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## Review

# Silane adhesion mechanism in dental applications and surface treatments: A review

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## ABSTRACT

**Objective.** To give a current review of silane adhesion chemistry, applications of silane coupling agents and related surface pretreatment methods in contemporary dentistry.

**Methods.** Silane coupling agents are adhesion promoters to chemically unify dissimilar materials used in dentistry. Silanes are very effective in adhesion promotion between resin composites and silica-based or silica-coated indirect restorative materials. It is generally accepted that for non-silica-based restorations, surface pretreatment is a mandatory preliminary step to increase the silica content and then, with help of silane, improve resin bonding. This review discusses the silane-based adhesion chemistry, silane applications in dentistry, surface pretreatment methods, and presents the recent development of silane coupling agents.

**Results.** A silane coupling agent is considered a reliable, good adhesion promoter to silica-based (or silica-coated) indirect restorations. Surface pre-treatment steps, e.g., acid etching for porcelain and tribo-chemical silica-coating for metal alloys, is used before silanization to attain strong, durable bonding of the substrate to resin composite. In clinical practice, however, the main problem of resin bonding using silanes and other coupling agents is the weakening of the bond (degradation) in the wet oral environment over time.

**Significance.** A silane coupling agent is a justified and popular adhesion promoter (adhesive primer) used in dentistry. The commercial available silane coupling agents can fulfil the requirements in clinical practice for durable bonding. Development of new silane coupling agents, their optimization, and surface treatment methods are in progress to address the long term resin bond durability and are highly important.

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## 1. Introduction: silicon

Silicon (Si) belongs to the main Group 14 (formerly IVA) with carbon (C), germanium (Ge), tin (Sn), and lead (Pb) on the periodic table and it has four valence electrons. There is another four valent group of elements, Group 4 (IVB), transition metals such as titanium (Ti), zirconium (Zr), hafnium (Hf), and rutherfordium (Rf) also with four valence electrons for the elements. The difference between the two groups is a partial filling electron configuration of 3d-5d orbitals in Group 14 4. The empty 3d orbital of Si makes it chemically different from other Group 14 elements, in terms of structure, reactivity and thereby physical and chemical properties.

Carbon ( ${}^6\text{C}$ ) is a typical non-metal and silicon ( ${}^{14}\text{Si}$ ) is a metalloid, semi-metal (a semiconductor). The metallic character increases down the group with tin and lead as the metals. Carbon occurs as graphite and diamond (allotropes), silicon is found as silica (silicon dioxide,  $\text{SiO}_2$ ) and numerous silicates and alumino-silicates in earth. The electronic configuration of C is  $1s^2 2s^2 2p^2$  and for Si  $1s^2 2s^2 2p^6 3s^2 3p^2 3d^0$ . They have, in some aspect, similar unique properties that distinguish them from the other element group members. Both C and Si have catenation property which decreases dramatically down the group. Carbon can form “endlessly” long chains with other carbon atoms  $(-\text{C}-\text{C}-)_n$ . Silicon can also bond to other silicon atoms  $(-\text{Si}-\text{Si}-)_n$  but with farshorter chain length (only up to 2-3 units) and such compounds are, in contrary, unstable. This is owing to the C-C bond energy (356 kJ/mol) which is much higher than the Si-Si bond energy (226 kJ/mol). How-

ever, silicon can form indefinitely long chains, but with oxygen atoms to form a siloxane linkage  $(-\text{O}-\text{Si}-\text{O}-)_n$  because of a very strong Si-O bond energy (368 kJ/mol) [1].

That said, silicon compounds are more reactive than carbon compounds because of the presence of vacant 3d orbital. Silicon tetrachloride ( $\text{SiCl}_4$ ) hydrolyses instantly to yield silicic acid,  $\text{Si}(\text{OH})_4$ , but carbon tetrachloride ( $\text{CCl}_4$ ) would not undergo hydrolysis. We may say that organosilicon chemistry is, in general, easier to manage than all-carbon chemistry. Organosilicon compounds are widely found in adhesives, coatings, caulks, and sealers. Other remarkable uses include both plant and agricultural control chemicals (fungicides and herbicides).

On the other hand, Si has several drawbacks as a viable alternative to C. Silicon interacts with very few other types of atoms because it is lacking the ability to form chemical bonds with diverse types of atoms required for metabolism. This is because of its atomic size. Elements forming organic functional groups with carbon include hydrogen, oxygen, nitrogen, phosphorus, sulfur, and metals, such as Fe, Mg, and Zn [2,3].

By strict definition, silane can refer to  $\text{SiH}_4$ , a group 14 hydride (analogous to methane,  $\text{CH}_4$ ), used as a precursor to elemental Si. Nevertheless, silane refers in particular to a vast amount of compounds with four substituents on Si. They are saturated compounds (i.e., no Si=Si bond) with one or more Si atoms linked to other elements. A silane contains a synthetic silicon to carbon  $(-\text{Si}-\text{C}-)$  bond. This bond is very strong and stable [4].

Organosilanes are synthesized from  $\text{SiO}_2$ , silica (silicon dioxide) one of the most abundant materials in the earth,

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