THE EFFECT OF ENVIRONMENTAL CONDITIONING ON THE ELECTROMAGNETIC PERFORMANCE OF RADAR ABSORBING ELASTOMERS

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ABSTRACT

Radar absorbing materials (RAM) have a great importance of designing fifth generation military aircrafts by providing low observable characteristics. In recent years, different types of polymer-based composites have been investigated to reduce the radar cross section (RCS) of the aircraft. Among those, elastomeric materials are mostly preferred due to their high flexibility, adjustable permittivity and permeability properties within the desired frequency range. In this study, silicone and polyurethane based elastomer materials have been used to investigate the changes of the electromagnetic properties under different environmental conditions. Temperature dependency of electromagnetic properties of radar absorbing elastomers were determined by using a Free Space measurement set-up. Also, the effect of humidity on the electromagnetic properties were analyzed.

INTRODUCTION

During World War II, Germany, concerned with radar camouflage for submarines, developed "Wesch" material, a carbonyl iron powder loaded rubber sheet about 0.3 inches thick and a resonant frequency at 3 GHz [Saville P., 2005]. After the development of radar absorbing materials and radar technologies, the area of utilization has expanded to aviation side of military purposes. In recent years, fifth generation military aircrafts designed based on low observable principles have been constructed with materials that protect the aircraft from radar waves. Even though radar absorbing materials can be categorized depending on chemical nature or mechanical strength, those are also need to be modified in order to provide required properties in terms of electromagnetic behavior. For this purpose, elastomers are most feasible materials to arrange its electromagnetic properties based on the desired values.

Radar Absorbing Elastomers

Elastomers are polymer based materials produced by special production techniques and they are used for various purposes. In the aviation industry, elastomers are the part of different sections of aircraft such as gasket, filler, seal etc. However, elastomers have become crucial

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with the development of stealth technology which gives strategic significance to military aircrafts. The factor that makes elastomers important in stealth technology is having ability to combine with additives which protect the structure from radar waves. Especially, those additives are playing important role in electromagnetic performance of elastomeric materials by drawing magnetic pathway to incident beam. These additives can be tuned to absorb at higher or lower frequencies depending on their types, shapes and size.

Effect of Environmental Conditioning on Electromagnetic Performance

Environmental conditionings are very important for aviation industry, since these procedures are basically simulations of the harshest environments that the air vehicle can face during its service life. All the mechanical properties vary with the conditionings such as water uptake and moisture adsorption. Even there are a lot of studies on the electromagnetic scattering properties of the polymer based materials [Özkan V., Yapıcı A., Karaarslan M., Akgöl O., 2020] while very few reports are studied on the effect of environment on the electromagnetic performance particularly. In this study, effect of moisture and water uptake was emphasized on two different based elastomers. Also, effect of temperature on conditioned and un-conditioned elastomers were investigated.

METHOD

Polyurethane and silicone based carbonyl iron loaded elastomers with the commercial name of ABS-NBE10 and MAST-MR11 were conditioned in water bath until fully saturation achieved. Prior to the conditioning and after saturation, electromagnetic characterizations were performed with a free space electromagnetic characterization setup of 2 antennas, 2 lenses, a temperature controlled oven and a Vector Network Analyzer. Samples were placed in the oven and heated up to 120°C with a ramp of 3°C/min. Electromagnetic characterizations were performed in every 2 minutes for a good resolution of trend in behavior of the sample. Schematic of the measurement setup is shown in Figure 1.

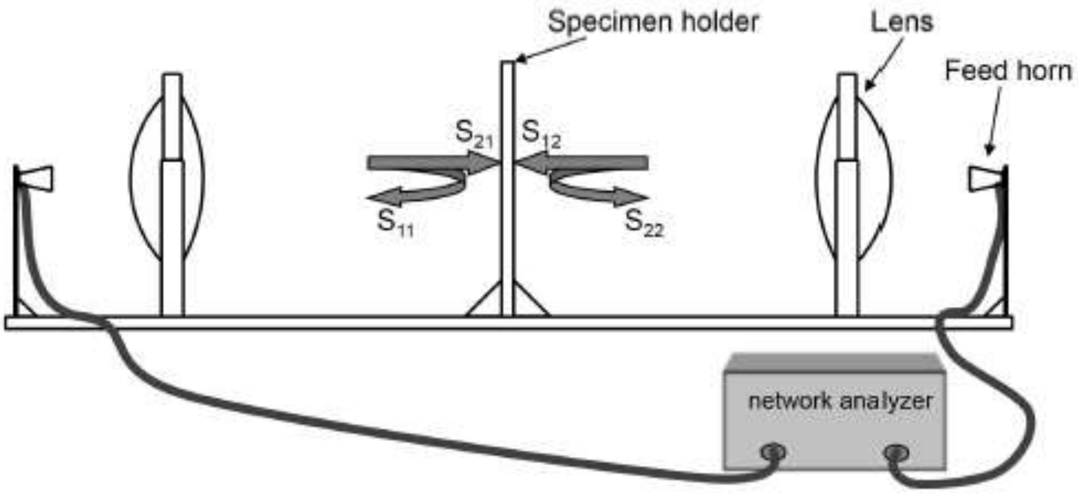

Figure 1 Schematic of free space electromagnetic measurement setup and attachment with sample holder.

RESULTS AND DISCUSSION

Electromagnetic properties of polyurethane and silicone based radar absorbing elastomeric materials have been investigated in dry and wet condition. For dry condition, specimens were tested as received and no special treatment was applied before the measurement. On the other hand, for wet condition, specimens were immersed in water at 23°C for 15 days. During immersion, traveler specimens were used to determine weight gain and those were prepared in the dimension of 50 x 50 mm. Since traveler specimens have the same thickness with tested specimens, they represent the same weight gain with the major specimens. After weight measurement at 0^{th} and 15^{th} day, total weight gain for both materials in wet condition were calculated and shown in Table 1.

Table 1 Weight Gain for Polyurethane and Silicone

Material	**Weight @0th day (g)**	**Weigh @15th day (g)**	**Weight Gain (%)**
Polyurethane based Elastomer	15.4861	15.7210	1.49
Silicone based Elastomer	14.4336	14.5190	0.59

As it is shown in Table 1, polyurethane based elastomeric material gained almost 3 times more moisture than the silicone based one.

Focused beam free – space electromagnetic measurements at high temperature were performed for the specimens in the dimension of 30 x 30 cm. For those specimens, reliable electromagnetic data can be obtained in the frequencies above 8 GHz. Therefore, spot frequencies have been determined as 10 – 11 – 12 GHz for this study and results were discussed in the range of stated frequencies which is also in compliance with the electromagnetic threats for the military air vehicles. Also, temperature was increased during measurements and data was taken at certain points to be able to monitor the environmental effects on the electromagnetic performance of the particular sample. The same procedure was applied to both silicone and polyurethane based materials and measurement sequence is stated in Table 2.

Table 2 Free Space High Temperature Measurement Sequence

Step	**Target**	**Ramp Rate**	**Measurement**
1	50°C	3°C/min	@ every 5°C
2	50°C at 10 min	-	@ every 2 min
3	100°C	3°C/min	@ every 5°C
4	100°C at 10 min	-	@ every 2 min
5	120°C	3°C/min	@ every 5°C
6	120°C at 10 min	-	@ every 2 min

By applying the procedure, which is stated in Table 2, real part of relative permittivity and real part of relative permeability data was obtained at different frequencies and different temperatures. Electromagnetic permittivity and permeability are directly related with the type of the base material [Duggal S., Aul G.D., 2014]. Therefore, electromagnetic behavior of silicone based elastomer and polyurethane based elastomers are considered in different manner. Relative permittivity of both wet and dry silicone based elastomeric materials in 10, 11 and 12 GHz spot frequencies at different temperatures were plotted in Fig 2, 3 and 4, accordingly. Also, relative permittivity of polyurethane based elastomer are presented in Fig 5, 6 and 7.

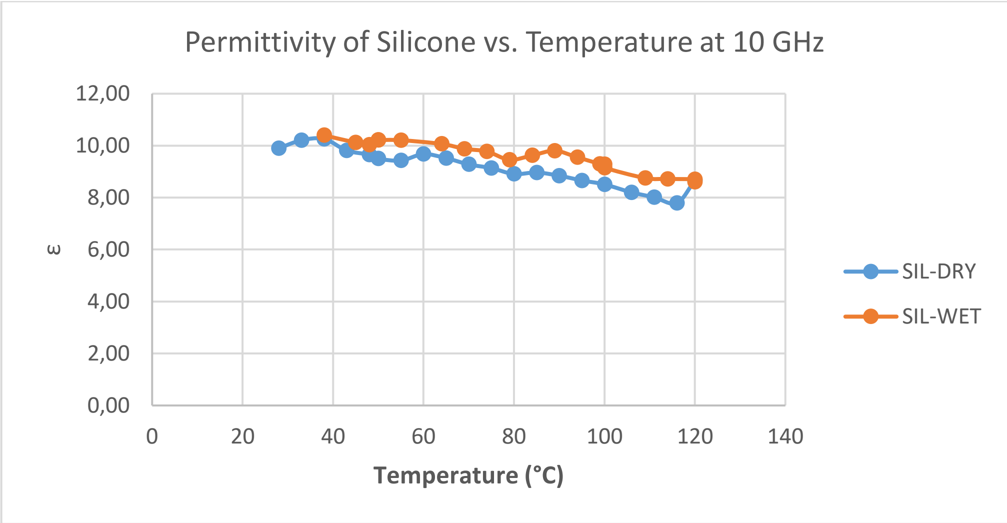

Figure 2 Permittivity vs. Temperature Plot of Silicone Based Elastomer at 10 GHz

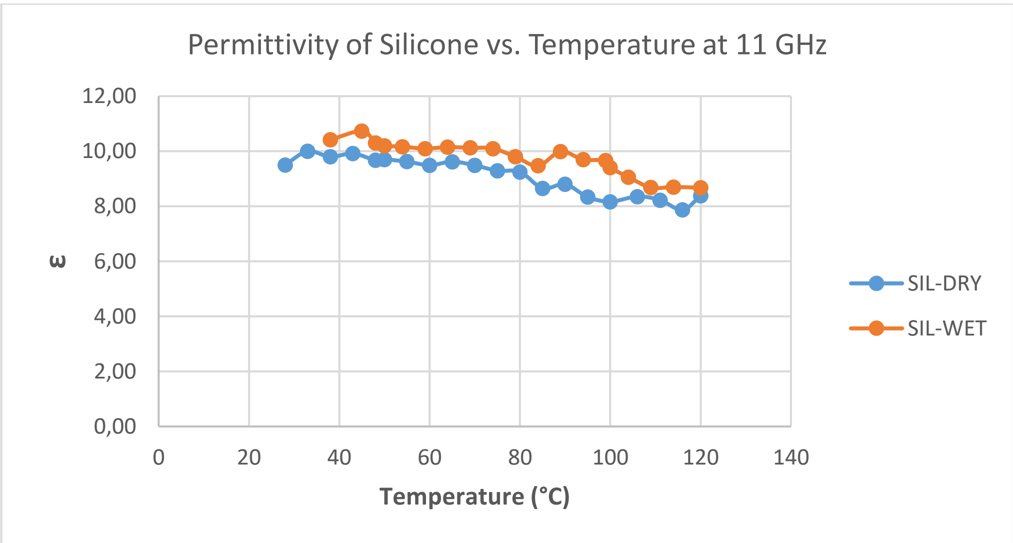

Figure 3 Permittivity vs. Temperature Plot of Silicone Based Elastomer at 11 GHz

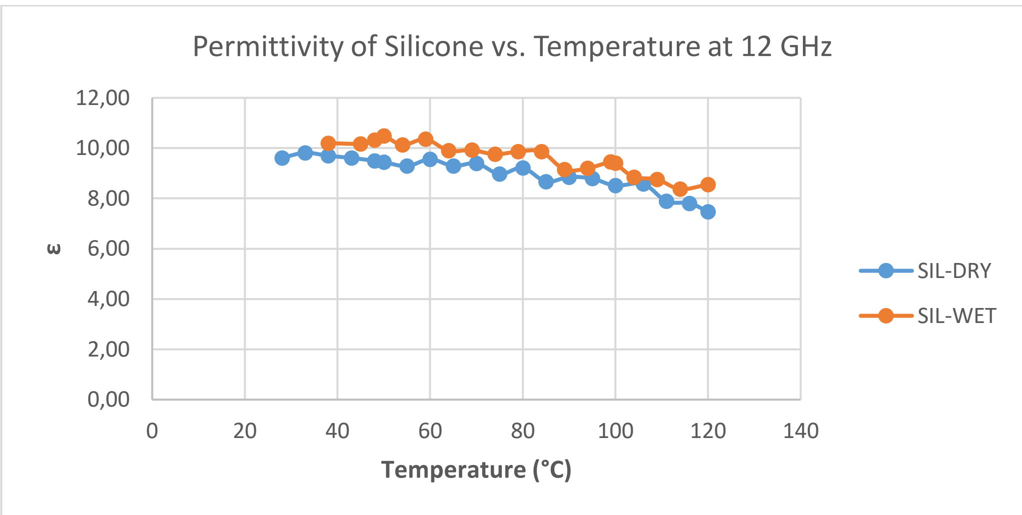

Figure 4 Permittivity vs. Temperature Plot of Silicone Based Elastomer at 12 GHz

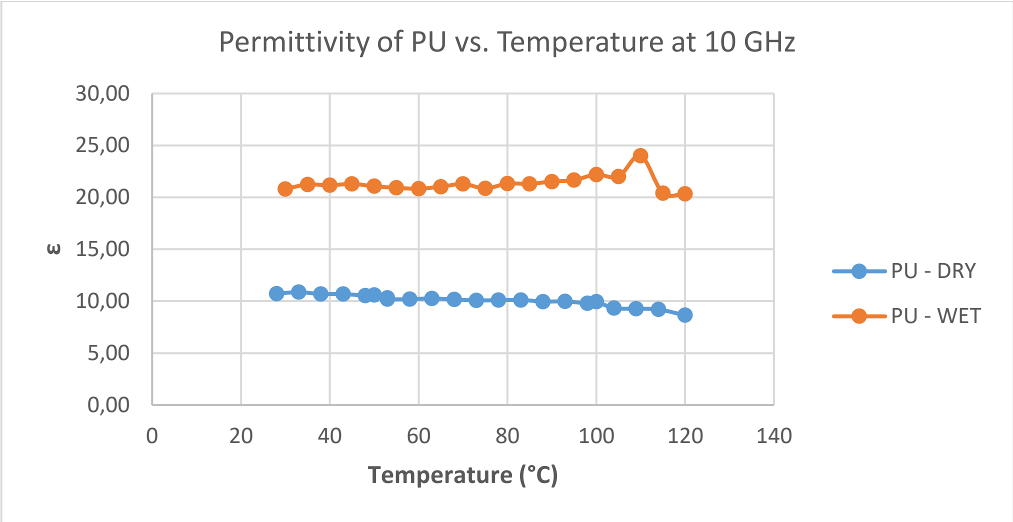

Figure 5 Permittivity vs. Temperature Plot of Polyurethane Based Elastomer at 10 GHz

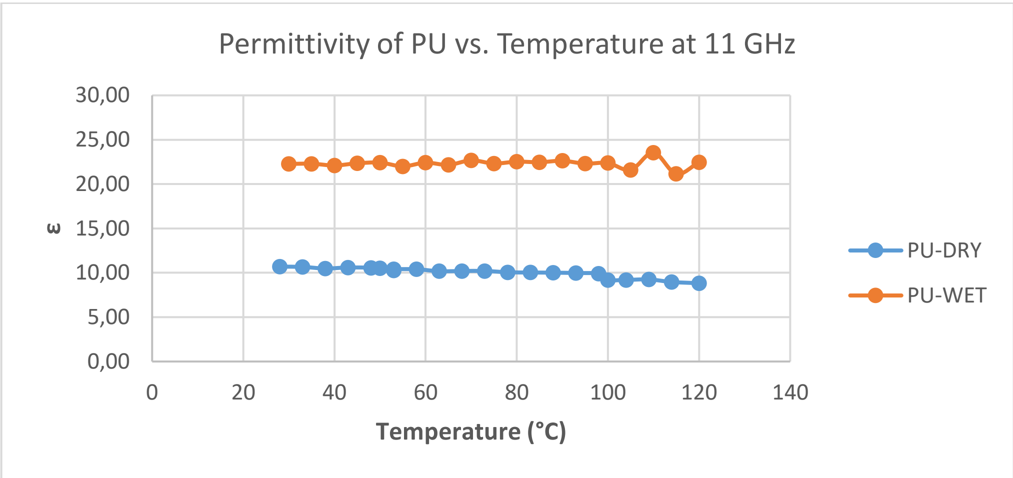

Figure 6 Permittivity vs. Temperature Plot of Polyurethane Based Elastomer at 11 GHz

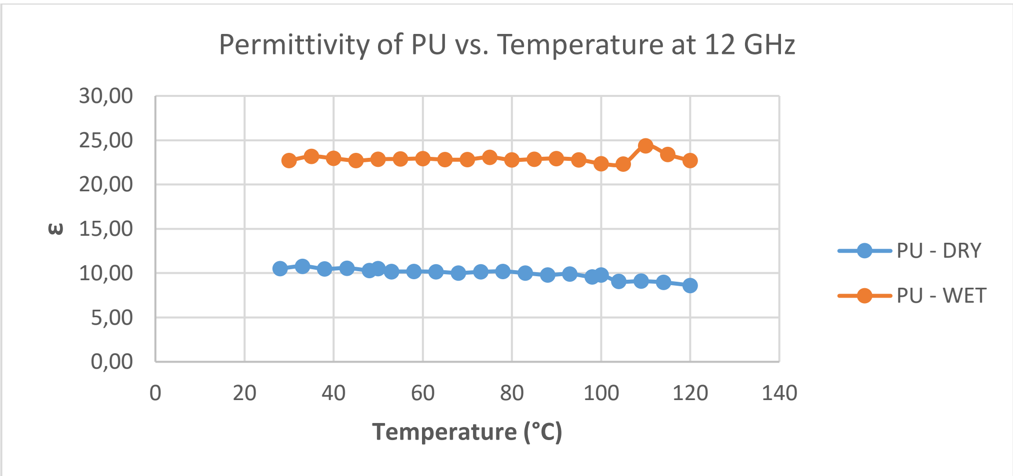

Figure 7 Permittivity vs. Temperature Plot of Polyurethane Based Elastomer at 12 GHz

As it is shown in Fig.2, Fig.3 and Fig.4, increasing temperature does not have a strong influence on the relative permittivity for silicone based elastomer. Since the water uptake of the silicone based elastomer is relatively low, there were no significant effect on any of the spot frequencies with respect to the dry sample. The relative permittivity behavior of polyurethane based elastomer is shown in Fig. 5., Fig.6 and Fig. 7. On the contrary of silicone based elastomer, polyurethane based elastomer shows a different trend depending on moisture content because it was observed that the relative permittivity of the dry and wet polyurethane based elastomers showed considerable difference in all frequencies. The water uptake results of the polyurethane based elastomers given in table 1, indicates 3 fold increase in the water uptake from silicone based elastomer. Since the water itself, has a relative permittivity value around 80 [Wightman, W. E., Jalinoos, F., Sirles, P., and Hanna, K., 2003], it increases the total relative permittivity of the system above 20 as expected. Also, higher moisture content might increase the polarization that directly affects the permittivity of material. Although there is a slight decreasing for silicone based elastomer, it was observed that there is no significant difference of the relative permittivity of both dry and wet samples for both material with respect to the temperature. It was expected to decrease the relative permittivity of the wet samples with the loss of the moisture in elevated temperatures [Landon R. Grace, 2015] while the polymer of the system acts as a host for the moisture and does not release the water until higher temperatures [Kast, O., Bonte, C., 2019]. It is suggested to increase the temperatures to observe the behavior of the moisture decrease in these type of materials as a future work.

Relative permeability of silicone based elastomer is stated in Fig.8, Fig.9 and Fig.10 and relative permeability of polyurethane based elastomer is presented in Fig.11, Fig.12 and Fig.13 at different frequencies.

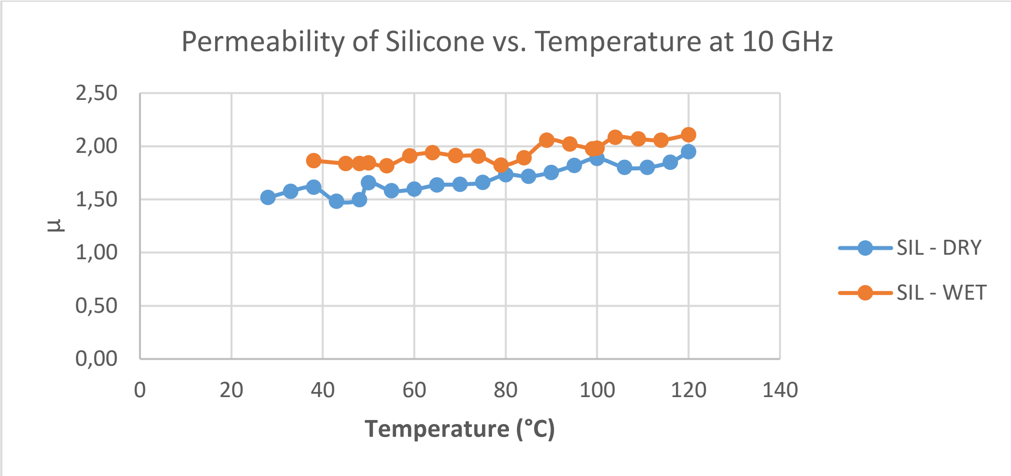

Figure 8 Permeability vs. Temperature Plot of Silicone Based Elastomer at 10 GHz

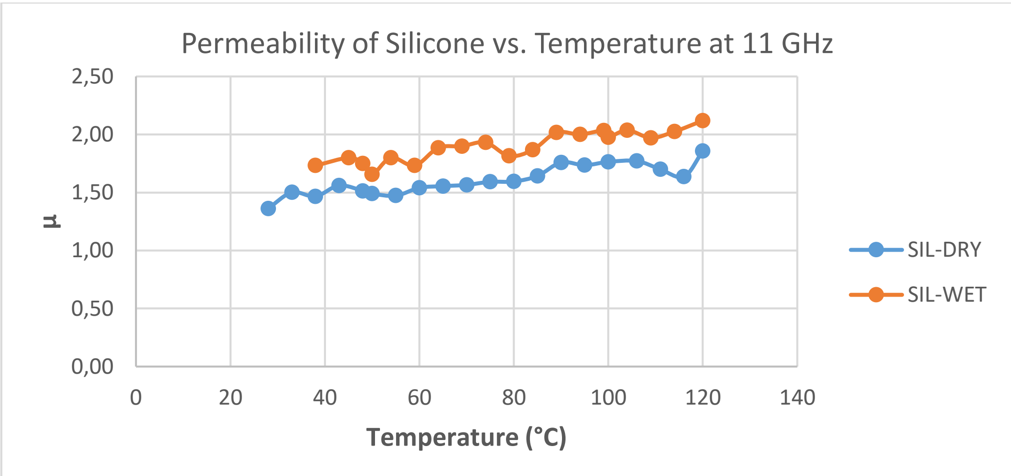

Figure 9 Permeability vs. Temperature Plot of Silicone Based Elastomer at 11 GHz

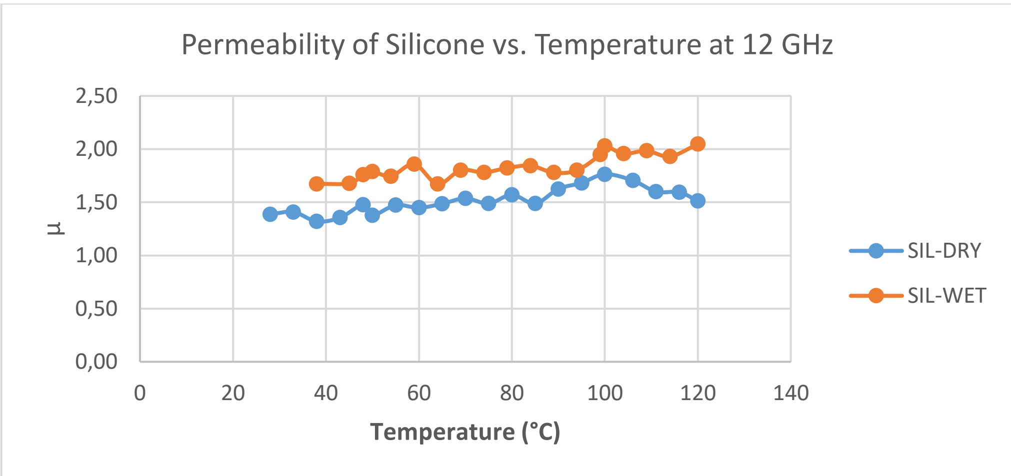

Figure 10 Permittivity vs. Temperature Plot of Silicone Based Elastomer at 12 GHz

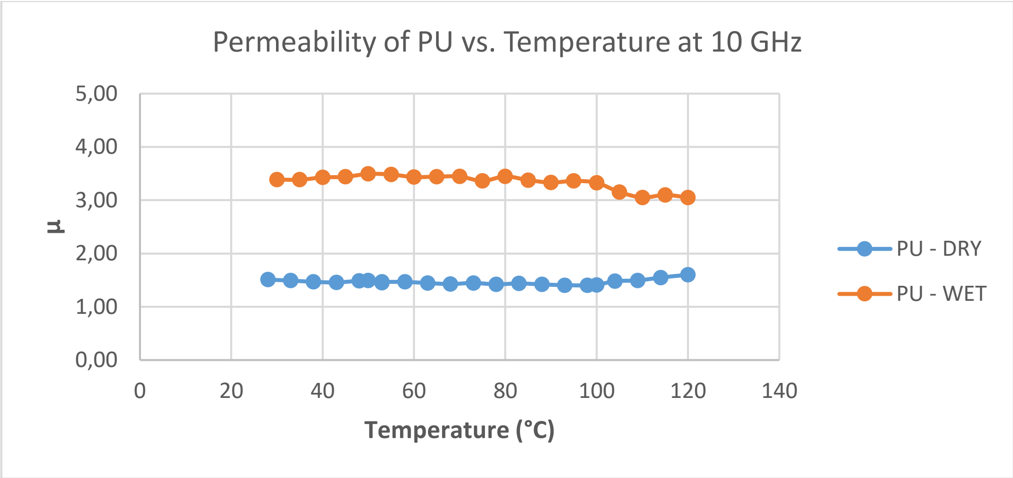

Figure 11 Permeability vs. Temperature Plot of Polyurethane Based Elastomer at 10 GHz

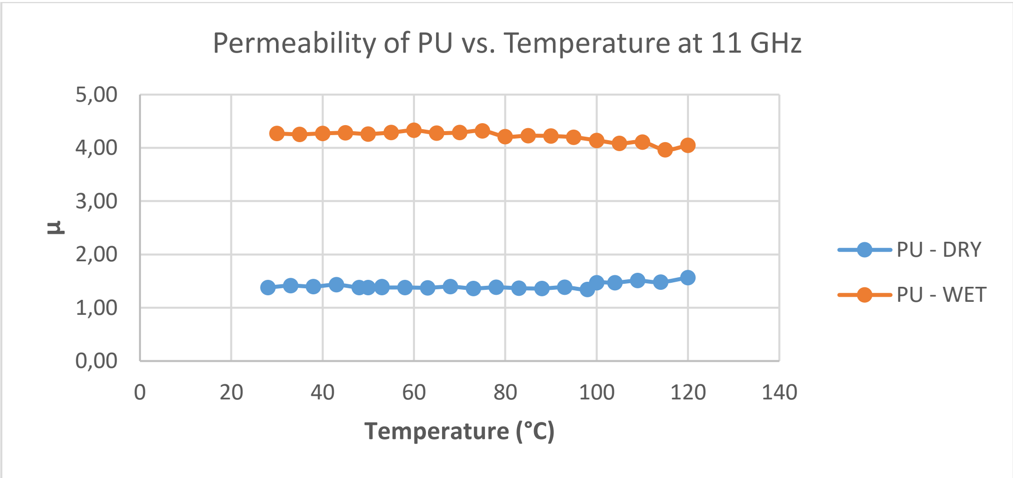

Figure 12 Permeability vs. Temperature Plot of Polyurethane Based Elastomer at 11 GHz

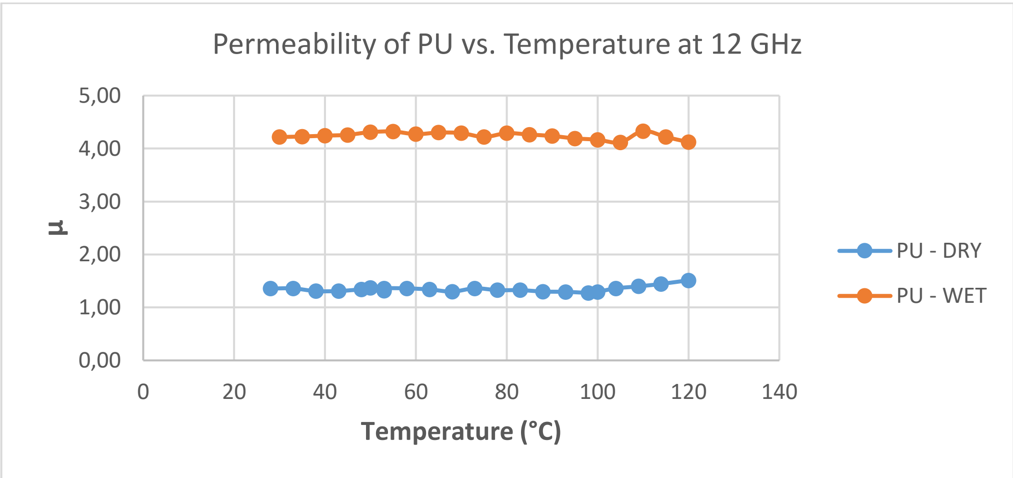

Figure 13 Permeability vs. Temperature Plot of Polyurethane Based Elastomer at 12 GHz

It can be clearly seen that moisture does not affect the relative permeability of the silicone based elastomer dramatically. In both condition, relative permeability tend to increase with respect to temperature. However, polyurethane based elastomer shows different behavior than silicone based elastomer in terms of relative permeability. Since the higher amount of water was absorbed by polyurethane as it is stated in Table 1, this kind of different relative permeability behavior might be obtained. Also, this might be due to the oxidation of the iron based magnetic particles in the polyurethane based elastomers since this rust shown in Figure 14 was not observed in silicone based elastomers after 15 days of immersion. These results indicate a differentiation on the sample and investigation of the electromagnetic properties should be considered based on material type and properties of its additives as well.

Figure 14 Wet Conditioned Polyurethane Based Elastomer

CONCLUSION

In conclusion, this study was performed to investigate electromagnetic properties of polyurethane based and silicone based radar absorbing elastomers under different environmental conditions. This is highly important in order to predict precise radar cross section of fifth generation aircraft when it was exposed to unexpected conditions in the sky. In the scope of this approach, the behavior of the materials with respect to water uptake and temperature were examined and compared with each other. Consequently, results showed that relative permittivity and relative permeability are sensitive properties to different conditions. For silicone based elastomer and polyurethane based elastomer, relative permittivity tends to increase if the material is exposed to water immersion at 25°C for 15 days. Water molecules during the immersion might increase the polarization of both materials and it was resulted by increasing relative permittivity. Also, relative permeability was affected by water uptake for both conditioned materials which have higher permeability than dry condition. Since the amount of water uptake of polyurethane based elastomer was observed 2.5 times higher than silicone based elastomer, electromagnetic properties of polyurethane based elastomer have been affected much more compared to silicone one. Even though relative permittivity decreased by increasing temperature, relative permeability increased when temperature was increased for silicon based elastomer. On the other hand, electromagnetic properties of polyurethane based elastomer did not change significantly with respect to temperature. Finally, the degree of deviations in the results always depend on the type of material and characteristics of additives inside. Therefore, determination of the electromagnetic properties of aviation materials should be performed at different conditions but results should be evaluated based on each material type.

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