

Study on the influence of raw material preparation on the performance of FX-4 rubber sealing rings

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Abstract: This article focuses on the three processes that significantly affect the performance of the FX-4 rubber sealing ring during its preparation. Combination verification tests with different parameters and levels are conducted, and corresponding testing items are performed to determine the optimal parameter combination.

Key words: billet preparation; FX-4; rubber sealing ring; performance

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FX-4 rubber has excellent high temperature resistance, vacuum resistance, and also strong acid resistance, resistance to various oils, and ozone aging resistance. Its comprehensive performance is very excellent, making it a widely used rubber in the field of aero-engines.

The preparation process of FX-4 rubber seal ring blanks involves three procedures: blank softening, blank thinning, and blank ring forming. This article focuses on these three procedures, conducting combination verification tests with different parameters and levels, performing corresponding testing items, and determining the optimal parameter combination. This research is of great significance for ensuring the precision of our company's FX-4 rubber seal ring production process and the stability of product manufacturing quality.

1 Experiment

1.1 Main equipment

Rubber mixing machine, XK-250; curing press, HPC-100D, 100 t; microcomputer-controlled electronic universal testing machine, CMT4303, 1 t; oven, WG3006, maximum operating temperature 300 °C; flash tester, VX3200D, resolution: 0.1 μm.

1.2 Sample preparation

The rubber compound is mixed and re-refined using a

rubber mixing machine. The roller gap is set to 1.7/2.85/4 mm, and the rubber compound is softened through 3/5/7 passes; the roller gap is locked for thin passing, which is performed 10 to 15 times; ethyl acetate is used to overlap and bond the ends of the rubber strip into a circle.

The rubber compound undergoes two-stage curing. The first stage is carried out using a curing press under the conditions of 175 °C for 15 minutes at 13 MPa. The second stage is conducted in an oven under the conditions of 250 °C for 8 hours.

Combination verification tests with different parameters and levels are conducted for blank preparation (blank softening, thinning, and blank ring forming), and corresponding testing items are carried out. The detailed scheme is shown in table 1.

1.3 Test method

GB/T 528-2009 "Rubber, Vulcanized or Thermoplastic-Determination of Tensile Stress-Strain Properties";

GB/T 3452.1-2008 "O-Rings for Hydraulic and Pneumatic Applications - Part 1: Dimensions and Tolerances";

GB/T 531.1-2008 "Rubber, Vulcanized or Thermoplastic -Determination of Indentation Hardness-Part 1: Shore Durometer Method (Shore Hardness)".

Biography: Wang Bingxue (1992-), male, engineer, mainly engaged in research in material engineering.

Table 1 Research plan table

Serial number	Process	Parameter	Protocol	Result Analysis	Expected goal
1	Blank softening	Number of softening times	A two-factor level experiment was conducted with 3 types of frequencies and 3 types of roller distances, involving a total of 9 sets of parameters and 45 test pieces, which were individually subjected to data detection and analysis	Optimal parameter analysis is conducted through the correlation trend chart of hardness with frequency and roller spacing	Determine the optimal combination of softening roller spacing and frequency
2		Softening roller distance			
3	Blank is thin and smooth	Number of thin-pass times	Conduct single-factor variation tests with 3 different thin-pass times, using 5 test pieces for each parameter, and perform data inspection and analysis	Evaluate the validity of parameters based on appearance quality, and analyze the optimal parameters through trend charts of the number of thin-passes and changes in hardness	Determine the optimal thin-pass frequency parameter
4	Blank ring forming	Lapping length	A two-factor level experiment was conducted with four types of molding ring inner diameters and three types of overlap lengths, resulting in 12 combinations of parameters. Each combination involved 10 test pieces for data collection and analysis	The minimum lap length is determined by the qualified rate of effective bonding within the group, and the optimal lap length is determined by the trend of tensile force change	Determine the optimal lap length

2 Results and analysis

2.1 Blank softening

Blank softening is a preparatory process for the re-refining process, aiming to reduce the hardness of the rubber compound and increase its overall temperature, thereby enhancing the re-refining effect. In previous process documents, the requirements for the softening process were simply "increase the roller spacing, allow the rubber compound

to pass through several times, and wait until it becomes soft."

To analyze the influence of roller spacing and passing times on the softening degree of the rubber compound, a combination verification test was conducted on roller spacing and passing times, using Shore A hardness to evaluate the softening degree of the rubber compound (lower Shore A hardness indicates better softening). Each combination was tested three times, and the results are shown in table 2.

Table 2 Softening degree test

Test Number	Roll spacing/mm	Number of passes/time	Rubber compound Shore hardness	Test Number	Roll spacing/mm	Number of passes/time	Rubber compound Shore hardness
1	1.7	3	48	24	2.85	5	38
2	1.7	3	46	25	2.85	5	37
3	1.7	3	50	26	2.85	7	49
4	1.7	3	47	27	2.85	7	48
5	1.7	3	44	28	2.85	7	50
6	1.7	5	43	29	2.85	7	47
7	1.7	5	47	30	2.85	7	49
8	1.7	5	39	31	4	3	58
9	1.7	5	50	32	4	3	59
10	1.7	5	39	33	4	3	61
11	1.7	7	48	34	4	3	60
12	1.7	7	40	35	4	3	58
13	1.7	7	50	36	4	5	58
14	1.7	7	47	37	4	5	57
15	1.7	7	31	38	4	5	60
16	2.85	3	51	39	4	5	53
17	2.85	3	50	40	4	5	54
18	2.85	3	55	41	4	7	58
19	2.85	3	51	42	4	7	57
20	2.85	3	50	43	4	7	60
21	2.85	5	42	44	4	7	53
22	2.85	5	39	45	4	7	56
23	2.85	5	43				

Calculate the average Shore hardness value for each set of parameters, and plot a curve graph for the relationship between roller spacing and the number of passes on the Shore hardness of the rubber compound, as shown in figure 1.

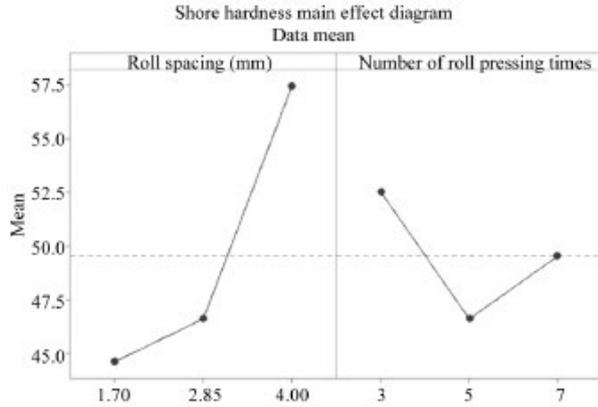


Figure 1 The influence of roller spacing and pass number on the Shore hardness of rubber compounds

As can be seen from Figure 1, with the increase of roller spacing, the Shore hardness of the rubber compound significantly increases; with the increase of pass times, the Shore hardness first decreases and then increases, with pass 5 < pass 7 < pass 3. Therefore, based on the above experimental verification and analysis of the rubber compound softening process, combined with the effect of the softening process on reducing the hardness of the rubber compound and production efficiency, the precise process parameters for the softening process are determined as follows: roller spacing of 1.7 mm; pass times of 5.

2.2 Blank thinning

The purpose of thin-passing the blank is to break the macromolecular chains of the rubber compound through the action of mechanical shear force, and to react with oxygen in the air to generate stable peroxide groups, thereby reducing the molecular weight. Referring to the requirements for thin-passing in the rubber product process of the Beijing Institute of Aeronautical Materials, it is recommended to lock the roller spacing for thin-passing after the rubber compound becomes soft, with a thin-passing frequency of 10 to 15 times.

From a theoretical perspective, the smaller the roller spacing during thin passing, the better the thin passing effect. However, considering factors related to the safe use of equipment, the operating instructions for the XK-

250 equipment used for FX-4 rubber recycling specify the requirements for roller spacing adjustment as follows: During normal spacing adjustment, the adjustment gap between the left and right rollers should be limited within the range of 0.2~20.0 mm. The roller spacing setting for the thin passing process test verification is set to a left and right roller adjustment gap of 0.2 mm, which means the roller spacing between the two rollers is 0.4 mm.

For the design of the thin-pass times indicator, within the scope of process requirements, the thin-pass times were set to 10, 13, and 15, respectively. The better the fluidity, the worse the resistance, and the lower the Shore hardness value. Therefore, after thin-pass, the sheet is subjected to Shore hardness testing to characterize the fluidity of the rubber compound. On this basis, after thin-pass, the surface appearance of the blank is inspected to verify the impact of thin-pass times on appearance quality. The verification results are shown in table 3.

Table 3 Test of thin-pass times

Test Number	Number of thin-pass times/time	Shore hardness/degree of rubber compound	Appearance quality
1	10	56	qualified
2	10	55	qualified
3	10	54	qualified
4	10	54	qualified
5	10	48	qualified
6	13	35	qualified
7	13	36	qualified
8	13	37	qualified
9	13	41	qualified
10	13	36	qualified
11	15	45	qualified
12	15	43	qualified
13	15	49	qualified
14	15	46	qualified
15	15	43	qualified

As can be seen from Table 3, the appearance quality of the rubber compound is qualified under different thin-pass times, proving that thin-pass times of 10, 13, and 15 have no impact on the appearance quality of the rubber compound. The relationship between thin-pass times and the Shore hardness of the rubber compound is plotted based on Table 3, as shown in figure 2 below.

As can be seen from figure 2, with the increase in the number of thin-pass cycles, the Shore hardness of the rubber compound first decreases and then increases, with thin-pass 13 cycles < thin-pass 15 cycles < thin-pass 10 cycles. Taking into

account the process requirement for 10 to 15 thin-pass cycles for FX-4, the impact of thin-pass cycles on appearance quality, and the trend of changes in the Shore hardness value of the rubber compound, the optimal number of thin-pass cycles is determined to be 13 cycles.

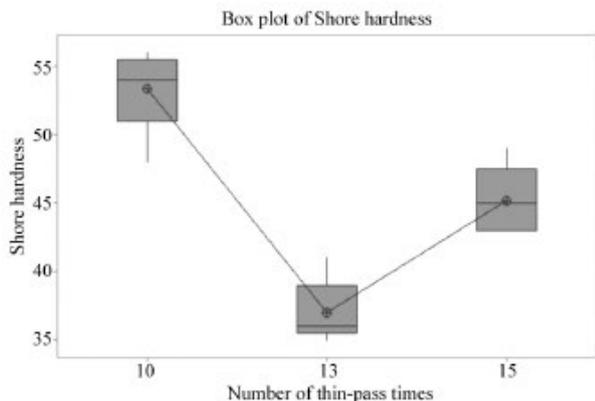


Figure 2 The influence of the number of thin-pass cycles on the Shore hardness of rubber compound

Through the testing and verification of the softening process and the thinning process, the optimal parameters are determined as follows: set the roller distance to 1.7mm, allowing the rubber compound to pass through 5 times; lock the roller distance to 0.4mm, and thin it 13 times.

2.3 Blank ring forming

To analyze the impact of lap length on bonding effectiveness, experiments were conducted using coils with inner diameters of 10 mm, 20 mm, 40 mm, and 60 mm. Ethyl acetate was used to assist in the bonding process, and lap lengths of 3 mm, 5 mm, and 7 mm were selected. The combinations of coil inner diameter and lap length were arranged and tested. Each experimental scheme involved bonding 10 samples to reduce the impact of abnormal fluctuations. The effective bonding pass rate and tensile strength indicators were used to reflect the bonding effectiveness. The effective bonding pass rate for each experimental scheme was calculated, as shown in figure 3 below:

As can be seen from Figure 3, after looping, the effective bonding pass rates of the test groups with lap lengths of 3 mm for $\Phi 10$ mm, $\Phi 20$ mm, $\Phi 40$ mm, and $\Phi 60$ mm are 90%, 100%, 100%, and 100%, respectively. When the lap length is 5 mm and 7 mm, the effective bonding pass rates are both 100%.

The relationship between the lap length and the tensile

breaking force is illustrated in figure 4 below:

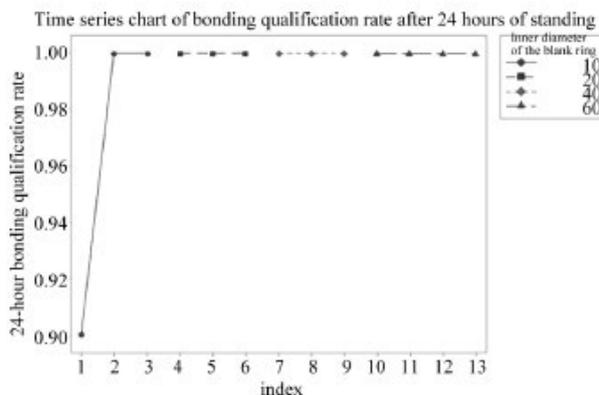


Figure 3 Trend chart of qualified rate of effective bonding under different test schemes

As can be seen from Figure 4, the tensile breaking force of the $\Phi 10$ mm test group is the highest when the overlap length is 7 mm; the tensile breaking force of the $\Phi 20$ mm test group shows no significant change for different overlap lengths; the tensile breaking force of the $\Phi 40$ mm test group is the highest when the overlap length is 5 mm, and slightly decreases when it reaches 7 mm; the tensile breaking force of the $\Phi 60$ mm test group shows an overall upward trend for different overlap lengths, with the highest tensile breaking force at 7 mm. When the overlap length is 3 mm and 5 mm, the breaking position is in the overlap area, while when the overlap length is 7 mm, the breaking position is in the non-overlap area. This is because when the overlap length is 7 mm, the strength of the overlap area is higher than that of the blank strip itself, resulting in the phenomenon where the blank strip is stretched and thinned until it breaks.

Therefore, considering the qualified rate of effective bonding and the lap strength after forming a loop, the optimal lap length is determined to be 5 mm.

3 Conclusion

Through experimental verification, the optimal parameters for the preparation stage of the blank for producing FX-4 rubber sealing rings are as follows: set the roller gap to 1.7 mm, soften the rubber compound 5 times; lock the roller gap to 0.4 mm, and pass it through 13 times; use ethyl acetate to overlap the blank ring, with an overlap length of 5 mm.

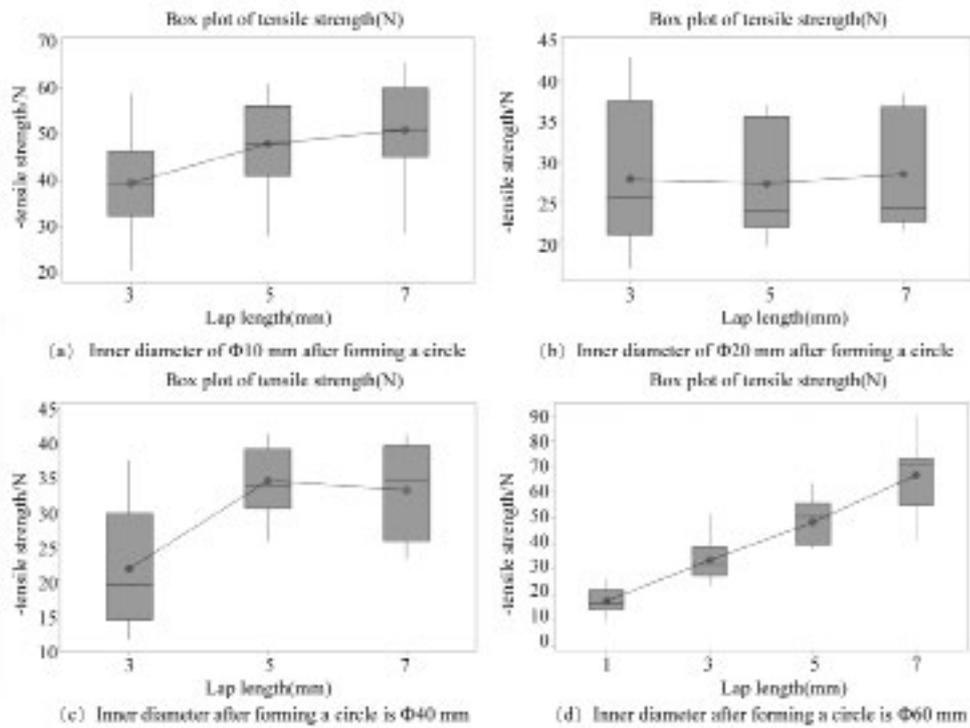


Figure 4 Diagram of the relationship between lap length and tensile breaking force