USE OF SILICONE IN ELECTROTECHNICS

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Abstract: Presented paper describes basic problems at composition of silicone rubber at making of composite pin and tension insulators.

Key words: silicone rubber, composite insulators

1. INTRODUCTION

Reliability of high voltage power line operation plays an important role at providing undisturbed provision of electrical energy to users. Important factors are high voltage insulators and surge arresters which have to endure higher and higher voltage charge even in worse environmental impacts (salt, industry pollution…).

Recently most common used insulators are made of glass or porcelain (classic insulators). Since 60.-ties composed insulators have been used. Nowadays due to bad characteristics of classical insulators (large weight, mechanical sensitivity) more and more composite insulators and conductors are being used.

Electrical characteristics of element (insulator, surge arrester) specially depend on shed which protects the core. Suitable shape (rings) is important because of good dielectric strength of element also at worse environmental impacts. Among various organic materials suitable for shed production (polyurethane, polyethylene, Teflon...) especially two have put into effect:

- EPDM (ethylene – propylene - dien monomer) and
- Silicon rubber.

It is important to emphasise that composed materials are mixtures. Material characteristics therefore depend on chemical structure, vulcanization process, fillings and additives. Composed material (for instance silicon rubber) of one producer can have essentially different characteristics as material of some other producer.

2. GENERALLY ABOT SILICONE

Silicones are common name for products of big group of materials – silocsan polymers. These are compound out of changing silicium and oxygen atoms with different organic compounds which are linked to silicium atoms and are therefore also called organic silicium compounds. Silicones can be found in liquid form, in form of elastomers and pitches.

Silicones are found in liquid form – for instance oils, fats, rubber and pitches, they can be linear or reticulated. Only these are stable in -50 to 250 ^{o}C range. They have low surface tension, are water repulsive, existent to UV radiation and weather existent. They have excellent dielectric characteristics; electrical insulation is relatively independent on temperatures. Silicones are non-polar and therefore function as sliding implement. Chemical existence is relatively good, none the less they fuse in many organic solvent.

Silicones compound from chains, possible reticulated, that are compound from changing silicium and oxygen atoms. Similar structure can be found in sand, glass and in most rocks. Chain – Si-O-Si-O-Si-O is modified with organic compounds that are linked to silicium atoms. Silocsans chains contain atomic links that are much more flexible as atomic links in ordinary layers. Is the issue of total rotation in Si-O link, especially when Si has small substitutes such as methyl groups.

Also in methyl silicones there are totally free rotations in Si-C links. Distances between methyl silicones chains are larger as between hydrocarbon chains. Intermolecular forces are weaker at silicones. Therefore hard silicones have low tension strengths and low glass crossing temperatures (-120^{o}C). For liquid silicones low point of collision and low surface energy are significant. Silicon oils are therefore good lubrication oils at low temperatures.

Due to open structure silicones pour gases through better as other polymers. Pouring is selective and extremely high for oxygen. Silicone membrane, which does not contain filling, pours oxygen through 10 times more as natural caoutchouc. Silicon materials are therefore used as artificial lungs. Molecular structure gives silicones almost unique characteristic: **constant characteristically profile in wide temperature interval.**

3. SILICON SILOPREN ELECTRO LSR

3.1. *Product description*

Silicone Silopren Electro LSR is two-component transparent silicone rubber. In production process is intended for mould injection. Silicone rubber is developed for layer production of all kinds of insulators and surge arresters.

Silicone Silopren Electro structure is determined with following characteristics:

- Pure silicone – no ATH filler**.**
- Low density = weight reduction up to 30%
- Very good tracking and arc resistance
- Fast hydrophobicity transfer and hydrophobicity recovery.
- Outstanding aging behaviour and weather resistance.
- Easy pigmentable with LSR Color Paste
- No peroxide byproducts.
- Excellent process stability and controlling.
- Particularly suitable for large volume applications.

3.2. *Use instructions*

Ready-for-use mixtures (components A and B) are fed directly to the injection-moulding machine from the original containers by means of multi-component mixing and metering units. The mixture, consisting of the two components in the ratio 1:1, is injected into the heated mould. Mould temperatures must be in range of 90-150°C. Short vulcanisation times and special metering units permit automated production of large numbers of articles per unit time, as for example high voltage suspension insulators, bushings and cable terminations.

Separated components of Silicone Silopren Electro can be used 6 months after delivery if stored in original unopened containers and at temperatures below 27^{o}C.

3.3. Hidrophobicity

Silicones repulse water atoms and are therefore self-cleaning. Figure 1 shows lifted water drops that can flow off easily and at the same time clean the surface of insulator.

Figure 1: Water drops on the surface of silicon layered insulator

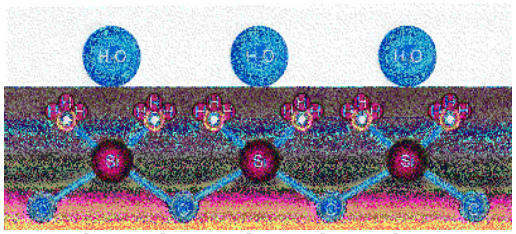


Figure 2: Silicon Silopren Electro chemical structure

At the production beginning all polymers are hydrophobic. Dirt, salt, corona, discharges and

chemicals are factors that reduce hydrophobia. At polyesters and artificial resin materials above mentioned factors eliminate the hydrophobicity. At silicon materials excessive corona and strong dischargescan permanently eliminate hydrophobia.

3.4. *Silicone rubber fillers*

To improve tracking and erosion resistance of silicon acid is added to silicon mixture. To improve tracking and erosion resistance inorganic fillings – usually ATH aluminium tri-hydrate; this should contain 70-80 % of total weight. Silicon itself is very expensive and therefore various quantities of cheaper fillers are added. This reduces the quality of silicon and because of that great attention to fillers in silicon is needed. To lower the price some producers instead of ATH use even silicon powder and such rubber is very stiff.

According to above mentioned problems the following is very important:

- Inorganic fillers improve tracking and erosion resistance .
- EP, EPDM, artificial resin materials need high filler content (>50%).
- Many silicones contain small quantities of fillers.
- To increase hydrophobicity the quantity of filler must be reduced.

Silicone LSR Silopren Electro has excellent tracking and erosion resistance and hydrophobicity without filler.

3.5. *Leakage currents at silicone housings*

Silicone housed insulator hydrophobicity is also excellent when air pollution is high – because of that leaing currents equals zero. Relative humidity in range of 40% to 80% also does not affect leaking currents of silicon housed insulators. On contrary, on EPDM housed insulators leaking currents increase by relative humidity increasing. (ref. J. Kindersberger TU Dresden Institut of High Voltage Technik).

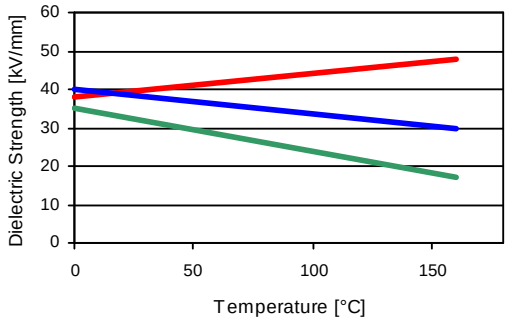
3.6. *Silicon Silopren Electro weather resistance*

Chart 1: Silicon weather resistance

	translucent		grey	
Exposure time	-	10.000h	-	10.000h
Hardness Shore A DIN 53 505	70	74	70	73
Tensile Strength (N/mm2) DIN 53 504	10,1	9,4	10,2	10,1
Elongation at Break (%) DIN 53 504	450	460	430	450

Chart 1 shows changes of Hardness Shore, Tensile Strength and Elongation at Break when silicone is exposed to weather conditions for 10.000 hours.

3.7. Dielectric strength as function of temperature



3.8. *Silicon waste material*

According to Rules amending the Rules on the management of waste (Uradni list RS št.20/01) silicon waste is marked wit 6-placed classification number (waste mark) and corresponding 2-placed classification number of group as well as with 4-placed number of subgroup.

Silicon waste comes from production, preparation, delivery and use of plastic, synthetic rubber and artificial fibres. Silicon waste classification number is 07 02 16 – this number refers to all waste that contains silicon.

According to Silicone Silopren Electro LSR Material safety data shift decomposition of silicon is carried out by incineration. Incineration must be done by registered company in accordance with official local rules.

4. COMPOSITE INSULATORS

4.1. *Structure and advantages*

Composite insulator is made of three parts and it has relatively simple structure. Main elements of insulator are:

- core,
- upper and lower end fitting,
- silicone shed.

At each insulator end there is suitable metal end fitting which is used for attachment to pillar respectively to conductor including protection arcing horns or rings for

potential distribution. Insulator itself is much lighter (even only 1/10 of total weight) than classic insulator chain.

As the core takes carrying function, it is so vital for insulator mechanical features. The core has a pole shape and it is made of glass fibres and special filling. It is extremely resistant to tensile and bending force activities. Pole is flexible and so capable of holding up big pliable forces.

Electrical characteristics of insulator depend on shed that protects the core. Suitable shape (rings) is important for good dielectrical strength of insulator also at harmful environmental conditions. Among various organic materials suitable for shed production (polyurethanes, polyethylenes, Teflon), especially two have implemented widely:

- EPDM (ethylene – propylene - dien monomer) and
- Silicon rubber.

It has to be emphasised that composed materials are mixtures. Material characteristics therefore depend on chemical structure, vulcanization process, fillings and additives. Composed material (for instance silicon rubber) of one producer can have essentially different characteristics as material of some other producer (filler content and other additives).

Good characteristics of composite insulators, which are at the same time, also the advantages in comparison to ceramic or glass insulators are as follows:

- low weight
- simple transport, handling and set up
- higher dielectric strength,
- higher mechanical stamina (vandalism, thermic load vault),
- higher reliability of functioning and
- no maintenance costs.

Advantages of silicone rubber compared to EPDM are:

- higher ageing resistance (UV rays influence),
- hydrophobicity preservation on polluted insulator and
- sustainability at low temperatures.

As a rule silicone rubber is a bit more expensive than EPDM.

4.2. *Electrical characteristics*

Undamaged insulator easily preserves electric field inside. The biggest charges are on the surface of insulator especially because of negative environmental influences. The most common influence is pollution which can, joined with humidity, decrease surface dielectrical strength to a great extent. Similar as classical insulators chains composite insulators have special rings to extent creepage distance. Composite insulators have at polluted conditions higher dielectrical strength (up to 50%) compared to ceramic or glass insulators with the same creepage distance.

Ageing of silicone rubber insulators, that contain high share of fillers, causes decrease of sustainability to the same or even lower level to those at classical insulators.

One of main characteristics that have influence on electrical characteristics of insulator is hydrophobicity. Measurement for hydrophobicity is angle at which water drop falls on insulator surface. Operating experiences and laboratorial measurements show that silicone and EPDM insulators loose hydrophobicity when exposed to discharges along dry surface. Even if the surface is exposed to pollution, the hydrophobicity is being lost. However silicone materials in contradistinction to EPDM restore their lost hydrophobicity.

Deterioration of insulator characteristics at operating, leads to unpleasant phenomena such as surface discharges, arcs and breakthrough of rings. As well electrical phenomena between composite shed and insulator core may appear due to bad manufacturing (partial discharges, moisture irruption at staples, cracks). Possible cause of all that may be also defects of material. Those defects may coalesce into more or less conductible ways which have great influence on dielectrical strength of insulator when overvoltage appears. At first approximation they can be represented with metal electrode adequate shape with floating or fixed potential. It was found out that sustainability on switches overvoltages reduces for almost 20 % if total length of conductible defect carries together 10 to 15% of total insulator length.

4.3. *Mechanical characteristics*

Composite insulators have very good mechanical characteristics and when operating easily maintain normal charging. Strength (both tensile and bending) is assured with glass fibres reinforced core. Withstand tension force equals withstand tension force of steel at 75% lower weight.

None the less some insulators that were operational for a long time suffered breakage respectively tearing up. In literature this phenomena is known as “brittle fracture”. The most probable cause for this phenomenon is corrosion of core by acids. Acids pour inside insulator along with pouring water, usually at the point of contact where core and metal end meets. Often insulator gives in at this point of contact. Acid is either already in water or it is forming under influence of corona.

Therefore good insulator must prevent water pouring. Some producers of insulators already use glass, resistant to acid.

Coating (shed) is flexible and therefore insensitive to impacts. Mechanical defects at transportation and set up are so rare.

It has been observed that some defects on sheds of insulators that were operational were caused by birds with pecking.

Composite insulators are by rule more resistant to vandalism than classic insulators. Direct gun hit usually does not destroy insulator however damages the shed. At classical insulators there is risk of total breakage and therefore insulator is destroyed.

When overvoltages (i.e. lightening struck) occurs arc happens; this results to arc with high temperature. At classical insulators many times due to thermic stress mechanical defects happen. In this respect silicone insulators are insensible. Because of that reason operating composite insulators with no protection arcing horns, is allowed, although arcing horns otherwise protect the insulator in the way that they push arc a bit aside.

5. OPERATING EXPERIENCES IN THE WORLD

5.1. Israel

In 1993 Israel Electric Corp-Ltd carried out research of 60000 composite insulators made of silicon rubber in 16 companies from South Africa, Canada, Australia, Spain, Switzerland and USA. The research stated basic reasons for use of insulators that are made of silicone rubber:

- lower maintenance costs and better characteristics as vandalism is concerned,
- no cleaning is needed,
- not numerous defects, if defects occur this were the consequence of “brittle fracture” due to moisture irruption.

5.2. South Africa

ESKOM Company replaced glass insulators with composite due to vandalism and pollution on 400 kV wires:

- at coastal areas they abandoned expensive washing of glass insulators using helicopters,
- characteristics of wires improved, number of defects reduced.

5.3. Australia

Electric distributors in Australia came to following conclusions:

- building in on tough ground,
- building of compact wires, as weight is 27 % lower,
- reduced corridor costs,
- smaller consoles are being used
- no problems at set up on wire near cement works
- EPDM layered insulators are not good.

6. CONCLUSION

Use of composite materials is increasing both abroad and in Slovenia. They have been used for last 40 years and have many advantages compared to classical (porcelain or glass) materials.

Electric and mechanical characteristics of insulators and surge arresters with silicon rubber layer are of such kind that they can be used on existing electric wires instead of classical insulators and surge arresters. Concerning new electric wires they allow planning and building in settled method (classical pillars) and also enable totally different approach.

Adequate mechanically dimensioned composite insulators can be attached directly on to pillar (with no horizontal pillars). Due to that, technically shorter distances between phase conductors are allowed as well as different, lower pillars and narrower laying–out are possible. With use of yokes along stretch it is possible to build compact power lines with fundamentally shorter distances between conductors.

This has an important impact on reduction of electrical and magnetic fields at ground, which becomes more and more important.

Figure 3: Example of overhead power line with composite insulators

Regarding insulator different approaches are possible. Composite insulators (especially silicone) for their characteristics enable shorter creepage distances. Thermic resistance at arc raises a question about necessity of protection arcing horns (shift of arc away from insulator). This specially holds true at surge arresters on wires usage. Although for successful utilization of all enumerated possibilities this area should be properly regulated in technical regulation. Namely regulation does not take into account the advantages that are brought composite insulators usage.

According to comparison between silicone rubber insulators and EPDM insulators first have better characteristics. From different sources it can be found out that silicone insulators are more resistible as far as ageing is concerned and that they preserve hydrophobicity in pollution conditions. Characteristics of materials from which same insulators are produced differ from manufacturer to manufacturer due to different fillings and additives that are used during production process. Silicone compounds essentially affect ageing and operating characteristics. Good silicone is the silicone without fillings which possesses good mechanical and electric characteristics end enables preservation of hydrophobicity. Referring to mechanical characteristics all attention must be paid to "brittle fracture" resistance.

Elements covered with silicone rubber have many economic advantages, although the purchase price of silicone insulators is higher than price of ceramic or glass insulators.

Economic advantages:

- lower costs because of breakthrough,
- no transport breakage costs ,
- lower maintenance costs – insulators do not need cleaning (hydrophobicity)
- lower leaking currents resulting in lower wire losses,
- lower building in costs due to lower weight,
- no costs concerning vandalism,
- lower disturbances on radio and TV devices.

Initial costs of silicone insulators purchase are comparing to porcelain or glass same but in operating time that cost repays. In 30 years the savings amount to 40-50%.
With regard to all advantages of silicone insulators towards porcelain and glass I estimate that elements with silicone layer are adequate for use in our distribution system and that they should oust insulators and surge arresters made of other materials.

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