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**THE COMPARISON OF CERAMIC AND NON-CERAMIC INSULATORS**

**ABSTRACT**

In this study, non-ceramic insulators have been researched and ceramic and composite insulators have been compared with respect to their various characteristics. The composite insulators are being accepted increasingly for use in outdoor installations by the traditionally cautious electric power utilities worldwide. The tremendous growth in the applications of non-ceramic insulators is due to their advantages over the traditional ceramic and glass insulators. These include light weight, higher mechanical strength to weight ratio, higher resistance, better performance in the presence of heavy pollution in wet conditions, and better withstand voltage than porcelain or glass insulators.

**Keywords:** Composite (Non-Ceramic) Insulator, Silicone Rubber, Hydrophobicity, Polymeric

**SERAMİK VE SERAMİK OLMAYAN İZOLATÖRLERİN KARŞILAŞTIRMASI**

**ÖZET**

Bu çalışmada, seramik olmayan izolatörler araştırılmış, seramik ve kompozit izolatörler çeşitli özelliklerine göre karşılaştırılmıştır. Kompozit izolatörler olarak da isimlendirilen seramik olmayan izolatörler, polimer ve polimerik izolatörler, güç sistemleri iletim hatlarında kullanılırlar. Kompozit izolatörlerin harici tesislerde kullanımı, dünya çapındaki elektrik güç şirketleri tarafından gittikçe artan ölçüde kabul edilmektedir. Seramik olmayan izolatörlerin uygulamalarındaki büyük gelişme, bu izolatörlerin geleneksel seramik ve cam izolatörlere göre daha avantajlı olmalarından kaynaklanmaktadır. Bu avantajlar; düşük ağırlık, ağırlık oranına göre daha yüksek mukavemet gücü, daha yüksek direnç, ıslak şartlarda ve ağır kirlenme koşullarında daha iyi performans ve porselen veya cam izolatörlere göre daha iyi dayanım gerilimi gibi özelliklerdir.

**Anahtar Kelimeler:** Kompozit (Seramik Olmayan) İzolatör, Silikon Kauçuk, Su Korkusu, Polimerik



## 1. INTRODUCTION (GİRİŞ)

Outdoor insulating bodies have traditionally been made out of glass of porcelain materials. The development and use of polymeric insulators started during the 1960s. Since the early 1990s, they can be considered a mature product [1], with a good service record [2 and 3]. This has been accompanied by an increased commercial interest [3 and 4] and increased research activities [4]. However, as always, bad news travels faster, spreads wider and lives longer than good news. Therefore failures in the earliest designs are still a holdback for polymeric insulators [5 and 6] and lacks of service experiences are often listed as the reason not to purchase polymeric insulators [2, 3, 6, 7, 8 and 9].

The 1930s and '40s saw the appearance of the first insulators to replace inorganic materials with organic, but these suffered problems of weather resistance, and their characteristics were unsatisfactory for outdoor use. In the 1950s epoxy resin insulators were developed, but they were heavy, suffered from UV degradation and tracking, and were never put into actual service. Worldwide composite insulators have been developed for outdoor application since the 1960's. By the mid-1970s a number of new insulating materials had been developed, and the concept of a composite structure was advanced, with an insulator housing made of ethylene propylene rubber (EPR), ethylene propylene diene methylene (EPDM) linkage, polytetrafluoro ethylene (PTFE), silicone rubber (SIR) or the like, and a core of fiber-reinforced plastic (FRP) to bear the tensile load [10]. Since these materials were new, however, there were many technical difficulties that had to be remedied, such as adhesion between materials and penetration of moisture, and the end-fittings, which transmit the load, had to be improved. Since the 1980s, greater use has been made of SIR due to its weather resistance, which is virtually permanent, and its hydrophobic properties, which allow improvement in the maximum withstand voltage of pollution, and this had led to an explosive increase in the use of composite insulators [11].

The need for non-ceramic composite insulators having characteristics such as light weight and good electrical and mechanical properties, for use in transmission lines, was greatly felt about 40 years ago. Today composite insulators have adequately replaced porcelain and glass insulators and are extensively used in high voltage lines. The use of composite insulators, with a 20% lower weight than their porcelain counterparts has become possible in lines [12 and 13]. The principle of composite insulators, manufacturing is based on a composite rod that should resist the mechanical stress applied by the cable and transfers this load to the tower. In order to protect this rod against weathering and environmental effects and also to increase the bearable creepage voltage [14], the rod is covered with SIR and the end-fittings are then joined at both ends with a special process [15]. A range of adhesives, curing agents and sealers are also used for this purpose [16].

## 2. RESEARCH SIGNIFICATION (ARAŞTIRMANIN ÖNEMİ)

The insulators have generally been made of ceramics or glass. These materials have outstanding insulating properties and weather resistance, but have the disadvantages of being heavy, easily fractured, and subject to degradation of their withstand voltage properties when polluted. There was therefore a desire to develop insulators of a new structure using new materials that would overcome these drawbacks. Non-ceramic insulators, also referred to as composite insulators, polymer or polymeric insulators are used in power transmission lines.



### **3. COMPOSITE INSULATORS (KOMPOZİT İZOLATÖRLER)**

Of all the electrical insulating materials, polymers are finding increasing utilization in HV systems and components serving at least two important functions: isolating the conducting components from each other and from the ground, and as load-bearing support. In the early stages of their use as electrical insulation, they were also thought to have very good resistance to degradation due to conditions found in service (moisture, oxygen, temperature variation). However, experience, observation and research in recent years has shown that all polymeric dielectrics are prone to degradation under stresses applied or induced in service which eventually leads to system failure. Most common stresses in service conditions to which an insulator is exposed include electric field, temperature variation, humidity, and other environmental factors [17, 18, 19, 20 and 21].

A typical composite insulator consists of a glass fiber reinforced (GFR), resin-bonded rod onto which metal end fittings are attached. To protect the core from environmental stresses, it is covered with a polymeric cover, called the housing. Epoxies were used for this purpose first, but after some bad experiences, hydrocarbons and silicones have dominated [1, 22 and 23]. Today, common housing materials are EPR and EPDM; different types of SIR; so-called alloy rubbers, which are blends of EPDM and SIR; and ethylene vinyl acetate-based elastomer (EVA) [4].

In recent years, polymeric insulating materials with excellent weather resistance and mechanical performance have been developed, and research, development and trial application of insulators made of such materials are being promoted [24]. Since polymeric insulators have excellent resistance to pollution and mechanical impact, these features can be used to reduce the size of transmission lines. In overseas countries, such insulators are effectively used as line-post insulators to reduce the size of transmission lines [25]. Polymer insulation arms with the functions of both steel tower arms and porcelain insulators are being developed [26].

#### **3.1. Historical Development of Composite Insulators (Kompozit İzolatörlerin Tarihsel Gelişimi)**

The history of insulators began together with the development of electrical communications. Ceramic materials and rubber have been used in insulators from 1800 onward. In 1850, the first porcelain post insulators were introduced. A few years later, in 1858, glass pin-type insulators appeared. At the beginning of the 20th century, suspension insulators became available, and by 1910, cap and pin insulators already had geometrical designs very similar to those seen today. Between 1920 and 1950, there was an almost explosive development of different insulator types and designs with the overall goal to increase performance under contaminated conditions. The concepts employed to achieve this were different and sometimes quite unexpected. Most often, designers developed geometry of the insulator so as either to enlarge creepage or to increase the self-washing property. Other approaches involved the search for a means to actively combat dry-band arcing. Among the different proposals in this regard were included oil-bath insulators, water-repellent insulators, insulators with built-in heaters, and semi-conducting glaze insulators. In parallel, various efforts concentrated on improving the quality of the different materials and the effectiveness of manufacturing technologies.

The history of polymeric insulators began in the 1940s when organic insulating materials were used to manufacture high voltage indoor electrical insulators from epoxy resins. These materials were



light weight, impact resistant, and could be used to form large complex parts [27]. Polymeric insulators for outdoor use were made feasible by the discovery in the 1950s that alumina trihydrate filler increases the tracking and erosion resistance of the polymer material [28]. However, polymeric insulators for outdoor application on transmission lines were not developed until the late 1960s and 1970s. Polymeric insulators finally came into general use on transmission lines in the 1980s.

The first polymers used for electrical insulation were bisphenol and cycloaliphatic epoxy resins. Introduced commercially in the mid 1940s, bisphenol epoxy resins were the first polymers used for electrical insulation, and are still used to make electrical insulators for indoor applications. Cycloaliphatic epoxys (CE) were introduced in 1957 [29], and were introduced in England for outdoor insulation in 1963 [30]. They are superior to bisphenol because of their greater resistance to carbon formation. However, the first commercial CE insulators in the U.S. failed shortly after installation in outdoor environments. Since then, new CE formulations have resulted in improved electrical performance [29].

In the early 1960s, distribution class (CE) insulators were first sold commercially in the U.S. under the name GEPOL [29]. These units failed due to surface damage and punctures [31]. CE was used later in experimental 500 kV station breaker bushings, and in 115 kV bushings in the 1970s, and for suspension insulators by Transmission Development Limited (TDL) of England. The TDL suspension insulators used slant sheds to provide natural washing of contamination. From the mid 1960s on, CE insulators were tested at up to 400 kV service voltage as suspension/strain insulators and cross-arms in the United Kingdom [29]. For various reasons, including poor cold temperature performance and insufficient weight reduction, CE did not gain acceptance in the US for outdoor high voltage suspension insulators. But today, CE is used in indoor and even semi-enclosed power systems.

In the 1960s an insulator having porcelain sheds supported by an epoxy resin fiberglass rod was developed. It was not widely used because of developments in lighter weight polymeric insulating materials.

Polymeric outdoor insulators for transmission lines were developed as early as 1964 in Germany [32], and by other manufacturers in England, France, Italy, and the U.S. In Germany, units for field testing were provided in 1967. In the late 1960s and early 1970s, manufacturers introduced the first generation of commercial polymeric transmission line insulators.

The composite insulators were widely used from the 1980's and the usage increased rapidly in the 1990's [33 and 34]. In 1980, Furukawa Electric was engaged in the development of inter-phase spacers to prevent galloping in power transmission lines, and at that time developed composite insulators that had the required light weight and flexibility. In 1991 the first composite insulators having a SIR housing were used as inter-phase spacers for 66 kV duty, and in 1994 their use was extended to 275 kV service with a unit 7 m in length. Excellent contamination and wetting performance, high ratios of strength to weight, vandalism resistance, easy transport and installation and obvious cost advantages over conventional ceramic insulators, especially in extra HV and ultra HV lines, are great attractions for utilities [35].

### 3.2. Structure of Composite Insulators (Kompozit İzolatörlerin Yapısı)

Typically a composite insulator comprises a core material, end-fitting, and a rubber insulating housing. The core is of FRP to distribute the tensile load. The reinforcing fibers used in FRP are glass (E or ECR) and epoxy resin is used for the matrix. The portions of the end-fitting that transmit tension to the cable and towers are of forged steel, malleable cast iron, aluminum, etc. The rubber housing provides electrical insulation and protects the FRP from the elements. Figure 1 shows the structure of a composite insulator [10, 36 and 37].

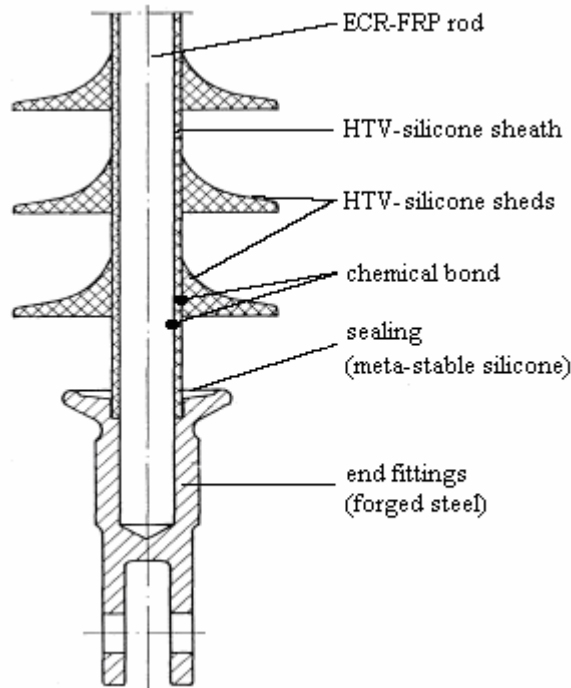


Figure 1. Structure of composite insulator  
(Şekil 1. Kompozit izolatörlerin yapısı)

Although the design of an insulator is important, it has been found in long term tests, that the housing material is more important than the design [38]. A good design with poor quality material will not perform [38 and 39]. In comparative testing, the alternating shed design has been found superior to the straight shed design [40] and the stacked shed design better than the distributed shed design [41]. Phillips et al. [42], in their work on corona aging, have shown the importance of stress grading rings [43].

### 3.3. Advantages of Composite Insulators (Kompozit İzolatörlerin Avantajları)

Polymeric transmission line insulators offer significant advantages over porcelain and glass insulators, especially for ultra HV transmission lines. Their light weight allows tower designs and compacting that porcelain and glass insulators do not. They can be used as phase spacers on compact lines to control galloping and to limit conductor motion due to through-faults [44]. They have generated considerable interest among utilities, including quality control and testing requirements [45]. Early evaluations indicated that their withstand performance was "equal to or better than that of a



comparable length of porcelain insulator chain" [29]. More recent tests have generally verified these evaluations. Lack of intermediate electrodes, and small diameter [22], contribute to this improved performance.

The specific advantages, compared with ceramic insulators [29], are:

- Light weight-lower construction and transportation costs.
- Vandalism resistance - less gunshot damage.
- High strength to weight ratio-longer spans/new tower.
- Better contamination performance.
- Improved transmission line aesthetics.

The reason for using composite insulators varies among utilities [2, 3 and 33], but one of the most common reasons is connected with the low weight. The weight of a composite insulator is normally only about 10% of the equivalent porcelain or glass type. Composite insulators enable lighter tower designs or upgraded existing lines [46, 47, 48 and 49]. Another important reason is associated with cost reduction, which would include lower cost for transport and construction, for narrower rights of way and for less maintenance. Recently, composite insulators, especially those for application in transmission lines, have actually become cheaper than counterparts made of glass and porcelain [23, 50 and 51].

The use of polymeric materials instead of porcelain or glass is not understood to its fullest potential, especially with regard to their water-repellent (hydrophobic) properties. Today, composite insulators are, in many cases, pessimistically designed for a hydrophilic state. This pessimism has led to a situation wherein some of the ideas and hypotheses, formulated right at the introduction of composite insulators, have been developing extremely slowly. The shortening of specific leakage distances and better control of stresses, advantages of compacting, as well as voltage upgrading can be named as examples. At the surface, there exists insufficient knowledge on the basic phenomena regarding the long-term performance of the materials used, together with a lack of reliable testing methods for material and product assessment. Many questions remain unanswered; there is, therefore, a great need today for more research activities to cover numerous aspects pertinent to outdoor insulation:

- The production and performance of new materials,
- The understanding of electrical, chemical, and mechanical deterioration mechanisms,
- The proper dimensioning, design, and manufacturing of the materials into insulators
- The development of methods for monitoring the performance and deterioration of the insulators in service [4].

Composite insulators do not shatter, break or cause any harm to personnel in the case of misadventure. SIR is also softer than EPDM in that the sheds are pliable. This feature allows greater safety in handling the composite insulators. Also, since the weight of each insulator is less, then the packaging that it comes in is more efficient. There is less packaging, less nails protruding from cases and less clean-up and waste at site.

SIR's superior capacity to bead water, make composite insulators better than glass, porcelain and EPDM rubber. While most composite insulators demonstrate the ability to bead water when new, all but SIR insulators eventually degrade under contaminated conditions and over long periods of time. The hydrophobic properties of SIR prevent reduction in the dielectric properties of the insulation system.



Composite insulators are not subject to high leakage currents, because regardless of the amount of contamination present on the insulator, SIR can continuously bead water. This insures lower line losses and consistent flashover values over the life of the transmission line.

The remarkable qualities of SIR's leakage performance allow for a reduction by 30% of the equivalent leakage distance required for porcelain and glass. Consider the different current carrying capacities between copper and aluminum conductors of the same size. The atomic structure of SIR too changes the leakage requirements over porcelain and glass. This 30% reduction in leakage requirements can influence the design height of transmission structures, or provide a greater factor of safety on existing structures.

To prove the superiority of SIR, laboratory and field tests were conducted on composite insulators alongside equivalent porcelain and glass designs. With 30% less leakage inches versus standard porcelain designs at 230 kV, the composite insulator demonstrated flashover at voltage levels 30% higher than porcelain under the worst contamination level.

Composite insulators are designed to provide cost effective solutions for the unique as well as the everyday applications. The variety of strength ratings available enables one to select the best insulator for a given application by using higher strength where required, and reducing cost when the strength is adequate.

The mechanical load bearing element of all composite insulators is a pultruded fibreglass reinforced resin rod. Because a composite insulator is only as strong as its core rod, reliable selects only those rod materials and manufacturing processes which can provide high mechanical strength under dynamic loading conditions. Each core rod must meet stringent quality control standards for dielectric strength, glass content, and moisture absorption which ensure long consistent service life.

Recently, although polymeric materials are much more sensitive to aging than conventional porcelain and glass materials, polymeric materials are applied to insulator surfaces, because of several advantages in the field of outdoor HV insulation [52]. One major advantage offered by polymeric materials is to impart a hydrophobicity to insulator surfaces [53]. The hydrophobicity can prevent contaminated water films from forming on the insulator surface even in wet conditions, which contributes to a suppression of leakage current. One type of polymeric materials is applied increasingly for housings of outdoor suspension and line-post insulators, bushings, arresters, cable terminators, line-spacers and protective coatings [34, 54, 55, 56, 57, 58, 59, 60 and 61]. SIR materials of this type can maintain their hydrophobicity for a longer time, over which most polymeric materials lose their hydrophobicity and allow leakage current and flashover to develop with reduced service time due to electrical and environmental stresses such as dry-band arcing and UV radiation [62, 63, 64, 65, 66 and 67].

The main disadvantages of composite polymeric insulators are:

1. They are subjected to chemical changes on the surface due to weathering and from dry band arcing [68],
2. Suffer from erosion and tracking which may lead ultimately to failure of the insulator [69],
3. Life expectancy is difficult to evaluate,
4. Long reliability is unknown,
5. Faulty insulators are difficult to detect [1].



### 3.4. Hydrophobicity (Su Korkusu)

The hydrophobicity of a polymeric insulator may influence its performance especially during wet and polluted conditions [70, 71 and 72]. Service experience and laboratory tests have shown that the surfaces of SIR and EPDM rubber insulators lose their initial hydrophobicity and become hydrophilic when they are exposed to prolonged dry-band arcing. The material can by exposure to wet and contaminated conditions lose its hydrophobicity due to a reorientation of the hydrophobic methyl (CH<sub>3</sub>) groups at the insulator surface. However, the SIR can recover and regain its hydrophobicity. In the past several investigations have been done on the wettability of polymeric insulators [73, 74 and 75].

Once every year, all the energized insulators are manually scrutinized. During this examination the hydrophobic properties of the insulators are determined by a spraying of their surfaces with a fine mist of tap water using an ordinary spray bottle. This provides only a rough estimate of the wetting of the insulator surfaces. However, it is a suitable method for rapid and easy checking of the hydrophobicity of the insulators in the field.

During the autumn and winter the insulators are less hydrophobic than summer. This is probably due to the wet and less sunny environmental conditions prevailing during these periods of the year. Generally, the SIR insulators are less hydrophobic on the under-sides of the sheds while, on the other hand, the EPDM rubber insulators are less hydrophilic on the under-sides [76].

### 3.5. Pollution Design of Composite Insulators (Kompozit İzolatörlerin Kirlenme Tasarımı)

Aging, which leads to loss of hydrophobicity, tracking and erosion, and eventually to flashover is still one of the main problems with polymeric insulators. Although the leakage current is a cause of aging, it can be used as an indicator of surface degradation. Thus, the parameters of leakage current waveforms have usually been used to evaluate polymer insulators performance. Several attempts have been made to correlate leakage current parameters to the contamination level and to the surface degradation like loss of hydrophobicity, dry-band arcing, and tracking and erosion of insulators [77, 78 and 79]. Hence, it is important to predict the level of leakage current before the occurrence of the loss of hydrophobicity and housing damage [80].

The performance of polymeric insulators is evaluated mainly based on IEC 61109. However, since the pollution design method for polymeric insulators has not yet been established, the conventional design method for porcelain insulators is adopted. In overseas countries, pollution design is performed according to an international standard, IEC 60815, based on pollution levels such as light (creepage distance 16 mm/kV), medium (20 mm/kV), heavy (25 mm/kV) and very heavy (31 mm/kV) [24 and 81].

Polymeric materials such as SIR and EPDM have been in use as weathersheds on outdoor insulators for about 40 years. Contamination-related power outages caused by dry-band arcing is a serious limitation with porcelain and glass. Standard laboratory tests, such as the salt-fog and clean-fog test, which evaluate their performance under simulated outdoor contamination conditions have been developed by the IEEE, CIGRE (International Conference for Large Electric Networks) and IEC (International Electrotechnical Commission). As there is no such standard test for polymeric insulator performance, they are being evaluated by methods developed for porcelain and glass [82].





The contamination performance of polymeric insulators is greatly dependent on the weathershed material performance. There are two important factors, which have been demonstrated in service that should be considered in the material evaluation. The first is due to the relatively poor thermal stability of polymers, dry band arcs can cause weathershed degradation in the form of tracking or erosion even before insulator flashover. The second factor is that SIR resists the formation of a continuous electrolytic film, thereby limiting leakage current, much better than EPDM and porcelain [83]. This has been the reason for the superior service performance of SIR insulators [84]. In order that a test be considered suitable for polymers, correlation with results obtained from service has to be demonstrated. The insulators made from polymers cannot be evaluated meaningfully using the same contamination test conditions which have been standardized for porcelain and glass [82].

### **3.6. Flashover Mechanism of Composite Insulators (Kompozit İzolatörlerin Atlama Mekanizması)**

The application of non-ceramic insulators is increasing rapidly in the world. A significant percentage of new lines is built with non-ceramic insulators. The main advantages of non-ceramic insulators are the reduced construction time and better contamination performance [85, 86 and 87]. The former is particularly important in emergency conditions [88] when the use of non-ceramic insulators permits the fast restoration of service after a hurricane.

The typical problem with non-ceramic insulators is the aging and deterioration of the shed material but not flashover [89]. Most of the flashovers reported in the literature occurred in extremely bad weather, during storms. A survey conducted by EPRI [90] indicates better contamination performance for non-ceramic insulators than for porcelain insulators. Particularly important is the better performance in contaminated conditions. This was discovered during the testing of the first generation of polymer insulators [91 and 92]. However, flashover of non-ceramic insulators has been observed in extreme condition [88], which gives importance to the study of the flashover phenomenon. Laboratory studies indicate that the flashover mechanism of non-ceramic insulators is different compared to porcelain insulators.

Some insulators are built with two shed diameters. The shed diameters alternate along the length of the insulator. The smaller sheds collect less pollution than the larger ones. The pollution is distributed uniformly on the insulator surface but the amount of pollution is different on the upper and lower surface of the shed, also different amounts of pollution were observed on the shank. Figure 2 shows these different areas on the insulator surface [93].

The flashover between two electrodes on a polluted SIR surface was studied [94 and 95]. Electrodes were placed on one shed of a SIR insulator. Both the upper and the lower surface were polluted with a kaolin and salt mixture and were permitted to recover hydrophobicity. The insulator was energized to 10kV (rms) and the pollution was wetted by steam. In nature, the early morning fog or dew wets the insulator in a similar way.

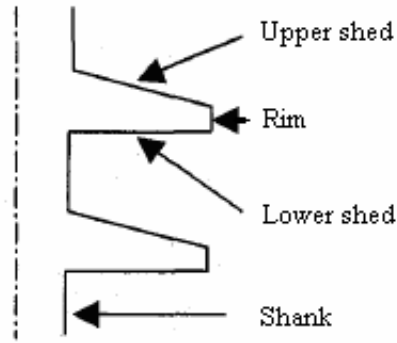


Figure 2. Pollution collecting areas on a non-ceramic insulator [93]  
(Şekil 2. Seramik olmayan bir izolatör üzerindeki kir toplama alanları) [93]

The flashover mechanism of an actual insulator is more complicated because the insulator is divided into four distinct areas shown in Figure 2. The areas are the upper shed, rim, lower shed and shank. The contamination survey showed that the contamination level on each area is different (Figure 3). Also the wetting process depends on the position of the surface. As an example, the water droplets tend to roll off the vertical surface [93].

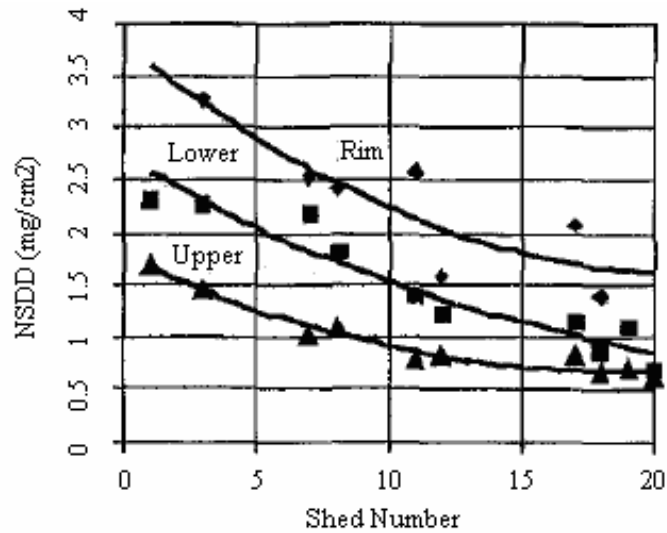


Figure 3. Pollution distribution on sheds [93]  
(Şekil 3. Şedler üzerindeki kir dağılımı) [93]

The actual flashover voltage in natural conditions cannot be measured. However, operating experience has proven that non-ceramic insulators perform better than porcelain in polluted conditions [96, 97 and 98]. When non-ceramic insulators replaced the porcelain ones, interruptions due to flashovers stopped. The leakage distance of the non-ceramic insulators was similar to the porcelain insulators. This proves that the flashover voltage of non-ceramic insulators is higher than the porcelain ones [99]. Also, laboratory tests showed significantly higher flashover voltages for both silicone and EPDM insulators compared to glass insulators [57 and 100]. Figure 4 compares the flashover voltage of SIR, EPDM and glass insulators [96].

The figure shows that the flashover voltage of an insulators decreases similarly by increasing the pollution level. In general the non-ceramic insulators performed better than the glass insulators. It is important to note that the flashover voltage of a hydrophobic SIR insulator is higher than that of a hydrophilic one, whose hydrophobicity has not yet recovered. Figure 4 also shows that the performance of SIR insulators is better than those of either EPDM or glass. These data can be used only for comparison, because the actual flashover voltage depends on the insulator age, shape, the distance between the sheds, and the shed diameter [93].

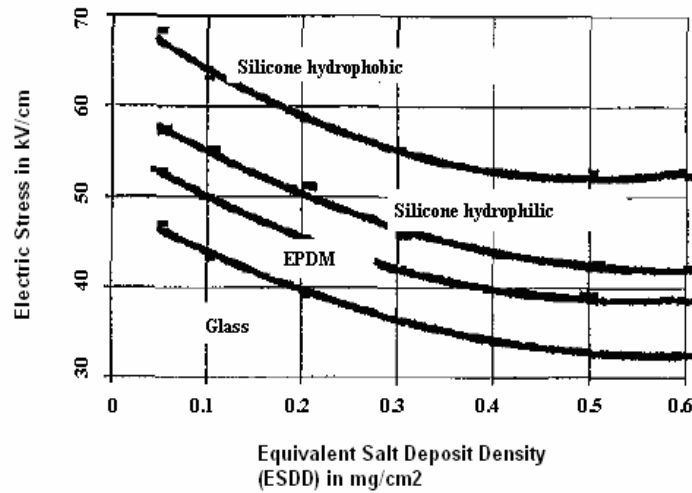


Figure 4. Comparison of pollution performance of aged non-ceramic and cap and pin glass insulators [96]

(Şekil 4. Kasket tipi cam izolatörler ile seramik olmayan yaşlı izolatörlerin kir performanslarının karşılaştırması) [96]

Karady [93] has described the flashover mechanism of non-ceramic insulators and he has obtained the following results:

1. Non-ceramic insulators collect more pollution than porcelain insulators.
2. Pollution on SIR insulators forms a thin layer consisting of dust, salt and silicone oil mixture.
3. This mixture prevents the release of conductive material when wetted, which results in high surface resistance.
4. The flashover mechanism of non-ceramic silicone insulators is different from the flashover mechanism of porcelain insulators.
5. The actual flashover voltage of non-ceramic SIR insulators is higher than the flashover voltage for porcelain insulators in polluted conditions.
6. Aging slightly reduces the flashover voltage.
7. The results of flashover tests are not conclusive. The salt-fog and clean fog tests can produce greatly different flashover voltages.

#### 4. THE COMPARISON OF CERAMIC AND COMPOSITE INSULATORS (SERAMİK VE KOMPOZİT İZOLATÖRLERİN KARŞILAŞTIRMASI)

1. Polymeric insulators are increasingly being used in both the distribution and transmission voltage ranges and are steadily capturing a wider share of the market [101]. The primary impetus for their increased acceptance by the usually cautious electric power utilities is their substantial advantage compared to inorganic insulators which have primarily been porcelain and



glass. One of their major advantages is their low surface energy [102 and 103] and thereby maintaining a good hydrophobic surface property in the presence of wet conditions such as fog, dew and rain [104]. Other advantages include:

2. Light weight which results in a more economic design of the towers or alternatively enabling to upgrade the voltage of existing systems without changing the tower dimensions. The light weight of the composite insulator strings also permits an increase in the clearance distance between the conductor to ground and an increase in the phase-to-phase distance in order to reduce the electric and magnetic fields which are becoming a growing concern to some members of the general public. The light weight of the composite insulators also obviates the need to use heavy cranes for their handling and installation and this saves on cost [46],
3. A higher mechanical strength to weight ratio which enables the construction of longer spans of towers,
4. Line post insulators are less prone to serious damage from vandalism such as gunshots which cause the ceramic insulators to shatter and drop the conductor to the ground [105],
5. Much better performance than ceramic insulators in outdoor service in the presence of heavy pollution [76, 97 and 106] as well as in short term tests [107] when done according to the method outlined in [108],
6. Comparable or better withstand voltage than porcelain and glass insulators [97 and 98],
7. Easy installation thus saving on labor cost,
8. The use of composite insulators reduces the maintenance costs such as of insulator washing which is often required for ceramic and glass insulators in heavily contaminated environment.

Table 1. Comparative general capabilities of insulators  
 (Tablo 1. İzolatörlerin karşılaştırmalı genel yetenekleri)

	Porcelain Ceramic	EPDM Polymer	SIR
Hydrophobic Recovery	No	No	Yes
Light Weight	No	Yes	Yes
Contamination Resistant	No	No	Yes
Leakage Current Control	No	No	Yes
Resists Weather	Yes	Yes	Yes
Lower Cost Installation/Breakage	No	Yes	Yes
Resists UV	Yes	Varies	Yes

Comparative general properties of different insulators are given in Table 1. Compared with a competitive insulator, such as a porcelain insulator, ceramic insulator, glass insulator and EPDM polymer insulator, SIR insulators offer many advantages, including:

- Superior long-term insulation,
- Strong yet light weight,
- Less susceptible to damage caused by shipment, installation or vandalism,
- Reduced maintenance costs,
- Sustained hydrophobicity, resulting in lower leakage currents, reduced dry band arcing, and less risk of flashover,
- Resistance to atmospheric and chemical degradation,
- Outstanding UV resistance compared with EPDM,



- Good property and color retention under all weathering conditions.

When it comes to selecting the best material for HV insulators used in power transmission and distribution applications, there's really only one choice. For overall performance and long-term value, SIR is the clear winner. Insulators made with silicone are easy to install, reduce maintenance costs, are more resistant to vandalism, and offer superior long-term insulating properties [109].

Compared with porcelain, insulators made with SIR are far easier to install. That's because silicone insulators require no assembly and generally weigh less than 25 percent of their ceramic counterparts. That can mean a weight saving of up to 180 kilograms per insulator, depending on the application a difference installation crews really appreciate when working on a transmission line high above the ground. In addition, power loss through leakage currents across the insulator is also minimized using SIR.

Porcelain insulators are frequently vandalized simply because they shatter dramatically when struck. Even when struck by bullets, SIR insulators are better equipped to go on doing their job with almost no performance loss. And since there is no dramatic visual loss of insulator integrity, vandals quickly lose interest in shooting at them. This can significantly reduce maintenance costs.

Silicone polymers have inherently good electrical insulating qualities. They are nonconductive because of their chemical nature and, when compounded with the proper fillers and additives, are used to produce rubber for a wide range of electrical insulating applications.

A comparison of life cycle costs (LCC) for ceramic discs (incl. washing), silicone coated ceramic discs and SIR insulators was carried out (Figure 5). The annual LCC for a coated ceramic disc are about 60-67%, the LCC for a silicone insulator are only 30-34% referring to the LCC for a ceramic discs string.

Traditionally, insulator failure rate (FR) is defined as the number of insulator failures per 10.000 insulators per year. In accordance with international practice, the failure rate acceptable to the electric utilities worldwide is less than one. Failure is defined as the loss of ability of a device to perform any of its intended functions. Therefore, actual insulator failures or flashovers, even if the insulation is self restored, will be counted as insulator failures.

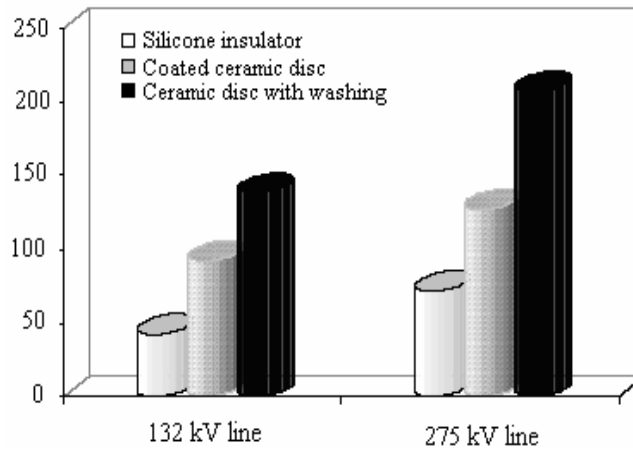


Figure 5. Comparison of annual LCC [44]  
 Şekil 5. Yıllık LCC karşılaştırması) [44]

The following equation was developed to calculate the reliability index (RI) from the failure rate of used SIR insulators as well as other used insulators:

$$RI = 1/(1+FR) \quad (1)$$

where RI = 1

FR : Number of failed insulators per 10.000 insulators per year

The LCCs of the insulators are shown in Table 2 and calculated as follows using a 30 year life for porcelain desert long rod (DLR) insulators and a predicted life for SIR insulators of 25 year:

$$LCC = \text{purchase cost} + \text{replacement cost} + \text{lifetime wash cost} \quad (2)$$

Also, each cost component as a percentage of LCC and LCC saving given by use of SIR insulators, are shown along with LCC comparison in Table 2.

The above calculations show that the LCC of DLR insulators is about 1.5 times that of SIR insulators. This means that the saving is the result of the difference in purchase cost (89% of LCC for DLR insulators and 85% of LCC for SIR insulator). Nevertheless, other significant advantages of SIR insulators include easier installation, transportation and improved power-system reliability.

Because of the technology of SIR insulators is relatively new, this development could still have greater advantages over porcelain insulators as the benefits from improvements in materials and design and the economies of mass production materialize. These potential benefits seem likely to make SIR insulators the most cost-effective type of insulator in future, even for applications in desert environments [110].

Table 2. LCC percentage distribution and comparison [110]  
 (Tablo 2. LCC dağılımı (%) ve karşılaştırma) [110]

Item	DLR Insulators	SIR Insulators
LCC	SR2,824,600 [US\$753,230]	SR1,578,130 [US\$420,840]
LCC per string/year	SR83 [US\$22.13] (R1)	SR55.7 [US\$14.85] (R2)
Purchase cost	89% of LCC	85% of LCC
Replacement work cost	11% of LCC	15% of LCC
LCC saving in 25 years	(R1-R2) × 25 × 1134 = SR773 955 [US\$206,388]	
R1/R2	1.5	



#### 4. CONCLUSION (SONUÇ)

Composite insulators are used in increased numbers for the insulation of HV transmission lines. They are manufactured from different materials by different manufacturing processes and show different design aspects. Thus, these composite insulators are not equal. Their innovative details become obvious only if particular service stresses act together in such a way that the particular design items are challenged. Composite insulators are light in weight and have demonstrated outstanding levels of pollution withstand voltage characteristics and impact resistance, and have been widely used as inter-phase spacers to prevent galloping. They have as yet, however, been infrequently used as suspension insulators. Since the mechanical stress is smaller, the body diameter can be thinner, and so the polymeric insulators can be made smaller and lighter since their pollution withstand voltage performance is better than that of porcelain insulators.

It is expected that the market share of polymer insulators will continue to grow worldwide. The expected life time of polymer insulators still presents an unknown quantity and therefore is of concern to some power utilities, particularly for applications in heavily polluted and wet conditions. Substantial improvements can still be made to the formulations, the designs of the weather sheds, stress relief rings and to the metal end fittings. These will undoubtedly bring about further improvements in the electrical performance of composite polymer insulators, leading to their acceptance worldwide and a further reduction in their cost.

World wide service experience with silicon rubber insulators is excellent. Especially, under heavy pollution conditions silicon insulators outperform any other type of insulator by far. So far there have no laboratory test been known to judge performance in service or life expectancy. Suitability of composite insulator design and materials can be proven by long-term service experience only. Composite insulators offer economic advantages such as low cost compact lines, low transportation and installation costs and drastically reduced maintenance costs. Due to their superior performance under any service conditions and their technical and economic advantages composite insulators with silicon rubber housing will represent the absolute future insulation material.

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