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# Investigation of Shelf Life for Door Seal Mixture in Automotive Industry

**Barış KANTOĞLU[1] ORCID** *0000-0002-7832-1619*
**İrem DÜZDAR ARGUN[*1] ORCID** *0000-0002-7642-8121*
**Ahmet CİHAN[1] ORCID** *0000-0001-9110-2368*
**Yusuf GÜNER[2] ORCID** *0000-0003-1786-5599*

[1]*Düzce University Engineering Faculty Industrial Engineering, Düzce*
[2]*Standart Profil A.Ş., Düzce*

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## Abstract

The door seals for vehicles in automotive industry, which are one of the most important components, provide insulation and damping. Quality of the product highly depends on the shelf life of the seal compound under required temperature. The most important parameters of the compound are its viscosity and scorch values. The aim of this study is to determine the most suitable shelf life in manufacturing and storage processes for seal compound. For stating the important factors affecting shelf life of frequently used main two types of seal compound, interviews are made with the producing firm. Then for both types of compound, series of controlled experiments are performed, and linear estimation models are developed with the help of the results of these experiments. In this study, the results of generated multi variable regression models are presented. It is seen that the generated estimation models can be employed by the producers, and the results of the experiments are overlapping with the results of studies performed in the literature.

**Keywords:** Seal compound, Viscosity, Scorch, Shelf life, Regression analysis

### Otomotiv Endüstrisinde Kapı Fitil Hamuru için Raf Ömrünün Araştırılması

## Öz

Otomotiv endüstrisindeki araçlar için en önemli parçalardan birisi olan kapı fitili, yalıtım ve sönümleme sağlar. Ürünün kalitesi, gerekli sıcaklıktaki sızdırmazlık karışımının raf ömrüne büyük ölçüde bağlıdır. Karışımın en önemli parametreleri, viskozitesi ve kavrulma değerleridir. Sıklıkla kullanılan ana iki tip

[*]Sorumlu yazar (Corresponding author): İrem DÜZDAR ARGUN, *iremduzdar@duzce.edu.tr*

sızdırmazlık karışımının olgunlaşma sürelerini etkileyen önemli faktörleri belirlemek için üretici firma ile görüşmeler yapılmıştır. Bu çalışmanın amacı, sızdırmazlık maddesi için üretim ve depolama süreçlerinde en uygun raf ömrünü belirlemektir. Daha sonra, her iki karışım tipi için kontrol altında bir dizi deney gerçekleştirilmiştir ve bu deneylerin sonuçları yardımıyla doğrusal tahmin modelleri geliştirilmiştir. Bu çalışmada, geliştirilen çok değişkenli regresyon modellerin sonuçları sunulmaktadır. Geliştirilen tahmin modellerinin üreticiler tarafından kullanılabileceği ve deney sonuçlarının literatürde yapılan çalışma sonuçlarıyla örtüştüğü görülmektedir.

**Anahtar Kelimeler:** Profil hamuru, Akışkanlık, Kavrulma, Raf ömrü, Regresyon analizi

# 1. INTRODUCTION

The door seals for vehicles in automotive industry, which are one of the most important components, provide insulation and damping [1]. In this context, sealing systems for automotive industry are a developing sector in Turkey. The aim of this study is to determine the most suitable shelf life in manufacturing and storage processes for seal compound in place of Standard Profil A.Ş. established in Düzce.

Seal compound is used as raw material in the production of door seals. The quality of seal compound can decrease because of structural distortions through manufacturing or post manufacturing processes. Defects of the seal compound cause production and quality problems on the final product. Quality of the compound also highly depends on preparation methodology and conditions of the holding and storing periods. Because of this reason the storage conditions and periods are important for the quality and efficiency of final product. Quality measures of the compound are described by its scorch and viscosity parameters. These viscosity and scorch parameters are highly affected from the climatic conditions of storage area and the preparation place.

Generally, in the recent studies there are some researches testing the reactions of elastomers stretch-stress context related to temperature and lose as the time passed. Besides, in automotive industry the importance of seal compound shelf life conditions is emphasized in some studies, but there is no experimental design study. In this study, after preparation of seal compound viscosity and scorch are analysed, through the shelf life before the extrusion, within different storage conditions (temperature, humidity, and air pressure).

This study is distributed into sections as follows: In the first section, similar studies in the literature are provided, in the second section, the specifications of seal compound are identified and the procedures employed in this study are described. In the third section of this study, the collected data, performed analyses, and the created empirical models are explained. In the fourth section, the obtained results are discussed and suggestions are proposed to the business for their future production processes.

# 2. LITERATURE REVIEW

In the literature it is seen that, the manufacturing process of seals have different operations at various phases. It has been said that there is a lack of studies on the effects of factors other than pressure, temperature, time and certain material properties on seal quality in the literature presented in this study [2]. Çağlayan et al. (2015) proposed a method determine the performance of noise isolation depending on the seal material and the design types, in a study analysing the effect of door seals on sound loss of a taxicab [3]. Launay et al. (2018) analyzed the thermal reactions of rubber experimentally to measure the viscosity of rubber at entry and exit of extrusion by putting a cylindrical measuring tool at both ends of extrusion press [4]. It is seen that the level of viscosity is depending on the thermal factors from the analysis of experimental results. The results of experiments performed for this study to detect the thermal reactions of rubber compound to various temperature levels, are evaluated by employing the comparative assumption model. Choi (2002) performed a study analysing the effects of time and temperature on the rubber storage. The initial storage temperature of silane, a component of the rubber, is important because of the bonding attribute of it. Since the high percentage of silane in the rubber compound, rubber can be stored more than 20 days under proper conditions. In this study an experimental design is done to determine the storage periods of rubber having various percentages of silane at various times and temperatures [5]. Choi and Ko (2014) performed a new study to measure with new experiment procedures, the bonded rubber generation under various temperatures. The temperatures are 900 °C and 1800 °C; the procedures are the ammonia synthesis and sanitation. Their experiments show that the rubber formation occurs in three forms. Those are nucleus form, clogged and tight at initial phase, and the binding wire form at second phase. The measurements of each form are derived with the applied temperatures and new test methods [6]. Cheheb et al. (2012), in their study to search the thermal conductivity of rubber in storage presented a device calculating and controlling the vulcanization ratios. The hot disk method is used to measure the thermal conductivity. They concluded that the thermal conductivity is a function of vulcanization ratio [7]. The rubber elastomers are used frequently in automotive industry because of their effects on driving performance and comfort. The application of temperature-viscosity model is important to test them under various temperatures at different times [8]. In another study, under compression-displacement stress, each of the stresses is smaller if the structure is controlled by density; indicates that if the structure is controlled by displacement, each of its displacements is smaller [9].

Sahinoglu et al. (2019) analysed how affected are the surface unevenness, noise level, and current vibrations of motor from the cutting setups in operating on AISI 1040 (American Iron and Steel Institute) steel by employing the ANOVA (ANalysis Of VAriance) and regression [10]. Akgün and Dere (2007) looked at the possibility of recycling the used frying oils in the industry with experimental design to observe the change of reactions behaviour in different conditions [11]. Nnanwube et al. (2020) tried to find the optimal parameters to separate the pigments by using hydrochloric acid activated Ogbunike kaolinite ($Al_2Si_2O_5(OH)_4$) from the palm oil. ANOVA is employed to prove the statistically significance of operation parameters [12].

## 3. METHODOLOGY

### 3.1. Material

It is observed through the research that the cooking process is triggered. The heat affects the shelf life of the compound. It is thought that the basic reason of this is the Sulphur content of the compound. The heat is catalyzing the cross bonding of Sulphur. In these uncertainties, various experiments are performed to define the relation between the compound and the heat. To detect the change of compound under heat, various studies are done and data is recorded. The examples of both compounds are kept in the refrigerator first. It is seen that most of the various compounds can be stored in the limit values for 40-45 days. Then examples are detected under the room temperature and the shelf life is found between 15-30 days. Some variances are detected at shelf life of the examples stored in the cold room. It is thought that the reason for these variances is the difficulties to keep constant the temperature of cold room. Besides, some detection is performed at 40 °C and 70 °C in the incubator. It is detected that the shelf lives of these examples are less than a day and varying with the hours. Research and publication ethics were complied with in this study.

In this study, mostly used raw materials Compound 1 and Compound 2 in the production of seal at Standard Profil A.Ş. are analysed. The viscosity and scorch parameters are shown on

Table 1 for Compound 1, the sponge type, and on Table 2 for Compound 2, compact type.

**Table 1.** Technical requirements for compound 1

| Parameter | Lower Limit | Upper Limit |
|---|---|---|
| Viscosity | 38.00 | 44.00 |
| Scorch | 3.80 | 5.30 |

**Table 2.** Technical requirements for compound 2

| Parameter | Lower Limit | Upper Limit |
|---|---|---|
| Viscosity | 78.00 | 88.00 |
| Scorch | 3.70 | 5.20 |

In the first experiments, temperature, humidity, time, and pressure are used as independent variables. The measure of molding ability, viscosity, scorch and the measure of storage period before molding are used as the response variables of experiments.

### 3.2. Experimental Design

Experimental design is systematically changing the values of variables under control, which directly affects the performance values of the process to see the effects of these changes. The experimental design for determining the variable parameters of processes, to minimize the variability of them, and process practicing is one of the most frequently used techniques [13]. It can be defined as searching the effects on/over response variables when the input parameters are changed, and getting results by evaluating them. The searched input variables and their levels, output variables, the experiment application process and the procedure for evaluating the results have to be determined before the experimental design process is started.

The general model of a system or a process is given by Figure 1. According to the Figure 1, process variables $X_1$, $X_2$, $X_3$, …, $X_p$ are the controllable process variables, and $Z_1$, $Z_2$, $Z_3$, …,$Z_q$ are the uncontrollable process variables. The experiment design has a very important role in developing a new process and improving a process to increase the productivity. The aim is to develop a healthy process. It means to minimize the effect of uncontrollable process variables (Zi's) which are the reason of variation at output [14].

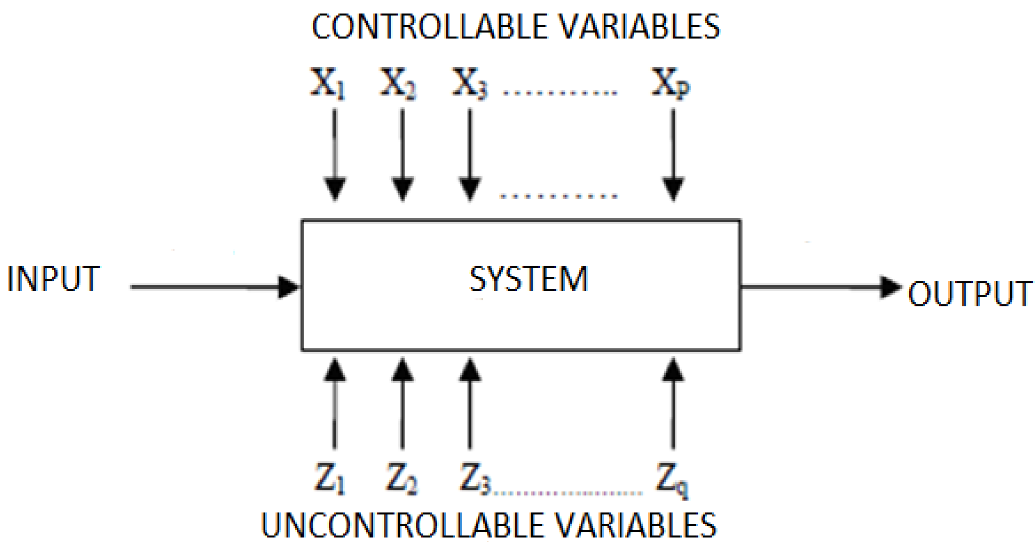


**Figure 1.** The general illustration of a system or process [14]

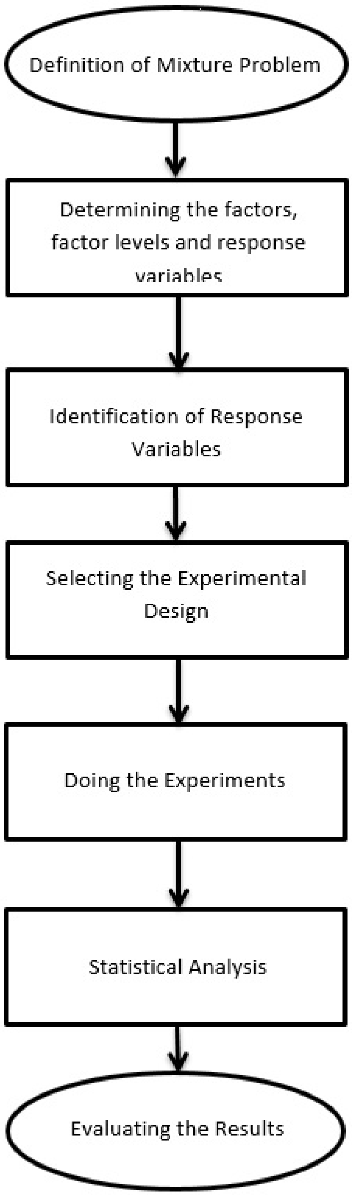


**Figure 2.** The flow-chart of followed procedure

The planning, application, and analysis steps of this study are seen on Figure 2.

One of the basic goals of experiment design is to minimize the experimental errors [15]. Full factorial experiment design offers important easiness to researchers at analysing phase when it is combined with the statistical techniques. Variance Analysis and Regression Analysis are used to analyse full factorial experiment design. The Variance Analysis defines the relationships between the processes and affecting factors statistically [16]. The Regression Analysis is used to state a mathematical relation with reason (independent input variables) and the response variable (dependent output variables) [17]. The effect of an element on the designed experiment can be calculated.

### 3.3. Multivariable Regression

In most of the practical applications, it is nearly impossible to achieve excellent information. The obtained data may deviate at many times. These deviations are caused by the immeasurable external effects and from the nature of measurement tools basically. The most frequently used method to derive information from the measured values is the regression analysis and the deviations from the regression model are referred as error term or measurement noise [18, 19].

The basic regression analysis depends on the idea of describing a dependent variable, with the help of independent variable. Where the dependent variable that will be described is denoted by $y$, and the describing independent variable by $x$; the model function is expressed mathematically as Equation (1).

$$y = a + bx \quad (1)$$

In some cases, to explain the dependent variable, more than one independent variable may require in regression analysis. Multivariable regression model assumes that the dependent variable can be explained by more than one independent variable and the measurement errors have a normal distribution. Multivariable regression model function is given in Equation (2), where $y$ is the dependent variable, and values of $x_1, x_2, \dots, x_n$ are independent variables.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n \quad (2)$$

Coefficient of determination ($R^2$) can be used as a goodness-of fit statistics [20], and indicates the explanation level of the dependent variable by independent variables. Thus $R^2$ is used in the consistency analysis of the results of multivariable regression analysis.

## 4. RESULTS

It is recognized that the storage time of the compound before production is directly affecting the quality of final product in automotive isolation seals industry. In this study for this aim, initially the controllable parameters are determined. Those are the temperature, time, pressure, and humidity in the production area. It is concluded together with producers that taking pressure and humidity constant is suitable.

The compound specimens which will be used in experiments are hold under similar to the factory conditions in refrigerators, cold rooms, normal room temperature, and incubator for various periods, and examined. The data of performed experiences on Compound 1 and 2.

The aim of this study is to determine the most suitable shelf life in manufacturing and storage processes for seal compound in place of Standard Profil A.Ş. established in Düzce. For this reason, the searches are performed on two different types of compound. The constructed multi variable regression model is formulated at Equation (3).

$$y_i = \beta_0 + \beta_1 \ Temperature_i + \beta_2 \ Time_i + \varepsilon_i \quad (3)$$

$y_i$ is response variable in the regression model. The results of the model are summarized in Table 3.

**Table 3.** The results of regression model non-considering the multi-interactions

| Type of compound | $y$ | $\beta_0$ | $\beta_1$ | $\beta_2$ | $R^2$ |
|---|---|---|---|---|---|
| **Compound 2** | Viscosity | 78.69 | 0.18 | 0.33 | 0.34 |
| **Compound 2** | Scorch | 5.03 | -0.02 | -0.02 | 0.37 |
| **Compound 1** | Viscosity | 40.85 | 0.27 | 0.06 | 0.22 |
| **Compound 1** | Scorch | 4.81 | -0.03 | -0.01 | 0.59 |

In analysis of the outputs at the non-considering the multi-interaction regression model, the coefficient of determination ($R^2$) of viscosity is 0.34, constant term ($\beta_0$) is 78.69 and regression coefficients are 0.18 and 0.33 for Compound 2. For Compound 2 the Scorch estimation $R^2$ value is 0.37, constant term is 5.03 and regression coefficients are -0.02 and -0.02. The coefficient of

determination of viscosity is 0.22, constant term is 40.85 and regression coefficients are 0.27 and 0.06 for Compound 1. For Compound 1 the scorch estimation $R^2$ value is 0.59, constant term is 4.81 and regression coefficients are -0.03 and -0.01.
Another model is constructed considering the relations between the temperature and time. The mathematical representation of this model is given by Equation (4).

$$y_i = \beta_0 + \beta_1 \, Temperature_i + \beta_2 \, Time_i + \beta_3 \, Temperature_i Time_i + \varepsilon_i \quad (4)$$

**Table 4.** The results of model considering the dual interactions

| Type of compound | y | β0 | β1 | β2 | β3 | R2 |
|---|---|---|---|---|---|---|
| Compound 2 | Viscosity | 80.90 | 0.11 | 0.12 | 0.01 | 0.43 |
| Compound 2 | Scorch | 4.89 | -0.02 | -0.00 | -0.00 | 0.42 |
| Compound 1 | Viscosity | 40.17 | 0.30 | 0.10 | -0.00 | 0.22 |
| Compound 1 | Scorch | 4.69 | -0.02 | -0.00 | -0.00 | 0.62 |

The results of this model considering the dual interactions are shown on Table 4.

In the analysis of outputs of the regression model considering the multi-interactions the coefficient of determination ($R^2$) of viscosity is 0.43, constant term is 80.90 and regression coefficients are 0.11, 0.12 and 0.01 for Compound 2.

Coefficient of determination ($R^2$) of scorch 0.42, and constant term is 4.89, and regression coefficients are -0.02, -0.00 and -0.00 for Compound 2.

Coefficient of determination ($R^2$) of viscosity for Compound 1 is 0.22, constant term is 40.17 and regression coefficients are 0.30, 0.10 and -0.00.

Coefficient of determination ($R^2$) of scorch is 0.62, and constant term is 4.69, and regression coefficients are -0.02, -0.00 and -0.00 for Compound 1.

Another model is constructed for the cases where to directly measure one of the viscosity or the scorch is impossible. In this model, when the scorch is measurable, the viscosity; if viscosity is measurable, scorch is tried to estimate. The mathematical representations of these models are given by Equations (5) and (6).

$$y_i = \beta_0 + \beta_1 \, Temperature_i + \beta_2 \, Time_i + \beta_3 \, Scorch_i + \varepsilon_i \quad (5)$$

$$y_i = \beta_0 + \beta_1 \, Temperature_i + \beta_2 \, Time_i + \beta_3 \, Viscosity_i + \varepsilon_i \quad (6)$$

The results of experiments conducted for these models are presented on Table 5.

**Table 5.** The results of models, estimating one of the parameters where the other is known

| Type of compound | y | β0 | β1 | β2 | β3 | R2 |
|---|---|---|---|---|---|---|
| **Compound 2** | Viscosity | 120.70 | -0.01 | 0.17 | -8.35 | 0.69 |
| **Compound 2** | Scorch | 9.97 | -0.01 | 0.00 | -0.06 | 0.70 |
| **Compound 1** | Viscosity | 110.62 | -0.11 | -0.12 | -14.50 | 0.53 |
| **Compound 1** | Scorch | 5.94 | -0.02 | -0.01 | -0.03 | 0.75 |

In the analysis of outputs of the regression model for estimating one of the parameters where the other is known, the coefficient of determination ($R^2$) of viscosity is 0.69, constant term is 120.70 and regression coefficients are -0.01, 0.17 and -8.35 for Compound 2. For the estimation of scorch, coefficient of determination ($R^2$) is 0.70, constant term is 9.97, and regression coefficients are -0.01, 0.00 and -0.06 for Compound 2. The coefficient of determination ($R^2$) of viscosity is 0.53, constant term is 110.62 and regression coefficients are -0.11, -0.12 and -14.50 for Compound 1. For the estimation of scorch, coefficient of determination ($R^2$) is 0.75, constant term is 5.94, and regression coefficients are -0.02, -0.01 and-0.03 for Compound 1.

The period estimation model, recording the initial viscosity and scorch parameters to decide the length of storage period at an expected temperature, is the most useful model to determine the material life for the compound. The mathematical representation of period estimation model is given by Equation (7).

$$y_i = \beta_0 + \beta_1 \ StorageTemperature_i + \beta_2 \ Viscosity_i + \beta_3 \ Scorch_i + \varepsilon_i \quad (7)$$

**Table 6.** The results of period estimation model

| Type of comp. | y | β0 | β1 | β2 | β3 | R2 |
|---|---|---|---|---|---|---|
| Compound 2 | Distortion period of product | 89.69 | -0.74 | -0.68 | 4.00 | 0.74 |
| Compound 1 | Distortion period of product | 181.36 | -0.25 | -5.02 | 16.18 | 0.77 |

Table 6 shows the period estimating model results. It is seen that the $R^2$ is 074, constant term is 89.69 and regression coefficients are -0.74, -0.68 and 4.00 for Compound 2; the $R^2$ is 0.77, constant term is 181.36, and regression coefficients are -0.25, -5.02 and 16.18 for Compound 1.

## 5. CONCLUSION AND DISCUSSION

In this study in an automotive seal producing factory, the changes on the parameters of compound with the thermal conditions of storage area and storage periods of the compound under the various climatic conditions is searched.

The high $R^2$ value for the scorch of Compound 1 implies that the variance is explained by the model successfully. In the viewpoint of the constructed model, it is seen that all of the models are usable at certain level. But it can be seen easily that the results of multi and single interacting models are so close, and the difference between values of coefficient of determination ($R^2$) is maximum 9 percentage. Besides these, in the analysis of derived coefficients from the models, in the model considering the interaction between the temperature and time the dual interaction coefficient is so close to zero. This indicates that the interaction effect can be ignored. It is also seen that because of the coefficient of determination for Compound 1 is so small, it is not suitable to estimate a value for viscosity.

It is realized that, the factories having a tool to measure only scorch or only viscosity can estimate the response variable by using the models formulated with Equation (5) and (6). In evaluating the results of models, the higher value of coefficient of determination for scorch estimation model implies the scorch parameter can be estimated more realistically.

In the period estimation model, it is tried to estimate the temperature and length of the storage period for distortion of the compound by measuring the viscosity and scorch parameters. It is seen that when scorch parameter of the compound is high, the life of the product will be longer; and it is converse for the viscosity parameter. The signs of the coefficients are also supporting this idea. The negative coefficients show that distortion of the compound will be slower if storage temperature is lower.

In one study performed on the seal compound, it is submitted that the viscosity parameter decreases depending on storage temperature and period [2-21]. The results of this study support their argument. It is seen that the time estimation model is so useful for production planning and/or cost analysis. If the compound will not be taken to production line, it can be stored in a cold place by accepting some additional costs. If the firms do not want to pay this cost, they can either sell the compound or use it by changing their production plans.

The convenient storage time is important for production planning and to decrease the rate of waste. This study showed that under the predetermined conditions, convenient storage period can be estimated. Since the importance of storage period is presented, the producers may design continuous recording systems for storage conditions and necessary tools can be designed to measure the viscosity and scorch parameters frequently. In future works, new systems can be developed to work integrated with Industry 4.0. These systems will reduce waste, improve logistics operations and product quality.

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