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MANUFACTURING OF MOULD DIE FOR NUT RING AND PROCESS CYCLE OPTIMIZATION

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Abstract - *Elastomer sealings have wide range of applications in automobile, construction and electrical sectors. Compression molding process is the most commonly used technique for manufacturing of nut rings. Mold die for nut ring was developed and fabricated. The design of mold die was simulated using ANSYS Workbench for three process parameters of compression molding: pressure, temperature and curing time. Nut ring samples were manufactured at various combinations of parameters by keeping pressure constant. Temperature of process were 165°C, 175°C and 185°C while curing time were 2,3 and 5 minutes. Shore-A-Durometer hardness of each sample was measured and results showed that closest to the optimum value was obtained for parameter combinations: 185°C, 2 minutes and 185°C, 3 minutes. ANSYS simulation showed that maximum total deformation was 0.26126mm, maximum Von-Mises stress induced was 1642.1Mpa and maximum Von-Mises strain induced was 0.008813 and were directly proportional to the rise in compression molding temperature.*

Key Words: Elastomers, Compression molding, Process parameters, Optimization, FE Analysis, Durometer

1. INTRODUCTION

O-rings and gaskets made of elastomers are having the wide range of applications in gas and oil fields due to its flexible and simple structure and their superior sealing capabilities [1]. Nitrile rubber is the most common material used for sealings due to its wear resistance and oil resistance [2]. It is observed that the performance of sealing materials is greatly influenced by the initial compression of sealing materials [3].

1.1 Global market survey on Elastomers

The global market for elastomers is estimated to reach very close to 17 billion USD by the end of 2023. From the records, Nitrile-based elastomers contributed the most to market share in 2017. Elastomers find the major applications in construction industries, automobile industries, electrical and electronics industries, health care industries and consumer goods. The market revenue (in USD million) of silicon elastomers in various fields of industries is as shown in Fig-1.

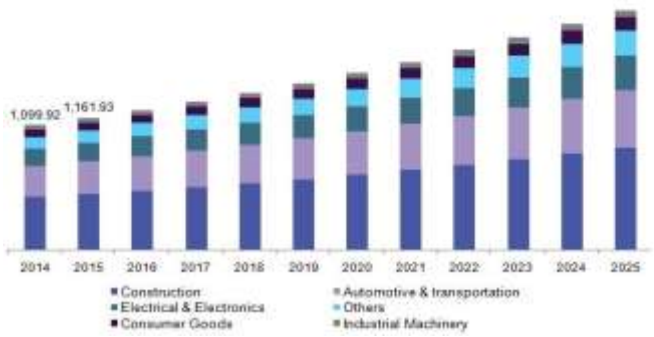

Fig-1: Market revenue of Silicone rubber

1.2 Compression molding process

In this process, the pre-loaded rubber material is placed inside the mold cavity and compressed into the shape of the cavity under elevated temperature and high pressure for the duration of few minutes (curing time) [4]. After curing time, the mold is opened and rubber gasket is taken out of the cavity. Compression molding process is the simplest rubber production technique and economical for mass production as shown in Fig-2 [5].

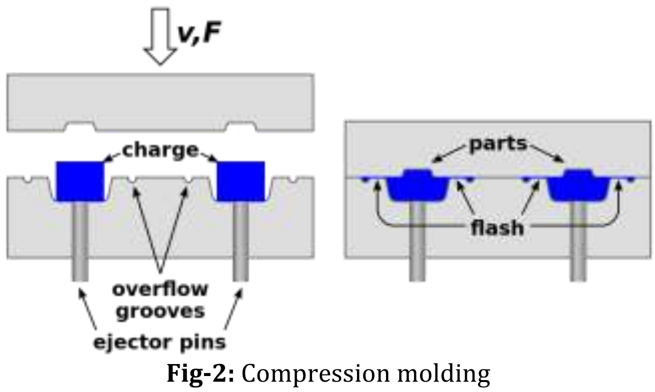

Fig-2: Compression molding

2. DEVELOPMENT OF MOLD DIE

The specifications of the nut ring component were measured using profile projector. The rubber elastomer was cut through cross section and various modelled using CAD tool SolidWorks. Once the design and modelling of the component part is done, mold die is designed using SolidWorks Tool Design. Exploded view of mold die assembly is as shown in Fig-3.dimensions necessary for designing the mold dies were measured in SI units. With the measured dimensions of specifications, the nut ring component was

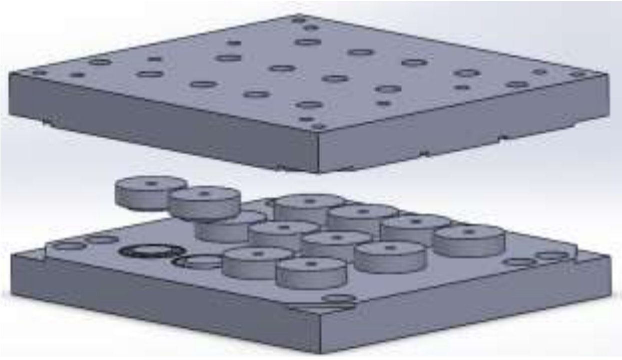

Fig-3: Assembly of mold die

2.1 Finite Element Analysis of mold die

Finite element analysis is carried out on the mold die model for various combinations of process parameters of compression molding process. Temperature and curing time of the process were varied while pressure applied is constant. ANSYS Workbench software was used for simulation. Data of tool steels required for simulation are listed in Table 1.

Table-1: Engineering data for simulation

Specifications	P20	D2
Density (kg/m^3)	7861	7695
Modulus of Elasticity (Gpa)	210	207
Poisson's ratio	0.3	0.3
Thermal conductivity (W/m/°C)	41.5	18
Coefficient of thermal expansion (/°C)	12.8x10^{-6}	11.6x10^{-6}
Compressive yield strength (Mpa)	862	254
Compressive ultimate strength (Mpa)	941	287
Reference temperature (°C)	24	24

Meshing process has to be carried out carefully in order to get more accurate values. The mold die assembly is divided into number of elements and the load is distributed equally on each element. Coarse type mesh is applied on the mold die with more refined on curvatures to optimize results at stress concentrated regions. Total number of elements is 203608 and total number of nodes created is 342707. Mesh of mold die generated during pre-processing of simulation is as shown in Fig-3

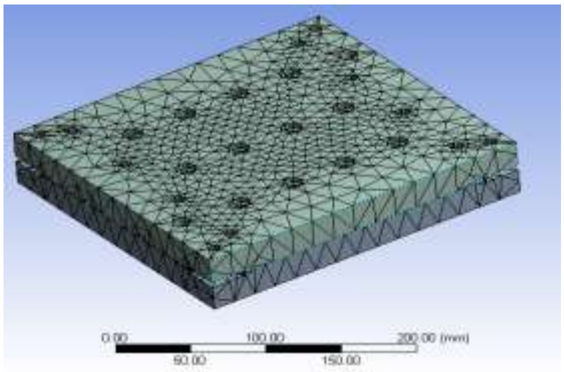

Fig-3: Mesh generated for simulation

2.2 Analysis different temperature and curing time

Mold die is simulated for thermal and static loading at 165°C temperature at bottom and top plates, pressure of 170 kg/cm^2 (890293.74N for area of 53439 mm^2) and fixed support at the bottom plate. Fig-4 shows the total deformation of mold die, Fig-5 shows Von-Mises stresses induced in mold and Fig-6 shows the Von-Mises strains induced.

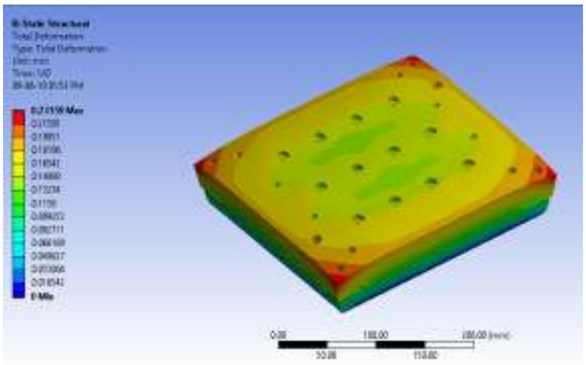

Fig-4: Total deformation induced

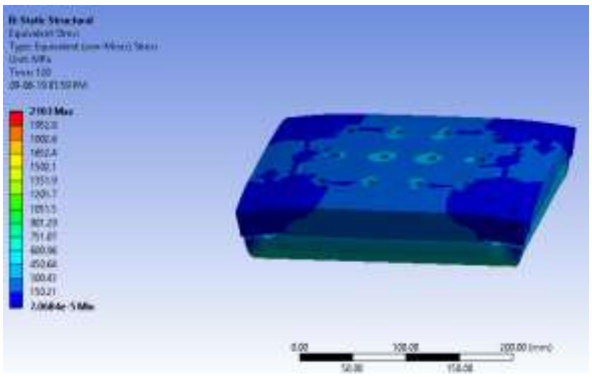

Fig-5: Von-Mises stresses induced

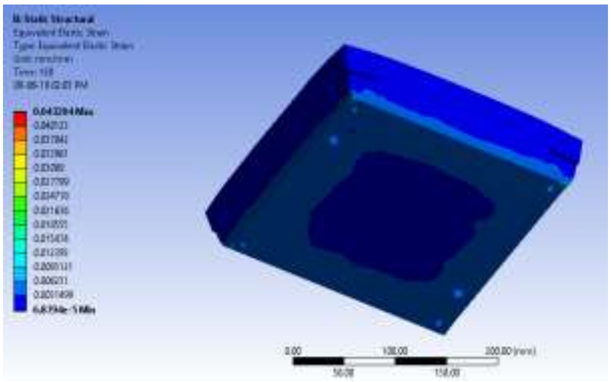

Fig-6: Von-Mises strains induced

Design of Experiments (DOE) was used to calculate total number of experiments to be carried out. For 2 parameters (curing time and temperature, keeping pressure constant) and 3 levels, total 9 experiments were carried out (3^2). Simulation of mold die for all the combinations of temperature and curing time was carried out and total deformation, equivalent stresses and strains were calculated and results are listed in Table 2.

Table-2: Results of ANSYS simulation

Parameter combination	Total deformation (mm)	Von-Mises stresses (Mpa)	Von-Mises strains
165°C, 2min	0.23159	1502.1	0.002164
165°C, 3min	0.22980	1580.1	0.006885
165°C, 5min	0.22981	1564.3	0.007493
175°C, 2min	0.24557	1579.2	0.007583
175°C, 3min	0.24553	1608.4	0.008813
175°C, 5min	0.24553	1609.4	0.008083
185°C, 2min	0.26126	1632.1	0.007820
185°C, 3min	0.26126	1642.1	0.007820
185°C, 5min	0.26125	1642.0	0.008597

2.3 Fabrication of mold die

Bottom plate and top plate are both machined on a 5-axes CNC Vertical milling machine and inserts were fabricated on a turning center. The CNC codes generated through Siemen's programming tool is fed into the Vertical milling machine through SD card. Nut ring cavities, flash grooves, fitting holes and all other features are machined at once. Machining of top plate took duration of around 4 hours and for bottom plate it was around 3 hours. Final assembly of mold die is as shown in Fig-7.

Fig-7: Final assembly of mold die

3 Manufacturing of Nut rings

Compression molding technique is used to manufacture the nut ring samples by varying the process parameters of the molding process. Fig-8 shows the compression molding machine used for this process. This machine is a constant pressure compression molding machine. Hence, the pressure applied on the mold die for pressing cannot be varied. The pressure is fixed to the value of 165 kg/cm^2 (16.671 Mpa). Temperature of the pressing and the curing time of elastomer nut rings are varied.

Fig-8: Compression molding machine

3.1 Nut ring samples at various parameters

As the pressure of the compression molding process is kept constant, only temperatures at top and bottom plates and the curing time of elastomer can be varied. The conventional process of compression molding is carried out at temperature of 165°C for top and bottom plates and the curing time is set to 5 minutes. In this work, the curing time is varied at 5 minutes, 3 minutes and 2 minutes. The temperature is varied at 165°C, 175°C and 185°C. Combination of all parameters values is considered and total of 9 set of combinations are obtained (3^2). Nut ring samples are manufactured at all 9 set of parameters and tested for quality. Nut ring samples at 165°C and 2 minutes of curing time is shown in Fig-9.

Fig-9: Nut ring samples at 165°C and 2 minutes of curing time

3.2 Shore-A-durometer hardness testing

Once the samples of nut rings are manufactured by compression moulding process, the quality of nut rings for each set of parameters combination has to be checked and verified. The quality of elastomer nut rings is measured by their hardness values. For nitrile butadiene rubber sealing, the nominal value of Shore-A-durometer hardness is 75. Fig-10 shows the analog Shore-A-durometer used for the hardness testing of nut ring samples.

Fig-10: Hardness testing of nut ring sample

The results of Shore-A-Hardness testing for nut ring samples of each parameter combination is listed in Table-3.

Table-3: Hardness of nut ring samples

Temperature (°C)	Curing time (min)	Hardness of sample 1	Hardness of sample 2
165	2	73	73
165	3	77	76
165	5	73	73
175	2	73	72
175	3	74	74
175	5	72	72
185	2	75	74
185	3	74	75
185	5	73	73

Average of hardness of two samples of each parameter combination is calculated as follow:
1. 165°C and 2 min = (73+73)/2 = 73.
2. 165°C and 3 min = (77+76)/2 = 76.5.
3. 165°C and 5 min = (73+73)/2 = 73.
4. 175°C and 2 min = (73+72)/2 = 72.5.
5. 175°C and 3 min = (74+74)/2 = 74.
6. 175°C and 5 min = (72+72)/2 = 72.
7. 185°C and 2 min = (75+74)/2 = 74.5.
8. 185°C and 3 min = (74+75)/2 = 74.5.
9. 185°C and 5 min = (73=73)/2 = 73.

4 CONCLUSION

Shore-A-Durometer hardness was found to be 74.5 for the parameter combinations: compression molding temperature 185°C, curing time of 2 minutes and 185°C, 3 minutes and were closest to the optimum value. These results showed that nut ring samples can be fabricated with reduced curing time of 2 minutes by increasing the pressing temperature without compromising the quality. ANSYS simulation showed that maximum total deformation was 0.26126mm, maximum Von-Mises stress induced was 1642.1Mpa and maximum Von-Mises strain induced was 0.008813 and were directly proportional to the rise in compression molding temperature. However, these characteristics were not affected by the reduction of curing time. In this direction, further work can be carried out by optimizing the compression molding pressure to reduce the curing time.

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