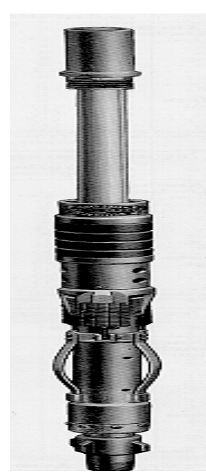
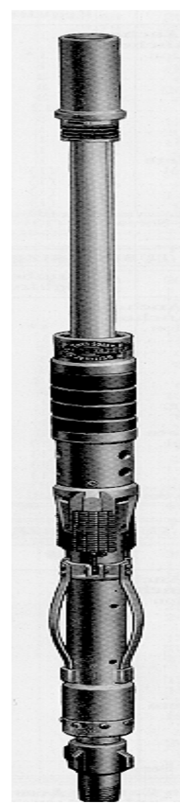
Chapter VII. C

Design Of Packer Elements

TYPICAL PACKERS





INTRODUCTION

Rubber products to be used in the oil field are among the most difficult to design. No base rubber has been specifically designed for use in the oil field and wells continue getting deeper and hotter with more hostile environments. Where do product users turn when they have specific problems? How can they get a product that will perform in a specific set of well conditions? How do we find a rubber that has the physical properties of steel, the corrosion resistance of plastics and the resiliency of rubber? The exact answers to these questions are non-existent. This is due to the inherent properties (chemical and physical) existing in present day rubbers.

This original work was designed to make oil field rubber product users more aware of the short fall of present day rubbers and also to enable the design of tools that can utilize rubbers exceeding their laboratory maximums. Todays thinking on rubber products is to emphasize the quality of rubber products at room temperature as the criteria that makes the rubber function properly in the finished product. This work indicates properties at an elevated temperature in a test media are more in order with those properties needed in down hole rubber products. A rubber formulation cannot just be designed for a set of laboratory conditions. It must be designed for those properties that are needed at the work point. This report is set out to do this.

The choice of packer elements, as the product shape to test and the packer element formulations, was an outcropping of the search for one of the severe tests of rubber in down hole use. It is felt many points have surfaced in this work that make for improvements that can be realized in the quality operation of rubber without continued costly trial and error testing. Although no panacea, the tool design engineer can, by utilizing some of the points learned herewith, become more adept at controlling the product (metal and rubber) that has been designed.

PROCEDURE

The procedures listed below describe each step of laboratory testing.

1. **The following ASTM tests were performed on each compound, at room temperature. The compounds tested were 20-003-70, 20-001-80 and 20-001-90.**

   a. Hardness D-2240-81
   b. Tear Resistance D-624-81
   c. Tensile D-412-80
   d. Modulous D-412-80
   e. Elongation D-412-80

2. **The tests described in step #1 were performed on the tensile samples of the three designated compounds, after each was immersed in ASTM #3 oil at 300°F for 4, 8, 16, 24 and 48 hours. The procedure employed was ASTM D-865-81. The results obtained in step #1 were used as a standard to compare with the results obtained in this procedure. The values obtained from this comparison were denoted as percent retention of physical properties.**

3. **Compression modulous tests were performed at room temperature, in accordance with ASTM D-575-81, method B. The compounds tested were 20-003-60, 20-003-70, 20-001-80, 20-001-90 and 20-001-95. The tests were performed on an Instron 1130 Testing Instrument equipped with a compression cage.**

4. **Compression modulus results were also taken on samples after 2 hours immersion in ASTM #3 oil at 300°F. The test procedure used was ASTM D-575-81 method B.**

5. **Compression and resistance to extrusion values were obtained by placing a packing element into a special fixture designed to simulate downhole conditions. The fixture was equipped with interchangeable side clearances of 0.50", 0.105", 0.160" and 0.233". See Fig. 1 for fixture design and dimensions.**

   A (0.15625") hole in the side of the fixture, into which an aluminum rod was inserted, was used to determine when the packing element came into contact with the I.D. wall of the fixture. This value was designated as the set point.

   The packing elements tested, measured 3.635" O.D., 2.753" I.D., and 1.764" height. The compounds tested were 20-003-60, 20-003-70, 20-001-80, 20-001-90 and 20-001-95. Each packing element in this stage of testing was designated as Configuration "A".

The procedure used to test each packing element was performed in the following manner.

- **a. Check and record the durometer reading of packing element to be tested (ASTM D-2240-81).**
- **b. Place the packing element in the test fixture with the predetermined side clearance, completely assemble the fixture, and place it in the laboratory clamping press.**
- **c. Allow the fixture to heat 20 minutes at 300°F.**
- **d. Insert the "set point" indicator into the 0.15625" hole in the side of the mold.**
- **e. Zero the micrometer used to measure compression of packing elements.**
- **f. Pressure (lbs. of force) is applied to the fixture until "set point" is reached. Set point is indicated by a predetermined movement of the aluminum rod. The pressure and micrometer reading is taken at this point.**
- **g. The packing element is subjected to varied, but known pressures. The pressure on the fixture (i.e. packing element) is increased until 45,000 lbs. of force is reached. Micrometer readings are taken throughout this pressuring procedure.**
- **h. Once 45,000 lbs. of force is reached the pressure on the fixture is released, the fixture is unloaded and the packing element is physically examined. The amount of extrusion present, is measured and a durometer reading is taken.**

6. Compression and resistance to extrusion at elevated temperatures was measured by using the procedure given in step #5 except that each packing element was heated for 4 hours at 300°F. in ASTM #3 oil before being placed in the test fixture. Test results obtained were recorded in the same manner as in step #5.

7. Steps #5 and #6 were also performed on two packing elements stacked one on top of the other. The stack combinations were:

TOP ELEMENT	BOTTOM ELEMENT
a. 20-001-90	20-001-90
b. 20-001-80	20-001-90
c. 20-003-70	20-001-90
d. 20-003-60	20-001-90

8. Steps #5, #6 and #7 were repeated on packing elements designated Configuration "B". Results obtained were recorded in the manner described earlier.

DISCUSSION OF RESULTS

Upon conclusion of the laboratory testing, charts from data sheets were plotted. All the charts have been presented in a manner to aid the layman in utilizing the information they contain, as well as enabling reproduction of this experiment with a minimum of laboratory variation As with all new procedures there is a certain amount of inherent experimental error but it is felt this experiment can be reproduced with error at a minimum of ± 5%. It is felt this procedure is one of the most effective ways presently available for properly matching a packing element compound with its intended function.

Data was recorded at the room temperature for the physical properties of the 3 compounds selected (20-001-90, 20-001-80 & 20-003-70). The hardness, tear resistance, ultimate tensile, modulus and percent elongation values shown are average values obtained from 10 separate but identical tests. These results were used as a standard for comparing heat aged physical properties .

In charts 1 thru 5 a comparison has been made of the pairs of compounds at the various durometer levels showing the per cent retention of the physical properties vs. the aging time in hours. From these charts one can determine that a compound irrespective of its original properties is either better than, worse than or equal to its competitor for the range of conditions set out in these tests. Naturally one might want to choose the compound with the highest physical properties to perform a job, but the best choice is the compound that is more stable and that has less reaction to the testing media. This is a better method of choosing, for we need a material that retains a high resistance to heat, that retains a high resistance to hydrocarbon fluids and a high resistance to tear and extrusion. A compound that retains a high per cent retention of its physical properties would indicate a compound that has been formulated to withstand the test conditions imposed. From this we can compare actual working conditions to the test conditions and determine which properties are most important to the proper function of a finished part and seek out that compound that has the best per cent retention of those physical properties.

To those working with materials trying to produce packer rubbers for the oil field, we feel the most important characteristic for consideration is the compression stress (compression modulus) of the rubber compound. Curves showing the compression stress (PSI) plotted vs. the per cent deflection are shown in charts 6 thru 10. Two curves are shown on each chart. One is for room temperature and the other is after aging of the test sample at 300^{o} F. for 2 hours in ASTM #3 Oil. The sample size molded for this test gives a flat surface of one square inch for one half inch of thickness. Shape factor would have some little effect on the obtained properties, but for a matter of comparison and according to ASTM the load force was shown for the original one square inch of area and the per cent deflection was calculated using a comparison to the original height of the sample.

Charts 6 thru 10, when used properly can be of great value in determining which compound would perform best in a downhole environment. For example; if the amount of compression the packing element will be expected to function under is known, one can go to these charts and select the compound with the highest compression stress at that point.

Closely associated with a compound's compression stress characteristic is its ability to resist extrusion. Charts 11 thru 39 show the relationship between the percent compression and compression force (lbs. x 1000) placed on CONFIGURATION "A"[1] packing elements molded from the test compounds (20-001-95, 20-001-90, 20-001-80, 20-003-70). The odd numbered charts (11,13, 15, etc.) show the results from packing elements which were heated in the test fixture for 20 minutes at 300°F. prior to testing. In the even numbered charts (12, 14, 16, etc.) one can find the results obtained when packing elements subjected to 4 hours of immersion in ASTM #3 Oil at 300°F were tested. The test fixture's side clearance (0.050”, 0.105”, 0.160”, 0.233”) was systematically varied in the two previously mentioned sets of charts. For instance; charts 11 and 12 show the results from packing elements exposed to dry heat and oil immersion before being compression tested in the test fixture equipped with 0.050" side clearance insert.

On these charts (11-39) one will note the designation "set point". This is the point at which enough force is exerted on the packing element to cause it to come into contact with the I.D. of the test fixture. It is felt that this point will be closely associated with the point at which a packing element becomes set in an oil well. Upon examination of charts 11-39 one is made aware of the fact that all of the packing elements molded from the test compounds required 20-30 percent compression before they reached "set point". This point was 5-12% less on the packing elements subjected to immersion in ASTM #3 Oil for 4 hours at 300° F. as compared to those exposed to dry heat (20 minutes at 300°F.). The compression force (lbs. x 1000) required for the packing element to reach "set point" varied from 200-1000 lbs. depending on the compound and the test fixture side clearance.

On the even numbered charts (12-38) there are 3 durometer readings given. These readings clearly show a drop in hardness due to the effects of heat and oil immersion on the packing element compound. In all of the charts, this decrease in hardness averages less than 5%.

Upon examining charts (11-39) as a whole, several interesting facts become evident. For instance; the oil immersion charts have a much smoother slope than the dry heat charts. This is due to the fact that the packing elements subjected to oil immersion are 300°F throughout while those exposed to dry heat are only 300° F on the outer-most surfaces. Since a packing element in a downhole environment would be at a constant temperature inside and out, by the time its set, we feel the elements subjected to the oil immersion test give a much more valid picture of the way they will perform down hole.

from that of a smooth parabola. Typically, the oil immersion packing elements began to extrude at a higher compression force value than the elements exposed to dry heat. Photos (1-14), which correspond to charts 11-39, show the amount and type of extrusion found in each of the tests.

All of the packing elements molded from the test compounds functioned adequately in the test fixture equipped with the 0.05", 0.105", and 0.160" side clearance inserts. However, when the packing elements molded out of 20-001-80 and 20-003-70 were put under pressure with the 0.233" side clearance insert in place the cold flow (creep) of the compound became too great to allow the packing element to function. Under these same conditions packing elements molded from 20-001-95 and 20-001-90 withstood 60-66% of the pressuring up procedure before showing extrusion and failure at 27,000-30,000 lbs. of force (load).

Charts 40-47 are composites of charts 11-39. There are two composite charts for each test compound; one in which the packing element was exposed to dry heat and one where the packing element was immersed in ASTM #3 Oil for 4 hours at 300^{o} F Each chart contains all the test fixture side clearances used. For example; chart 41 shows the test results obtained from a packing element molded out of the 20-001-95. It was immersed in ASTM #3 Oil for 4 hours at 300^{o} F and subjected to test fixture side clearances of 0.05", 0.105", 0.160" and 0.233".

The reason for combining several charts to form composites (40-47) was to illustrate the basic difference between packing elements molded from the same test compound but exposed to different pretest environments. The basic difference noted was the grouping of the oil immersed packing element curves as compared to the curves of the packing elements exposed to dry heat. The composite charts of the oil immersed packing elements have curves which are much more tightly grouped. For example; when chart 40 is compared to chart 41 the effect that the pretest environment had on the packing element is clearly shown by the 33% grouping variation between the two.

Charts 48-50 contain the results obtained from the testing of CONFIGURATION "B" packing elements (Note Figure 2). These packing elements were molded out of the 4 test compounds (20-001-95, 20-001-90, 20-001-80 and 20-003-70), immersed in ASTM #3 Oil for 4 hours at 300^{o} F. and run in the test fixture equipped with the 0.160" side clearance insert. In contrast to what was observed on the CONFIGURATION "A" packing element charts (12, 14, 16, etc.), charts 48-50 show extrusion and failure at much lower compression force levels. For example; on graph 50 the packing element composed of 20-003-70 showed excessive extrusion and failed at 23,000 lbs. of force. However, the corresponding chart (34) for the CONFIGURATION "A" packing element did not show evidence of failure until 27,000 lbs. of force was applied to the packing element.

The percent compression at 45,000 lbs. of force also varied depending on which packing element configuration was examined. In chart 50 the CONFIGURATION "B" packing was compressed 74% when 45,000 lbs. of force was applied to it. The CONFIGURATION "A" packing element was only compressed 69% under the same

The most plausible explanation for these differences is the "shape factor" that is inherent to each configuration.

"Shape factor" is the ratio of the area of one load face to the combined area of those surfaces free to expand laterally when the rubber is under compression. The formula used is:

$$SF = \frac{\frac{\pi}{4}(O.D.^2 - I.D.^2)}{\pi(\,O.D. \times h\,)}$$

SF = Shape factor

$\frac{\pi}{4}(O.D.^2 - I.D.^2)$ = Area of load face

$\pi(\,O.D. \times h\,)$ = Area of surfaces free to expand

The height value in the equation π(O.D. x h) is obtained by measuring from the mid-point of the packing elements upper most chamfer to the mid-point of its lowest chamfer.

CONFIGURATION "A"

$$SF = \frac{\frac{\pi}{4}(3.441^2 - 2.744^2)}{\pi(3.667 \times 1.301)}$$

$$SF = \frac{(11.840 - 7.530)}{4(3.667 \times 1.301)}$$

$$SF = \frac{4.310}{19.08}$$

$$SF = 0.226$$

CONFIGURATION "B"

$$SF = \frac{\frac{\pi}{4}(3.230^2 - 2.729^2)}{\pi(3.602 \times 1.452)}$$

$$SF = \frac{(10.433 - 7.447)}{4(3.602 \times 1.452)}$$

$$SF = \frac{2.986}{20.92}$$

$$SF = 0.143$$

The higher a compound's "shape factor" value the higher its resistance to stress relaxation and extrusion. This explains why different loads effect each configuration differently. CONFIGURATION "A", which has the higher shape factor, also has a higher resistance to extrusion and therefore can function under higher loading pressures.

Chart 51 is a composite of charts (48-50). Its purpose is to aid the observer in making comparisons of the 3 test compounds (20-001-90, 20-00180, 20-003-70) molded into CONFIGURATION "B" packing elements.

Plotted on charts 52-59 are the results from the stacked, CONFIGURATION "A" packing elements. The results are similar to those found in the single packing element tests (charts 11-39). From these charts and photos 15-22 it is evident that the 20-001-90 packing element functioned well as back up for the softer top element. If one considers the bottom element to be equivalent to an end ring in a packing element system and the top element a center ring in that same system, certain assumptions can be made. Upon comparison of chart 55 and 57 it can be stated that under laboratory conditions a CONFIGURATION "A" packing element stack, consisting of a 20-001-90 bottom element and 20-003-70 top element performs 8% better than a stack composed of a 20-001-90 bottom element and 20-001-80 top element.

Noteworthy is the fact that there is little difference between the elements exposed to dry heat and those that were immersed in ASTM #3 Oil before testing.

In comparing charts 52-59 to charts 60-61; stacked CONFIGURATION "B" packing elements, only minimum variations are present. There also appears to be little difference in the 20-001-90/20-003-70 CONFIGURATION "B" packing element stack when compared to the 20-001-90/20-001-80 stack. In this particular set of laboratory tests the CONFIGURATION "B" packing elements functioned adequately regardless of which test compound they were molded out of.

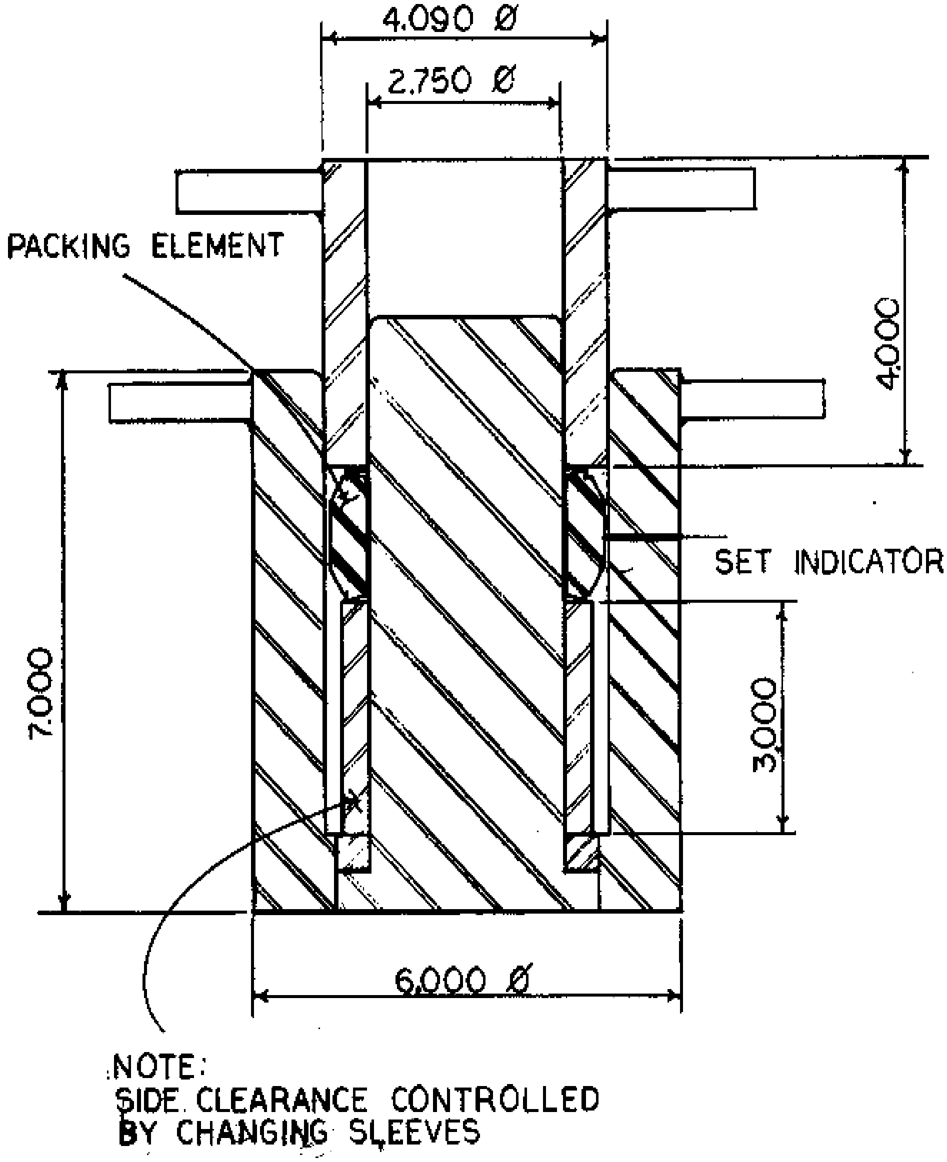
SUMMARY

The physical properties of the test compounds varied greatly depending on the type of environment and pressures they encountered. It is clear from the results obtained, that the test compounds exposed to dry heat perform differently than those subjected to oil immersion. The test compounds that were molded into packing elements and subjected to oil immersion typically performed better than the ones exposed to dry heat. The oil immersed packing elements took 5-12% less compressive force (lbs. X 1000) to reach "set point", dropped less than 5% in hardness during the duration of the test, and began to show signs of extrusion at a much higher compression force value than did their counterparts. This improved performance is due to the way the packing elements were heated. The packing elements exposed to dry heat received heat only on the outer-most surfaces while those that were immersed in ASTM #3 Oil for 4 hours at 300 ^{o} F.were heated throughout. Since packing elements in a downhole environment would be heated by immersion in hydrocarbons rather than dry heat, the oil immersion procedure outlined in this experiment would be a much more valid way to select a packing element compound.

Upon examination of the shape factor calculation, in the Discussion of Results section of this experiment, it is evident that this was the primary reason for the variations noted between the CONFIGURATION "A" and CONFIGURATION "B" packing elements. Since the performance of a packing element is mathematically governed by its shape, proper care must be taken when designing it. A poorly designed packing element with a low shape factor will perform poorly, even when molded out of the best of compounds.

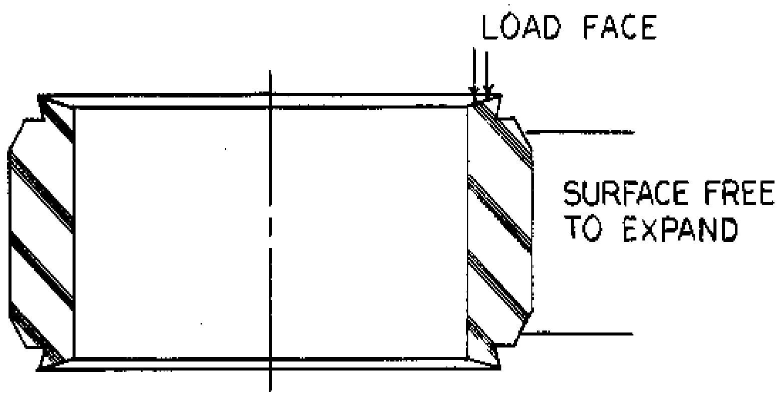
The bulk of the results obtained in this experiment are meant to be used as a guide, by which the layman can select a packing element compound that will most closely meet their needs. If the side clearance, temperature, and compressive force which the packing element will be subjected to are known, then the compound that will perform best under those conditions can be selected from the charts. Should specific properties, such as high ultimate tensile or high % elongation be desired, the compound with the physical properties closest to those sought can also be obtained from the charts.

FIGURE 1

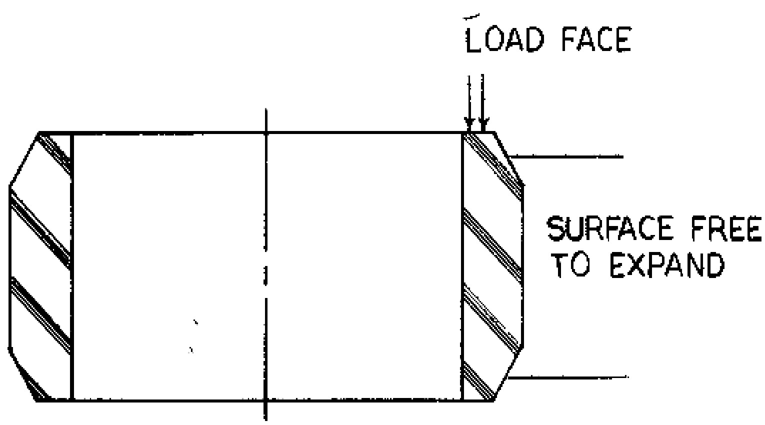


4.090 Ø
2.750 Ø
PACKING ELEMENT
4.000
SET INDICATOR
7.000
3.000
6.000 Ø
NOTE:
SIDE CLEARANCE CONTROLLED
BY CHANGING SLEEVES

FIGURE 2



CONFIGURATION A



CONFIGURATION B