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Technical note

RTV silicone elastomers in hand prosthetics: properties, applications and techniques

M. E. L. LEOW and R. W. H. PHO

Department of Orthopaedic Surgery, The National University of Singapore, Singapore

Abstract

In this technical note, an overview of RTV (room-temperature-vulcanising) silicone elastomers is provided. The properties and applications of 3 different types of RTV silicones in producing prostheses for the hand are discussed. Vinyl polysiloxanes are excellent silicone impression materials that offer the advantages of a rapid cure, near exact duplication of fine details and ease of removal of the cured impression without permanent deformation. RTV-2 dimethyl polysiloxanes are ideal for mould-making and fabricating prostheses given their favourable qualities that range from ease of pigmentation, adjustable consistency, manageable curing rate and accuracy in recording fine details in the liquid state to excellent stain-resistance, elasticity and biodurability in the vulcanised state. RTV-1 dimethyl polysiloxanes are self-curing, ready-for-use silicones that adhere adequately well to most substrates and are useful for extrinsic hue modifications and waterproofing of the prosthesis. The basic techniques for each of these applications are also discussed.

The cure-inhibition of addition-curing RTV silicones by sulphur-, tin- and nitrogen-containing contaminants and its damaging consequence is highlighted. A compilation of known contaminating agents is provided so that prior contact with these objects can be avoided when working with addition-curing silicones. The precautionary measures to prevent the problem are also outlined.

All correspondence to be addressed to Professor Robert W. H. Pho, Department of Orthopaedic Surgery, The National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, Singapore. Tel: (+65) 7724340, Fax: (+65) 7732558.

Introduction

Silicone elastomers, because of their unique combinations of qualities, have expanded the armamentarium available to prosthetists and added to the quality of rehabilitation for many patients. Silicone elastomers are now being used to produce roll-on suction sockets for both lower and upper limb prosthetics, prostheses for the upper limbs and maxillo-facial region, in addition to insoles in podiatry. However, many practitioners are inadequately familiar with silicone materials and their fabrication techniques, particularly as applied to hand prosthetics. There are several reasons for the unfamiliarity. Firstly, silicone products are readily available from established manufacturers without the need for the practitioner to be directly involved with their fabrication. Secondly, prosthetic programmes offered by educational institutions worldwide do not normally include laboratory instruction on the fabrication of aesthetic upper limb prostheses which must include silicone as a material of choice. Thirdly, the number of published reports on the exploitation of silicones in prosthetics did not seem to match their application growth in this field. However, the future will likely see a continued widespread use of silicones in prosthetics and present a challenge to the general practitioners to broaden their scope of capabilities to include silicone impression/fabrication techniques.

The authors have worked with the various grades of silicones over the past 11 years in the course of developing and fitting hand and finger prostheses (Leow *et al.*, 1998, 1997 and 1996; Pereira *et al.*, 1996). Despite their many qualities, a sound understanding of the physical properties and manipulative variables of silicone materials is essential in achieving predictable results. This technical note is intended to: 1) provide an overview of RTV (room-temperature-vulcanising) silicones; 2) discuss the properties and applications of 3 different types of RTV silicones in hand prosthetics and the techniques for each of their application; and 3) highlight the cure-inhibition of addition-curing RTV silicones by sulphur-, tin- and nitrogen-containing contaminants and outline precautionary measures to prevent the inhibition problem.

Types of RTV silicones: an overview

The name silicone denotes polymer having the formula:

$$(R_nSiO_{(4-n)/2})_m$$

where n=1-3 and m ≥2 (Kroschwitz and Howe-Grant, 1997). It contains a repeating silicon-oxygen backbone and has organic groups, R, attached to a significant proportion of the silicon atoms by silicon-carbon bonds. In dimethyl polysiloxanes, the largest group of commercial silicones used in the industry and in medicine (including prosthetics), most of the R groups are methyl, thus their common name methyl silicones. In vinyl polysiloxanes or vinyl silicones which are widely used as a dental impression material, vinyl groups are substituted to improve the vulcanisation characteristics.

RTV silicones can be divided into the *two-component* (RTV-2) and *one-component* (RTV-1) type in respect of their curing systems (Hechtl, 1991). As their name suggests the curing process for RTV-2 silicones is initiated when the base material is mixed with a catalyst, the two components being supplied separately. Vulcanisation proceeds evenly throughout deep sections. The curing time a 24°C is generally of the order of hours. In contrast, RTV-1 silicones cure by themselves on exposure to atmospheric moisture. They are packaged in airtight tubes or cartridges in pourable to soft paste consistency. Curing starts from the surface and progresses inwards to the material. The time taken for a complete cure depends on the thickness of the section and ambient humidity. At 24°C and 50% relative humidity, their surfaces will become tack free in 20-30 minutes. The basic properties of cured RTV-2 and RTV-1 are essentially similar despite their different curing mechanisms.

RTV-2 silicones are subdivided into 2 types, namely *addition-curing* and *condensation-curing* type (Kroschwitz and Howe-Grant, 1997; Hechtl, 1991). In addition-curing silicones, reaction is with vinyl end groups of the polymer by addition with no formation of by-products during curing. Vulcanisation can proceed in a closed system with the vulcanate being resistant to reversion – rapid vulcanisation is possible at high temperatures. The commonly used catalysts are platinum and chloroplatinic acid. In condensation-curing silicones, vulcanisation occurs by reaction of the hydroxyl end groups of the polymer with a crosslinking agent (e.g. silicic-acid esther) by condensation and release of a volatile by-product (e.g. ethyl alcohol). The reaction is catalysed by a tin catalyst such as dibutyl tin dilaurate. If vulcanisation occurs in a closed system, a reversal of reaction (refluidisation) will result from the heat released. Curing rate depends primarily on the amount of catalyst used.

RTV silicones in hand prosthetics: properties and techniques

The authors have used 3 different types of RTV silicones in the different stages of producing prostheses for the hand. The section that follows discusses their properties and manipulation in relation to each of these applications and the basic techniques involved. While the grades within each of these types of silicone can be numerous, the techniques are essentially similar.

Vinyl polysiloxanes – for impression taking

Vinyl polysiloxanes are a class of quick-vulcanising addition-curing RTV-2 silicones widely used by dentists for taking impressions of the oral cavity. Their curing times at 24°C is in the range of 6-8 minutes (Craig *et al.*, 1996). The base material and the catalyst are supplied in separate tubes in a number of viscosities ranging from putty-, regular- to injection-type. Manufacturers often add opaque pigments to the base or catalyst to aid in evaluating the completion of mixing.

In upper limb prosthetics, the creases and the fine details of the hand are important aesthetic features that need to be faithfully reproduced. One method of achieving this in finger prostheses is to use the impression of the corresponding digits of the patient's contralateral hand. For partial and total hand prostheses, the impression of a suitable "donor" hand can be used. The authors have exploited this method successfully using vinyl polysiloxane impression materials (Leow *et al.*, 1998 and 1997; Pereira *et al.*, 1996).

Although manufactured for dental applications, 3 properties of vinyl polysiloxanes make them ideal for taking the impression of the hand: 1) they can readily reproduce a V-shape groove with a width of 0.025mm (Craig *et al.*, 1996); 2) they cure quickly and thus shorten the time for impression taking process; and 3) the cured material is sufficiently supple to allow easy removal without permanent deformation – although the cured impression is somewhat stiff compared to the more elastic methyl silicones, this rigidity is nowhere near that of a plaster cast.

The impression taking technique involves mixing *equal* amounts of the base and catalyst on a mixing pad and applying it on the hand with a spatula to a thickness of about 2-3mm. A noteworthy disadvantage with this material is the opacity which precludes the viewing and immediate assessment of the impression results. Nonetheless, any air voids which may be introduced at the skin-material interface during the impression taking process will be recorded alongside the fine details of the skin in the impression mould, from which a model of the hand is made for defect rectification.

When using a fast-curing impression material, the working time available for the impression taking process becomes a critical consideration. The working time can be defined as the time (from catalysis) within which the mixture can be transferred and applied onto the subject (Craig *et al.*, 1996). With the standard use of two grades of vinyl polysiloxanes (Dent Silicone-V, Shofu Inc., Japan; Zerosil-light, Dreve-Dentamid GmbH, Germany), the working time available (2-3 mins. at 24°C) is generally sufficient to complete the impression of the digits. However, when working on the hand having a larger surface area, working time needs to be extended. This can be achieved by: 1) refrigeration of the material prior to use; 2) addition of a retarding agent to the material during mixing (Dent Silicone-V Retarder, Shofu Inc., Japan).The combined application of these two factors has been found to provided a longer working time than obtainable from both their individual effects (Leow, 1993). However, even with the increased working time, the impression of the hand is usually completed in 2 to 3 stages or sections.

RTV-2 dimethyl polysiloxanes – for mould-making and prosthesis-fabrication

The elasticity, stability and anti-staining properties of RTV-2 methyl silicones and their ability to replicate minute details make then widely popular in prosthetics. Two grades that have been used by the authors include the KE1300T silicone (Shin-Etsu Chemical Co., Ltd., Japan) and 617h43 silicone gel (Otto Bock, Germany), both of which addition-curing silicones. When used for making moulds and fabricating prostheses, these silicones offer the following versatility: 1) they are often supplied in clear viscous liquids and thus can be easily pigmented to match the wide range of skin tones; 2) their curing process is initiated upon addition of the catalyst and therefore can be timed after the colour-matching process is completed; 3) their slow curing rate allows sufficient time for the catalysed mixture to be degassed to remove air bubbles prior to moulding; 4) their curing rate can be hastened by oven-curing to meet tight work schedules; and 5) they can be made less viscous and pourable by the addition of silicone oil or organic solvents such as 111-trichloroethane and trichloroethylene. Silicone oil, which would remain in the cured material and reduce the tear strength of the silicone, may be used for mould-making purposes. However, in applications in which physical properties cannot be compromised, such as when moulding a prosthesis, the use of the volatile organic solvent (which will all evaporate) is recommended.

When making moulds, the authors suggest tinting the clear silicone material blue. This will serve to make conspicuous, against blue contrast, any air bubbles which may be entrapped in the material during the moulding process. The material is applied on the finished hand model using a spatula, spread evenly with an air jet and rotation-moulded on a single axis rotary fixture to maintain even thickness and left to cure at room temperature.

When used to fabricate a prosthesis, a very thin coat of release agent (e.g. petroleum jelly) is first applied on the internal surfaces of the cured silicone mould. The colour-matched liquid silicone (after degassing) is poured into the hollow mould which is then inverted to drain off the excess material, leaving behind a thin layer of silicone adhering to the inner surfaces. The silicone layer is cured to a solid but supple prosthesis and withdrawn from the mould.

A significant drawback of silicones lies in their poor tear strength which, depending on grades, ranges 14-27kg/cm, die B (Lynch, 1978). For prosthetic application, tear strength can be increased by reinforcing the prosthesis with nylon fabric where it is prone to tearing, such as the proximal section which is subject to repeated stretching during donning and doffing. Reinforcement can be achieved by lamination of the fabric between silicone layers. For a strong reinforcement, the moulding mixture must be fluid enough to permeate the intricate mosaic of fibres and pores of the fabric

RTV-1 dimethyl polysiloxanes – for finishing prostheses

RTV-1 methyl silicones are ready-for-use, self-curing silicones widely used in the industry as sealants, adhesives and coating agents. The time-consuming process of colour-matching that would expose the material to atmospheric moisture and trigger the curing process makes them unsuitable as a base material for fabricating prostheses. However, because of their self-curing property and good adhesion to substrates as varied as wood, glass, masonry, metals, plastics and all types of silicones, RTV-1 methyl silicones are useful when finishing a prosthesis. The clear soft paste grades can be pre-mixed with colour pigments and used to render subtle shades extrinsically on a completed prosthesis to camouflage minor colour discrepancies. They can also be used to seal and waterproof the foamed material used to fill the hollow segment of the prosthesis – keeping a prosthesis dry at all times is important in preventing fungal growth (Leow *et al.*, 1997). Another advantage is that small amounts of the material usually needed for these thinly coated finishings can be readily dispensed and cured.

Cure inhibition of addition-curing RTV silicones

A property peculiar to addition-curing RTV silicones is their susceptibility to cure-inhibition by sulfonates, amines, urethanes, unsaturated hydrocarbon plasticisers, organometallic salts and materials containing sulphur, tin and nitrogen (Hechtl, 1991; Lynch, 1978). When addition-curing silicones come into contact with these materials, the curing process is inhibited, leaving an uncured or tacky surface at the contaminated areas. the cure-inhibition is caused by the "poisoning" of the platinum catalyst by the contaminants which impairs the crosslinking process necessary for full vulcanisation.

Despite its detrimental effect, documentation on the subject of cure-inhibition of addition-curing silicones has been scarce and brief, even in textbooks on silicone technology.

More deserving attention was confined to dental literature but these reports concerned only vinyl polysiloxane impression material, with latex gloves being solely incriminated as the contaminating agent (Browning *et al.*, 1994; Kahn and Donovan, 1989). The fact that RTV-2 methyl silicones, widely used for mould-making and fabricating prostheses, are equally susceptible to cure-inhibition cannot be overstated. A completed prosthesis so affected would have to be rejected as no subsequent attempts can cure it into a resilient rubber.

Unfortunately, since it is frequently not possible to tell the chemical contents (e.g. as sulphur-containing) of the objects around from the outset, a contaminating agent is often identified only after a cure-inhibition has occurred. A beneficial contribution would therefore be a compilation of a list of known contaminating agents so that prior contact with these objects can be avoided when working with addition-curing silicones. Many commonly used items are unsuspecting menaces that loom large in a laboratory. Based on the authors' experience and printed information from two leading silicone manufacturers, some common contaminating agents include:

(i) soft PVC tapes (adhesive side);
(ii) masking tapes (adhesive side);
(iii) modelling clay containing sulphur;
(iv) neoprene;
(v) polyesters;
(vi) plastics containing residual plasticisers;
(vii) RTV silicones containing organo-tin catalyst;
(viii) latex gloves;
(ix) vinyl gloves;
(x) rubber bands;
(xi) ink erasers and any such rubbery items.

New contaminating agents can be added to the list as and when they are discovered. As an added insurance against a potential cure-inhibition, the following precautionary measures should be observed working with addition-curing RTV silicones:

1. a pre-test to ascertain full care is recommended whenever new modelling material is to be used;
2. use a clean brush when applying release agent on models or moulds;
3. use disposable vinyl or polyethylene gloves – latex and vinyl gloves are forbidden;
4. if bare hands are to be used to handle models, be mindful of any prior contact with known contaminating agents (e.g. hands that had previously worn latex gloves!);
5. as an added protection, wash hands thoroughly with washing liquid;
6. discard any contaminated models or moulds and start anew – do not wash and re-use.

When a cure-inhibition has occurred, it is important to identify and eliminate the source of the contamination so that it is not carried onto the subsequent procedures. Although thorough washing of the contaminated surfaces reduces the extent of the problem, the contaminants are extremely stubborn and difficult to remove completely. It certainly helps to know that just a minute amount of contaminant is sufficient to produce a damaging effect.

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