Mehran University Research Journal of Engineering & Technology
Vol. 39, No. 1, 195-204, January 2020
p-ISSN: 0254-7821, e-ISSN: 2413-7219
DOI: 10.22581/muet1982.2001.18

Ageing Analysis of Power Cables used in Nuclear Power Plants

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RECEIVED ON 19.11.2018, ACCEPTED ON 14.01.2019

ABSTRACT

The aim of nuclear power plant ageing management and assessment is to maintain an adequate safety level throughout the life time of the plant and helps in determining the useful operation. Various factors involved in the insulation of polymeric cables such as continuous heat, radiation and atmosphere result in the alteration of chemical and physical properties as well as lowers the service life of material. PVC (Poly Vinyl Chloride) is the most commonly used insulation material in NPP (Nuclear Power Plant). Purpose of this work is to predict the service life of PVC insulation cable for which extrapolation ageing has been performed. Ageing mechanism proceeds in laboratory scale rig to provide temperature and radiation sources. The variation in temperature is regulated and monitored through thermocouple. At higher temperature, semi crystalline free radical may escape out resulting in the degradation of polymer. Different tests have been carried out like shore hardness testing, tensile testing, Differential Scanning Calorimeter and Thermo gravimetric Analysis before and after ageing to analyze the Ageing effect. The impact of ageing days upon yield strength of single stress ageing has been carried out in this research work and it is found that aging has significant effect on service life of cables used in power plants.

Key Words: Differential Scanning Calorimeter, Nuclear Power Plant, Poly Vinyl Chloride, Accelerated Ageing.

1. INTRODUCTION

NPP works by fission reactions to produce heat and radiation. This nuclear process may cause adverse effect on cables located near NPP. Therefore, the insulation is highly affected by temperature, radiations and moisture. Insulation cable may damage severely, for instance due to current leakage and breakage of power. Insulation material when exposed to high temperature, heat, radiation and moisture may affect its chemical, mechanical and physical properties. Polymeric insulation must have enhanced performance and improved lifespan. Insulation material have advantages such as light weight, high strength to weight ratio, longer spans, better contamination performance, improved transmission line aesthetics and easy of processing and fabrication. Polymeric material also has a low surface energy which means it has good hydrophobic or water repellent properties [1-3]. Varieties of cables are used in NPP which includes Power Cable.

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These are high and low voltage distribution cables for e.g. Power transmission. These are also called secondary distribution cables used in overhead and underground transmission lines. Fire Insulation material: when exposed to temperature, radiation and moisture it produces severe changes in material with the passage of time. Changes occurred due to this exposure include increase in hardness, density and dielectric loss and decrease in weight and tensile strength. These deviations occur in insulation material and may retard the process of NPP. Insulation material is widely used in areas to reduce dielectric losses. Assessment of PVC is mandatory after a specific period to predict the service life. Expected life of Insulation Material may be calculated through accelerated ageing phenomena, in which temperature, radiation and moisture is provided.

1.1 Accelerated Ageing

A process of exposing higher temperature, radiation dose and moisture content to the material for a short span is called accelerated ageing. Furthermore, a rig is designed to precede experiment time by time to artificially aged material. This rig consists of a temperature source in which a thermostat is used to set a required temperature or thermocouple may also be used to check the temperature in between. Radiation dose is given through source and moisture content also takes part to react chemically with the insulation material. This rig covers with a Lead shell to avoid radiations leakage. These radiations are injurious and harmful to the living organism, exposed material and apparatus has to be dumped soon after the testing and use [4-6].

2. EXPERIMENTAL TESTING

2. 1 Material:

The major material used in this research is PVC. The properties of PVC are shown in Table 1. The process of PVC compounding starts with initiation, then propagation into long chain with a radical, which join with another long chain radical for bond formation called termination. The stages of these formations are presented in Fig. 1.

2.2 Ageing Method

Artificial ageing will be carried out in to a rig containing heating coils and radiation source is required. Radiation source may check the strength of insulation that serves in a severe environment at the power plant. Lead shielding will be provided for artificial ageing. Ageing is divided into two parts; Insulation Material (PVC) will be kept in the rig for different time duration mentioned in Table 2. This table represents ageing specification of PVC sample. The objectives of most aging studies in the past have

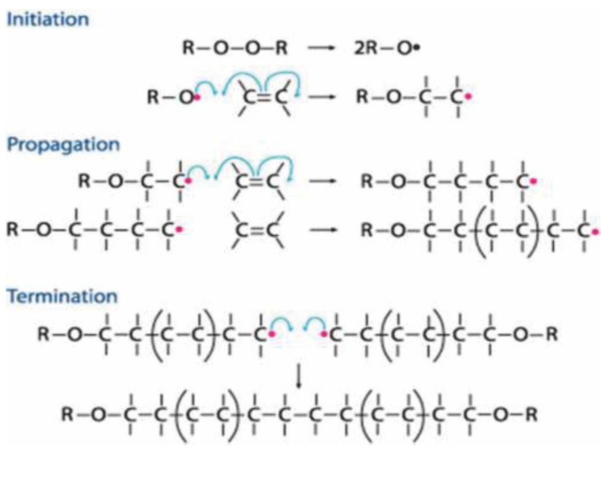

FIG. 1. STEPS OF PVC COMPOUNDING

TABLE 1. SHOWING PROPERTIES OF PVC

Material Used	Specific Gravity	Tensile Modulus (GPa)	Tensile Strength (MPa)	Yield Strength (Mpa)	Elongation at Break (%)
PVC	1.30-1.58	2.4-4.1	40.7-51.7	40.7-44.8	40-80

been either to predict life-to-service failure or to compare the performance of different candidate materials. As per IEEE Standards [7-8], Equivalent ageing years have been calculated with respect to Ageing time and temperature. Standards for radiation and temperature are IEEE STD 775-1993 and IEEE Transactions on Dielectrics and Electrical Insulation respectively.

2.3 Apparatus

Two Rigs are made to precede the (a) Only temperature Ageing (b) Temperature and radiation ageing as per defined standard. Samples are prepared for this Ageing process as shown in Fig. 2.

2.4 Testing

Hardness, tensile strength and DSC (Differential Scanning Calorimetric) tests were performed on the un-aged and aged samples and results were analyzed and compared. DSC curve for un-aged sample is given in Figs. 3-4. The results for the tensile stress curves of samples that are un-aged and aged for 5 and 7 days are shown in Figs. 5-7 and the parameters values for single stress ageing are given in Table 3. Tensile testing of 10 days aged multiple stress sample is not possible due to radiations. It shrinks with respect to dose and become out of tensile test parameters as shown in Fig. 8. The parameters values of multi stress aged samples for tensile testing are given in Table 4.

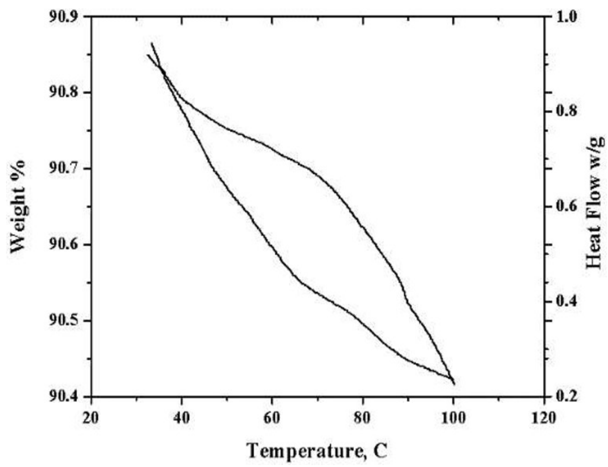

FIG. 3. DSC CURVE OF UN-AGED SAMPLE

TABLE 2. AGING TIME AND TEMPERATURE

PVC Sample	Ageing Days	Equivalent Years	Temperature (°C)	Radiation (Mill Curie)
A	5	15	100	94
B	7	20	100	94
C	10	30	100	94

FIG. 2. SHOWING APPARATUS AND SAMPLES PREPARED.

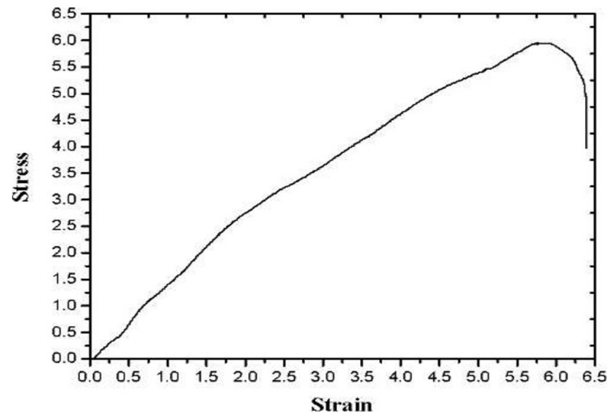

FIG. 4. UT'S CURVE OF UN-AGED SAMPLE

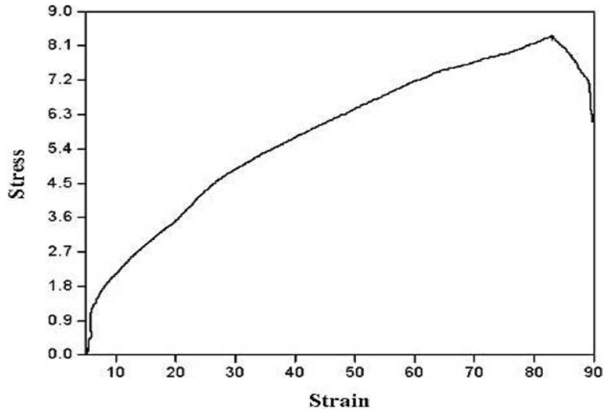

FIG. 5. STRESS STRAIN CURVE AGED FOR 5 DAYS

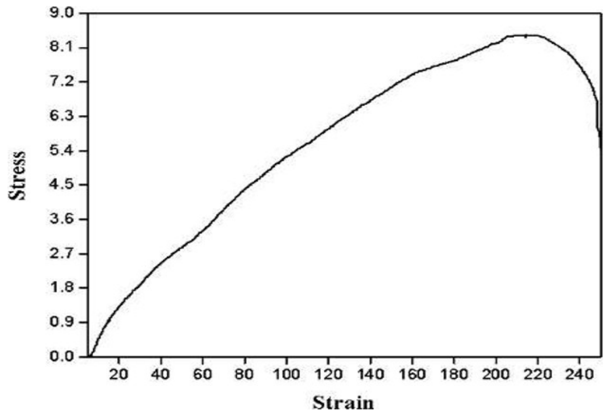

FIG. 6. STRESS STRAIN CURVE AGED FOR 7 DAYS

Hardness value of un-aged sample was found to be around 34 (Shore Hardness) whereas hardness of aged samples varied between 46-48 shore hardness as shown in Table 5.

DSC results of Single Stress Aged Samples are presented in Figs. 9-11 and for single stress ageing a tabular summary is given inside Table 6 i.e. single stress ageing Table 6

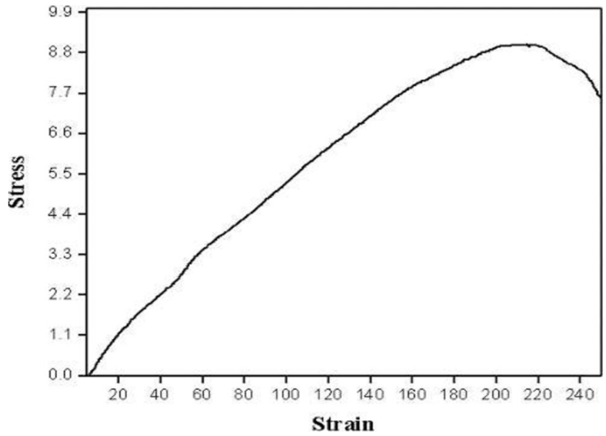

FIG. 7. 10 DAYS AGED STRESS STRAIN CURVE

FIG. 8. SAMPLE OUT OF PARAMETER

TABLE 3. TENSILE RESULT OF STRESS, STRAIN, YIELD STRENGTH AND LOAD OF A SINGLE STRESS AGEING.

Days	Years	Time (Hours)	UTS	Strain (%)	Load (N)	Yield Strength
Unaged/Reference	-	-	6.5	103.53	327.19	3.7
5	15	118	10.1	300	330	2.2
7	20	166	9.4	210	320	2
10	30	238	8.9	83	445	-

represents the transition temperatures as per the heat flow rate. DSC results of Multi Stress Aged Samples are presented in Figs. 12-14.

3. RESULTS AND DISCUSSION

The impact of ageing days upon yield strength of single stress ageing is shown in graph in Fig. 15. The graph shows the combined effect of all specified samples. It is quite clear from the graph that as the ageing days increase, the yield strength of PVC material is continuously reducing.

Graph shown in Fig. 16 represents the impact of ageing days upon tensile strength. Ageing day's increment cause first increase in strength due to cross linkage bond density increases at the start but after some time, it shows decrement due continuous loss of plasticizer. Polymers depend on temperature and strain rate. In our experiment, strain rate was kept constant to compare all the results with the reference sample i.e. un-aged sample. Test results proved the literature study that Cross linkage bond density increases at the start of ageing afterward strength continuously decrease with the decrease in ductility and modulus of elasticity. This shows that continuous loss of plasticizer and additives occur with the increase in ageing time.

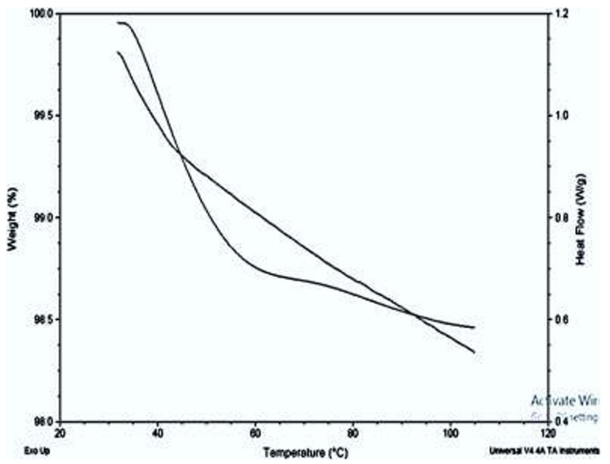

FIG. 9. DSC AND TGA CURVE FOR SAMPLES AGED FOR 5 DAYS

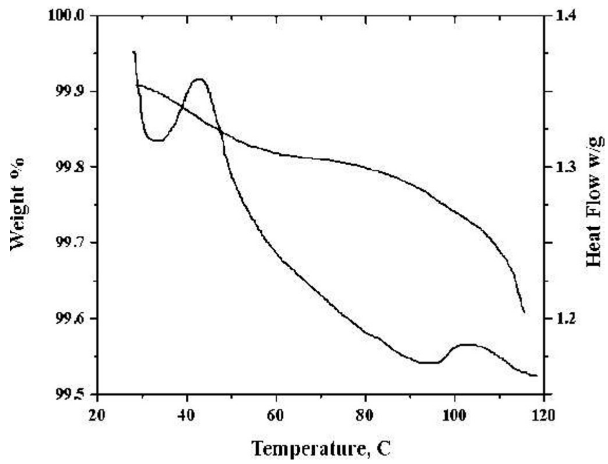

FIG. 10. DSC AND TGA CURVES FOR SAMPLES AGED FOR 7 DAYS

TABLE 4. TENSILE RESULTS OF STRESS, STRAIN, YIELD STRENGTH AND LOAD OF MULTI STRESS AGEING

Days	Years	Time (Hours)	UTS	Strain (%)	Load (N)	Yield Strength
Unaged/Reference	-	-	6.5	103.53	327.19	3.7
5	15	118	7.45	258	380	3.5
7	20	166	6.47	270	333	3.1

TABLE 5. SHORE HARDNESS OF AGED SAMPLES.

Days	Hardness Values			Concordant Reading
Un-Aged	34	34	34	34
5	45	47	48	46.6
7	47	47	48	47.3
10	49	48	49	48.6

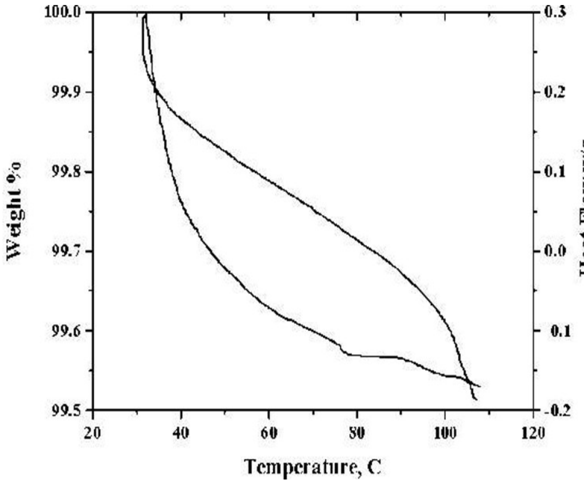

FIG. 11. DSC & TGA CURVE FOR 10 DAYS AGED

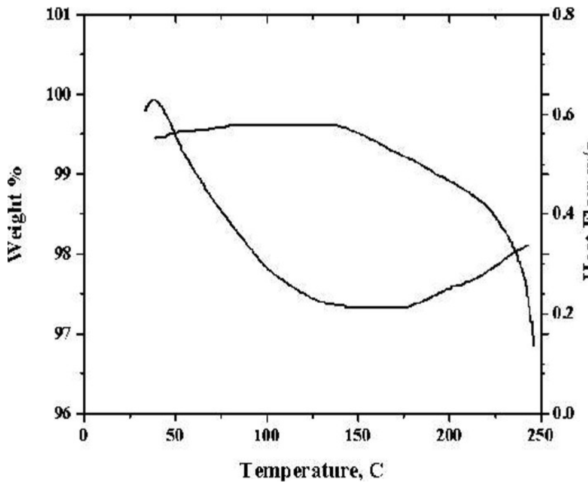

FIG. 12. DSC & TGA CURVE 5 MULTI STRESSED

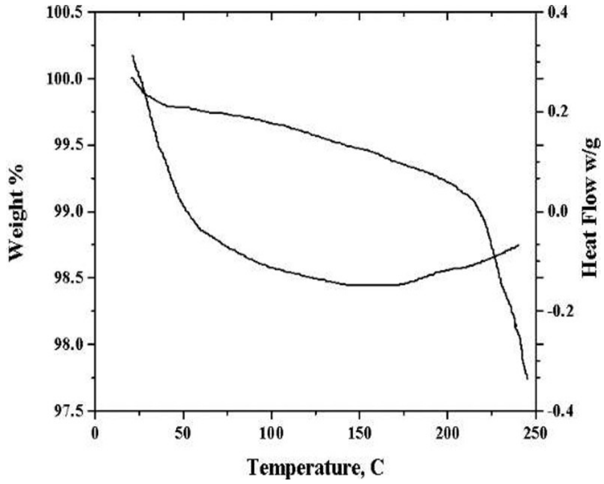

FIG. 13. DSC AND TGA CURVE FOR 7 DAYS AGED SAMPLE (MULTI STRESSED)

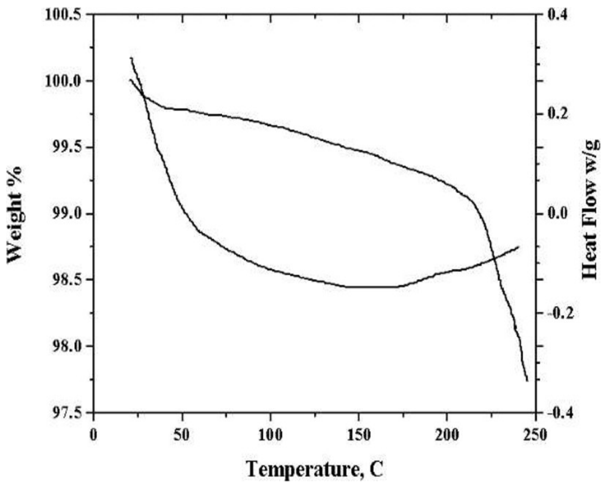

FIG. 14. DSC AND TGA CURVE FOR 10 DAYS AGED SAMPLE (MULTI STRESSED)

TABLE 6. DSC TEST RESULTS FOR SPECIFIED SAMPLES

Days	Year	Time (Hour)	Tg (i)	HF	Tg (m)	HF	Tg (e)	HF
Un-Aged/Reference	-	-	30.52	0.944	65	0.3472	104.19	0.2461
5	15	118	31.77	1.182	65.76	0.6831	104.88	0.5843
7	20	166	32.72	1.389	66.47	1.175	105.51	1.151
10	30	238	31.52	0.298	63.94	-0.101	103.63	-0.1610

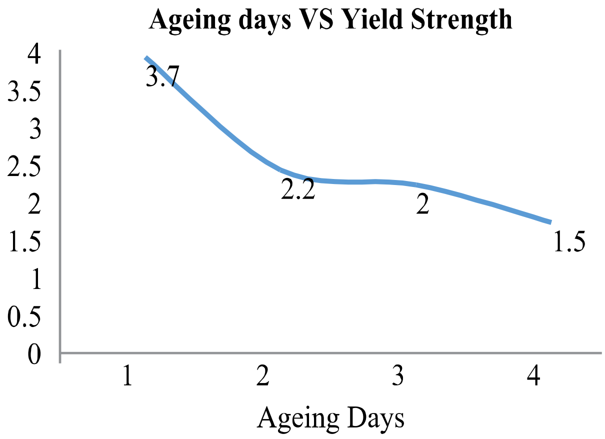

FIG. 15. EFFECT OF AGEING DAYS

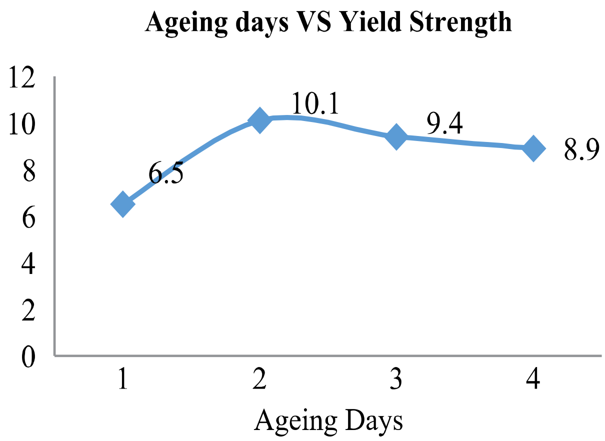

FIG. 16. EFFECT ON TENSILE STRENGTH

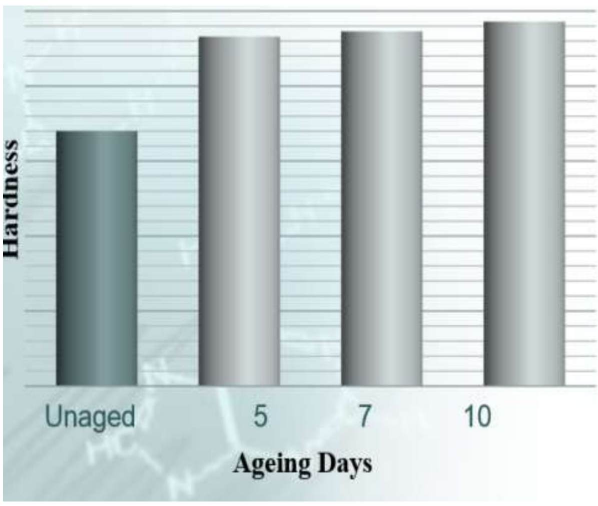

FIG. 17. EFFECT OF AGING DAYS ON HARDNESS ON YIELD STRENGTH

Hardness effects have been shown in Column chart Fig. 17 that shows the variation occurs in Hardness between un-aged, 5, 7 and 10 days ageing. It is quite clear from the chart that the hardness of PVC material increases upon ageing time. Therefore, hardness increases the chance of embrittlement in PVC material due to which leakage of current started after breakage of insulation over high amount of radiation, temperature and moisture. On further heating, long chain polymer bond start to break. Insulation becomes brittle and hard. At last, completely amorphous region cause deterioration. Graph shown in Fig. 18 of single stress ageing represents heat flow rate with increasing ageing days with respect to temperature. Similarly graph of multi stress ageing shown in Fig. 19 represents heat flow rate with increasing ageing days with respect to temperature [9-12].

It has been observed that the shift of the baseline accompanying the glass transition for each PVC sample. The transition temperature shift upper as the plasticizer decreased as per literature survey. Furthermore, the temperature range of glass transition (difference between the tig and teg) narrows as the temperature increase with the decrease in plasticizer concentration. This further decreases the molecular weight between the entanglements of polymer chains. According to literature survey, changes in Specific Heat initiated during transitions range.

The continuous reduction in plasticizer cause the chain scission increases due to the loss of crystalinity in PVC compound as per increasing temperature. That chain scission is the dominant mechanism in the polymer's response to irradiation [13-20].

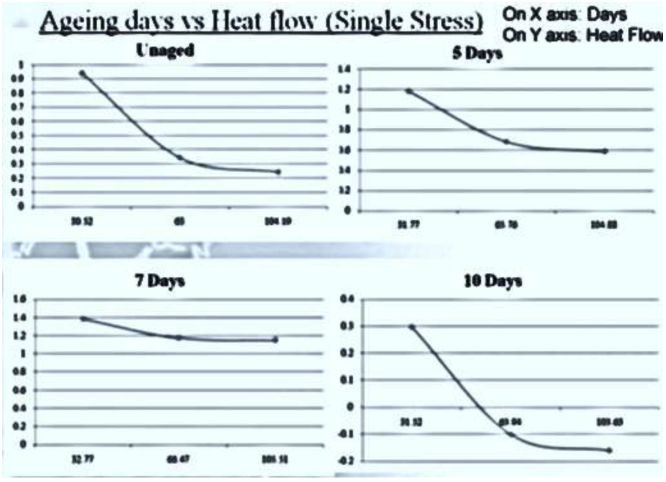

FIG. 18. AGEING DAY'S VS. HEATING (SINGLE STRESS) RESPECT TO HEAT FLOW

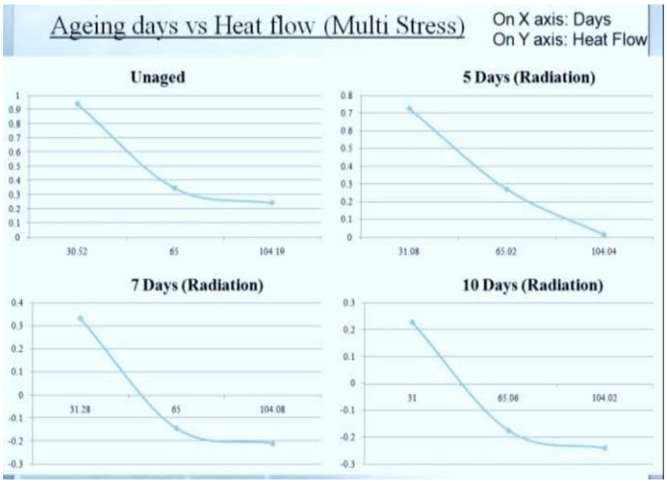

FIG. 19. EFFECT OF AGEING DAYS WITH MULTI STRESS SAMPLE

4. CONCLUSIONS

Power plant consists of several segments which are highly exposed at high degree of temperature, radiation and moisture content etc. These factors allow material to fail after completion of its life. So, it would be very important to analyze the life of material before its failure. The segment covered in this project is to predict insulation life on NPP. There is the vast variety of insulation material used. PVC polymer is often used for insulation material because; one characteristic that makes PVC different from other polymer is the ability to greatly adjust the elasticity and hardness of product through the addition of plasticizer. To predict the PVC life, the cheapest way is the accelerated ageing phenomena i.e. on target and conservation in its representation of long term service effect. The macroscopic or molecular level processes (such as chain scission, cross linking, oxidation, evaporation or diffusion) that produce changes in the material were studied. These properties of PVC are affected when expose to temperature, radiation and moisture etc. on NPP. This focuses on the problem of demonstrating that a selected set of intensified stresses (accelerated ageing) applied in a given way/ does produce the same changes in the insulation as will a certain number of years under assumed normal service condition.

ACKNOWLEDGMENT

Authors are grateful to department of materials engineering, NED University of Engineering & Technology, Karachi, Pakistan, for their support and help to complete this research work.

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