scientific Leadership Award (DHS-SLA), under Grant No. DHS-SLA 2014-ST-062-00060-02, and the National Science Foundation (NSF), Award No.: 1643799.

ACKNOWLEDGMENT

Not mentioned by authors

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author declared no potential conflict of interest or conflict of interest.

5. REFRENCES

[1] De Buyl F. Silicone sealants and structural adhesives. International Journal of Adhesion and Adhesives. 2001 Jan 1;21(5):411-22. [View at Google Scholar] ; [View at Publisher].

[2] Silicone, American Chemistry Council, Inc. (2014). https://www.chemicalsafetyfacts.org/silicones-post/ Accessed on June 17, 2018. [View at Publisher].

[3] Jia Z, Fang S, Gao H, Guan Z, Wang L, Xu Z. Development of RTV silicone coatings in China: Overview and bibliography. IEEE Electrical Insulation Magazine. 2008 Mar 21;24(2):28-41. [View at Google Scholar] ; [View at Publisher].

[4] Kim SH, Cherney EA, Hackam R. Hydrophobic behavior of insulators coated with RTV silicone rubber. IEEE Transactions on Electrical Insulation. 1992 Jun;27(3):610-22. [View at Google Scholar] ; [View at Publisher].

[5] Size EO. Share & Trends Analysis Report By Application (Cleaning & Home, Medical, Food & Beverages, Spa & Relaxation), By Product, By Sales Channel, And Segment Forecasts, 2019-2025. Report ID. 2019:978-1. [View at Google Scholar] ; [View at Publisher].

[6] Boström L. Ageing effects on the fire resistance of building structures. SP Swedish National Testing and Research Institute; 2002. [View at Google Scholar] ; [View at Publisher].

[7] Paroli RM, Delgado AH, Cole KC. Applications of thermogravimetry and PAS-FTIR in the characterization of silicone sealants. Canadian journal of applied spectroscopy. 1994 Feb 1;39(1):7-13. [View at Google Scholar] ; [View at Publisher].

[8] Anderson E, Almond MJ, Matthews W. Analysis of wall plasters and natural sediments from the Neolithic town of Çatalhöyük (Turkey) by a range of analytical techniques. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2014 Dec 10;133:326-34. [View at Google Scholar] ; [View at Publisher].

[9] Fernández-Carrasco L, Torrens-Martín D, Morales LM, Martínez-Ramírez S. Infrared spectroscopy in the analysis of building and construction materials. Infrared spectroscopy–Materials science, engineering and technology. 2012 Apr 25:369-82. [View at Google Scholar] ; [View at Publisher].

[10] Accardo G, Cioffi R, Colangelo F, d'Angelo R, De Stefano L, Paglietti F. Diffuse reflectance infrared fourier transform spectroscopy for the determination of asbestos species in bulk building materials. Materials. 2014 Jan;7(1):457-70. [View at Google Scholar] ; [View at Publisher].

[11] Luca De S, Raffaele C, Francesco C. Comparison between Two FT-IR Spectroscopy Analytical Procedures for Micrograms Determination of Asbestos Species in Bulk Materials. American Journal of Analytical Chemistry. 2012 Jan 5;2012. [View at Google Scholar] ; [View at Publisher].

[12] Leung Tang P, Alqassim M, Nic Daéid N, Berlouis L, Seelenbinder J. Nondestructive handheld fourier transform infrared (FT-IR) analysis of spectroscopic changes and multivariate modeling of thermally degraded plain portland cement concrete and its slag and fly ash-based analogs. Applied Spectroscopy. 2016 May;70(5):923-31. [View at Google Scholar] ; [View at Publisher].

[13] Nasrazadani S, Springfield T. Application of Fourier transform infrared spectroscopy in cement Alkali quantification. Materials and structures. 2014 Oct 1;47(10):1607-15. [View at Google Scholar] ; [View at Publisher].

[14] Chollet M, Horgnies M. Analyses of the surfaces of concrete by Raman and FT‐IR spectroscopies: comparative study of hardened samples after demoulding and after organic post‐treatment. Surface and Interface Analysis. 2011 Mar;43(3):714-25. [View at Google Scholar] ; [View at Publisher].

[15] Schneider dos Santos R, Rolim SB, Hepp Pulgati F. Application of visible and near infrared spectroscopy in non-destructive evaluation of cement materials. International Journal of Remote Sensing. 2015 Feb 1;36(3):917-38. [View at Google Scholar] ; [View at Publisher].

[16] Li H, Yi Z, Cheng G, Wen H, Xie Y. Effects of ultraviolet radiation, high temperature and alkaline chemicals on ageing of silicone sealants used in ballastless track expansion joints. Journal of Wuhan University of Technology-Mater. Sci. Ed.. 2018 Oct 1;33(5):1015-21. [View at Google Scholar] ; [View at Publisher].

[17] Yao Y, Lu GQ, Boroyevich D, Ngo KD. Effect of Al2O3 fibers on the high-temperature stability of silicone elastomer. Polymer. 2014 Aug 5;55(16):4232-40. [View at Google Scholar] ; [View at Publisher].

[18] ASTM C 834-00, Standard specification for latex sealants, ASTM, January 10, 2000, U.S.A. [View at Publisher].

[19] ASTM C920-98e1, Standard Specification for Elastomeric Joint Sealants, ASTM International, West Conshohocken, PA, 2002. [View at Publisher].

[20] Kassu A, Farley III C, Mills J, Sharma A. Analysis of Spectral Signatures of Silicone-Based Sealant Materials Used in Residential and Commercial Buildings. Journal of Building Construction and Planning Research. 2018 Jul 23;6(3):112-21. [View at Google Scholar] ; [View at Publisher].

[21] Sullivan L. The influence of educational information on understanding and perceptions of root canal treatment (Doctoral dissertation, University of Otago). [View at Google Scholar] ; [View at Publisher].

[22] American Chemistry Council, Silicone Environmental, Health, and Safety Center (SEHSC), 2017. [View at Google Scholar] ; [View at Publisher].

[23] Socrates G. Infrared and Raman characteristic group frequencies: tables and charts. John Wiley & Sons; 2004 Jun 18. [View at Google Scholar] ; [View at Publisher].

[24] Nakanishi K, Solomon PH. Infrared Absorption Spectroscopy. 2nd Ed., Holden-Day, Inc. 1977, U.S.A. [View at Google Scholar].

[25] Vickers NJ. Animal communication: when i'm calling you, will you answer too?. Current biology. 2017 Jul 24;27(14):R713-5. [View at Google Scholar] ; [View at Publisher].