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Drill Pipe Protector Development

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Drill Pipe Protector Development*

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Sponsored by

Geothermal Drilling Organization

Abstract

The Geothermal Drilling Organization (GDO), formed in the early 1980s by the geothermal industry and the U.S. Department of Energy (DOE) Geothermal Division, sponsors specific development projects to advance the technologies used in geothermal exploration, drilling, and production phases. Individual GDO member companies can choose to participate in specific projects that are most beneficial to their industry segment. Sandia National Laboratories is the technical interface and contracting office for the DOE in these projects. Typical projects sponsored in the past have included a high temperature borehole televiewer, drill bits, muds/polymers, rotary head seals, and this project for drill pipe protectors. This report documents the development work of Regal International for high temperature geothermal pipe protectors.

* The work described in this report was performed for Sandia National Laboratories under Contract No. 02-7768.

CONTENTS

TECHNICAL BACKGROUND AND OBJECTIVE	1
EXECUTIVE SUMMARY OF RESULTS, ACCOMPLISHMENTS AND RECOMMENDATIONS	2
TASK 1--ELASTOMERIC MATERIAL EVALUATION AND SELECTION	3
Evolution of Test Procedures	4
Screening of Candidate Materials	4
TASK 2--ELASTOMER-TO-METAL ADHESION EVALUATION	6
Primer and Adhesive Selection	7
TASK 3--PROTOTYPE FABRICATION, TESTING AND EVALUATION	8
CONCLUSIONS/RECOMMENDATIONS	10

TECHNICAL BACKGROUND AND OBJECTIVE

Drilling into inherently abrasive geothermal formations utilizing conventional rotating drill strings subjects both casing and tool joints to excessive wear and possible premature failure. Hardbanding of tool joints with tungsten carbide, using a welding deposition process, is commonly done for these conditions, and is adequate to protect the tool joint during rotation. Casing wear, however, is substantially accelerated by contact with the hardbanding, increasing well costs by requiring inner strings of casing and/or casing liners to be set in order to accomplish a safe completion.

Traditionally, expendable drill pipe/casing protectors, typically hinged metal cages with an outer sacrificial elastomer sleeve, clamped to the drill pipe O. D. and rolling on the I. D. of the casing are used by the oil industry to protect both the casing and drill strings from wear extremes caused by rotation of the drill string inside the casing. Most state-of-the-art protectors that are commercially available meet the general criteria for such applications. However, because conventional elastomers, i.e., nitriles and neoprenes, are commonly used in pipe protector manufacturing, these protectors are subject to operating temperature limitations that preclude their general use in the hostile geothermal conditions of highly abrasive cuttings, high temperature, and high pressure brine/steam.

The objective of this program has been to develop an elastomer and chemical bonding method that could be used to fabricate/test a drill pipe/casing protector suitable for commercial use in geothermal wells. The program was sponsored by the GDO in cooperation with Sandia National Laboratories (SNL), Brookhaven National Laboratory, and with funding from the U.S. DOE.

The program was divided into three TASKS:

TASK 1: ELASTOMERIC MATERIAL EVALUATION AND SELECTION

TASK 2: ELASTOMER-TO-METAL SUBSTRATE ADHESION EVALUATION AND PRIMER SELECTION

TASK 3: PROTOTYPE MANUFACTURING FOR LABORATORY AND FIELD PERFORMANCE EVALUATION

EXECUTIVE SUMMARY OF RESULTS, ACCOMPLISHMENTS AND RECOMMENDATIONS

The primary objective of developing a commercial drill pipe/casing protector capable of performing satisfactorily in the proposed test environments (brine at 550°F, 5000 p.s.i., and/or saturated steam at 500°F, 660 p.s.i.) was not accomplished. However, Regal's endeavors in completing TASK 1 indicate that an available polymer, properly formulated and reinforced, is capable of retaining its elastomeric properties under the pressure and temperature extremes of both environments. TASKS 2 and 3, however, indicate that deficiencies exist in available commercial bonding systems for vulcanizing the elastomer to a metal substrate. Coupon testing of candidate systems in the laboratory provided two combinations which were very effective after 48 hours exposure in circulating air at 500°F, retaining 99% adhesion when subjected to peel tests (ASTM D429, Method B). Identical coupons tested in hot fluids did not survive. Full scale prototype parts, produced under TASK 3, also exhibited good adhesion after similar high temperature air exposure, easily meeting the target of 3,500 lbs. radial load for a sustained period while rotating at 120 R.P.M. Facilities to perform hot fluid testing of the prototype protectors in the laboratory were not available.

Recognizing that the adhesion test results obtained in the laboratory might not be directly correlatable to actual field conditions, six prototypes were provided to UNOCAL for field testing in their Geysers Geothermal field. Three conventional nitrile protectors manufactured to a 60 durometer condition were furnished as control specimens to gauge the severity of downhole conditions.

The field test did not confirm the adhesion problems encountered in the laboratory test. Failure of the lowest protectors in the test well string occurred within 24 hours of running time as a result of extensive rubber loss due to high velocity discharge of drill cuttings, steam and air circulating up the casing annulus during drilling operations. A second test conducted in a different well in the same field yielded essentially the same results. In both wells, the indicated downhole temperatures did not reach the extremes used in the laboratory tests. None of the prototype geothermal protectors exhibited bonding system failure. The conventional control specimens exhibited massive failure.

In summary, the performance of the drill pipe/casing protectors developed in this program has not attained the level of confidence necessary for commercial geothermal use. A more abrasion resistant elastomer is definitely required for the high flow, harsh steam environment such as encountered in the Geysers. The issue of adequate elastomer adhesion to metal substrate, although substantially improved over existing conventional bonding systems, is still unresolved in high temperature steam and unknown in the higher pressure, high temperature brine environments found in other geographical areas. Additional opportunities to field test prototypes in these areas have been postponed indefinitely due to decreased drilling activity. There may be additional opportunities in the future for testing, and additional test protectors have been sent to UNOCAL to await the proper opportunity.

One issue that was identified when Regal was trying to solve the high temperature bonding problem was that the manufacturers of bonding materials did not consider the geothermal high temperature market large enough for them to invest additional funding and research time. This issue could possibly be addressed by the DOE Geothermal Division granting funding for high temperature bonding system research and development (R & D), thus taking the R & D investment burden off of the private sector for an important, but limited market in renewable energy.

TASK 1--ELASTOMERIC MATERIAL EVALUATION AND SELECTION

A thorough search was undertaken to identify and obtain samples of commercial polymers potentially compatible with the anticipated environments. Available sources were researched, including polymer vendor technical publications, bulletins and manuals as well as industry association technical publications. In cases where specific polymer data indicated some chance of success, the vendor was contacted to factor their recommendations and experience into the identification process. As a result, the following commercially available polymers were selected for initial evaluation: (Brand name-Vendor in parenthesis)

- 1) Fluoroelastomers -
(Aflas 100S -Zenox)
- 2) Nitrile
(Hycar 1312 - B. F. Goodrich)
- 3) Hydrogenated Nitrile
(Zetpol 2000 - Nippon Zeon)
- 4) Chlorosulfonated Polyethylene

(Hypalon 20 - DuPont)
- 5) Polybutadiene
(#6081 - Polyscience)
- 6) Ethylene - Propylene Copolymers (EPM)
(Vistalon 404 - Exxon)
(Epsyn 4106 - Copolymer)
- 7) Ethylene - Propylene - Diene Terpolymers (EPDM)
(Nordel 1660 - DuPont)

(Epsyn 2308 - Copolymer)

(Epsyn 5206 - Copolymer)

8) Silicone Modified EPDM

(Royal Therm - Uniroyal)

9) Y267 EPDM Compound

Developed by L'Garde Inc. under the sponsorship of the U. S. Department of Energy. (Ref: Geothermal Elastomeric Materials, GEM Program, by A. R. Hirasuna, et al, July 1979.)

Evolution of Test Procedures

Concurrent with the initial processing of the candidate polymers, outside independent research sources were contacted to locate and/or fabricate a suitable test chamber for testing of the candidate materials in the specified environments. This was to be done under load conditions, simulating, as close as possible, the actual environment and mechanical stresses anticipated in downhole geothermal use. Some equipment capable of simulating the mechanical conditions was located; however, none of the facilities, including Regal's own in-house testing facility, was capable of mechanically testing at the extreme temperatures while maintaining a high pressure, brine/steam environment.

Cost estimates for designing and fabricating a new facility were inordinately high as was the consideration of a scaled down model utilizing an existing environmental test chamber owned by Brookhaven National Laboratory and loaned to L'Garde Inc., of Tustin, California. Discussions with the field site operators regarding building new test facilities led to the conclusion that mechanical, thermal and chemical testing downhole was more practical and would be more indicative of performance, assuming that the candidate materials and coupling systems satisfactorily withstood the environmental tests under static conditions. However, a means of at least screening laboratory samples was still required.

A lower cost high pressure test chamber, based on ASTM E-1068, was fabricated for the laboratory static tests. The test chamber was designed to maintain an internally controlled pressure of 5000 psi on either liquid or gas test environments while the chamber was externally heated inside a furnace with circulating air.

Screening of Candidate Materials

Basic test compounds of each candidate polymer were mixed on an open lab mill with formulations recommended by the polymer vendors and/or developed in-house at Regal. Each test compound was molded into 0.25" x 1.0" x 3.0" test coupons which were then post-cured. After post-

curing, standard laboratory procedures were used to identify those compounds which exhibited acceptable physical properties. Those compounds were then subjected to circulating air tests at 550°F for 48 hours. The coupons were then visually examined during flexing and bending to 180 degree position. The test samples which did not exhibit cracks or blisters were then subjected to pressure vessel tests in saturated steam at 550°F. Additional testing in liquid brine at 550°F was conducted on the samples if the previous test indicated an acceptable performance. Also, separate molded and post cured coupons from each test compound were tested in each discrete environment. The results were as follows:

- 1) Fluoroelastomer: Three compounds were tested. All survived circulating air at 550°F for 48 hours with good resilience and no visible surface effects. However, in both saturated steam at 500°F and brine at 550°F, all coupons produced extensive swelling and blistering. None of the three compounds were deemed suitable for further testing.
- 2) Nitrile - This liquid Hycar 1312 polymer was evaluated primarily as an enhancement plasticizer for the other base polymer compounds, particularly the EPM and EPDM formulations which traditionally used polybutadiene. The Hycar polymer was found to be superior to the polybutadiene #6081 recommended by others in similar formulations.
- 3) Hydrogenated Nitrile: Two compounds were tested, both surviving the circulating hot air test in fair condition. Further steam and brine tests produced excessive swelling and blistering. Material was deemed unsuitable for further testing.
- 4) Chlorosulfonated Polyethylene: Evaluated as a component in EPDM compounds. Confirmed that the material contributes to heat and fluid resistance when used in combination with other ingredients as published by L'Garde.
- 5) Polybutadiene: (See No. 2 - Nitrile)
(Discarded due to superior performance of Hycar 1213.)
- 6) EPM: Two (2) compounds were tested; one in-house formulation, one vendor formulation. Both compounds suffered heat cracks and embrittlement after circulating air test at 550°F for 48 hours; no further testing was conducted.
- 7) EPDM: Four (4) compounds were tested, including the Y267 formulation from L'Garde. All compounds, except the Y267, suffered heat cracking and embrittlement in the circulating air test. Because of the known qualities of Y267, further testing in saturated steam and brine was deferred until a broader range of compound variations could be studied.
- 8) Silicone Modified EPDM: Two (2) formulations were tested, both vendor furnished. Neither survived the circulating air heat test at 550°F and both exhibited extensive heat cracking.

As previously noted, of the EPDM compounds tested, those derived from the published Y267 formulation developed by L'Garde proved superior. This was confirmed by testing in the high pressure chamber in both simulated environments. A total of 32 variations of this compound were mixed, press molded, then post cured at various temperatures and times; i.e., 350°F for one (1) hour, 400°F for one (1) hour, 450°F for one (1) hour, 500°F for five (5) hours. Duplicate specimens were also post-cured at 350°F for one (1) hour, 400°F for one (1) hour, and 450°F for 5 hours.

L'Garde recommended that Y267 be post cured in a nitrogen environment to decrease its permeability under sustained high pressure. However, no appreciable difference in permeability from either nitrogen or oxygen post cures was observed during the testing. This may have been due to inadequate control of the nitrogen inside the oven. An attempt was then made to post cure a set of specimens inside the test chamber in a pure nitrogen environment. This was not successful because restricted circulation through a bleed line did not allow the volatiles in the specimens to dissipate properly and resulted in extensive blistering on all the specimens. Subsequent post curing of all follow-on specimens was done in an air environment.

Of the 32 EPDM base compounds tested, three (3) were selected as prime candidates for further development due to their retention of physical properties, flexibility and appearance after testing. The three candidates were then designated as experimental compounds: 818L, 819L and 821L. Further modification of the compounds was undertaken to determine the effect of liquid polymer substitutes, and adjustments were also made to the levels and alignment of the Aramid (Tm) fiber reinforcement. Further testing, repeating the procedures previously outlined, confirmed that all three candidates exhibited temperature and environmental resistance superior to the L'Garde Y267 for a geothermal drill pipe/casing protector application.

TASK 2--ELASTOMER-TO-METAL ADHESION EVALUATION

Because of the extremely corrosive nature of geothermal environments, it was decided early in the program to fabricate all the metal components in the prototype protectors out of type 303 stainless steel (SS), fully annealed. The standard metal structure used for oilfield protectors is normally a low carbon, draw-quality steel, fully annealed. The standard hinge pin used on all protectors manufactured by Regal remains a type 316 cold finish stainless steel round. A 400 series, heat treatable grade of stainless steel was used for the tapered drive pin on the test protectors.

For the purposes of this evaluation, the type 303 stainless steel cage was to be chemically bonded to the elastomers; therefore, all coupon adhesion tests subsequently conducted used this material as the substrate. (Earlier tests on different grades of stainless indicated large variations in adhesion, apparently caused by differences in alloy metallurgy). Historically, EPDM based compounds have proven very difficult to bond to most metal substrates.

Primer and Adhesive Selection

Several major vendors of rubber/metal bonding primers and adhesives were contacted for their recommendations and experience with the polymer types and metal substrates proposed in the program. Based on the suppliers' recommendations and in-house experience with various primers, the following candidates were selected for evaluation, both singularly and in combination with others.

- a) Chemlok AP-144 (Lord Chemical)
- b) Chemlok 610 " "
- c) Chemlok Y4310 " "
- d) Chemlok Y1540 " "
- e) Chemlok 205 " "
- f) Chemlok 220 " "
- g) Chemlok 252 " "
- h) Ty-Ply BN " "
- i) Thixon P-6-1 (Whittaker-Dayton)
- j) Thixon 508 " "
- k) Thixon P-14 " "
- l) Megum 3270 (Chemetal)
- m) Megum V12588 "
- n) Megum 9290/1 "

To minimize the possibility of variance in the metal substrate, all specimens for adhesion testing were cut from a type 303 SS full size cage skeleton. Each specimen was nominally 1/2" in width x 3.0" in length with a thickness of .060". To prepare for priming, all specimens were degreased, shot blasted with GL25 steel shot and degreased again to remove any dust or residue. The various primers were then mixed to the proper consistency and the specimens hand painted. Each specimen was identified as to primer(s) and number of coats. After drying, each specimen was vulcanized with each of the 3 EPDM test compounds in a bar type mold at 350°F for 20 minutes. Two or more control specimens were also molded from each compound. All specimens were post cured for the same time and at the temperatures used in polymer testing.

Initial tests were conducted for 48 hours in the circulating air oven at 550°F. Of the samples tested, only combinations of Megum V12588 over Megum 3270 primer, and Megum V12588 over Lord's TY-PLY BN looked promising, both sustaining a 99% elastomer-to-substrate adhesion after cooling. All other samples had marginal or non-existent adhesion.

A second test was performed, using new specimens produced under the same procedure, and subjected to 550°F for 48 hours in brine at 5000 PSI. After cooling, the Megum 3270/V12588 and TY-

PLY BN/V12588 both exhibited spotty adhesion, approximately 10 to 20% on both. All other specimens exhibited no adhesion.

A third test was conducted, again using new samples, in saturated steam at 500°F for 48 hours. Again, the Megum combination and TY-PLY BN/Megum both produced marginal adhesion to the metal substrate. All other samples exhibited no adhesion.

Although neither candidate primer/elastomer combination produced adequate adhesion for subsequent testing, it was felt that the TY-PLY BN/Megum V12588 system exhibited the best potential for improvement. One method suggested was to phosphate the samples prior to priming using an Oakite Phosphate dip system. Additional sample specimens were taken to Brookhaven Laboratories by L. Kukacka to have two (2) BNL-proprietary phosphate systems applied. All of the control specimens that were phosphated proved to have substantially inferior adhesion for subsequent physical properties control tests; therefore, no test vessel evaluations were conducted on those specimens.

To determine if the adhesion problems were caused by attempting to bond to stainless steel, a control test using carbon steel cage specimens, was performed. Using both of the candidate priming systems, and testing in progression from hot air at 550 degrees F to brine at 550 degrees F and 5000 PSI and then to saturated steam at 500 degrees F, 660 psi. environments, identical adhesion problems occurred; i.e., less than 10% spotty adhesion.

TASK 3--PROTOTYPE FABRICATION, TESTING AND EVALUATION

At this point in the development program, it seemed that developing an elastomer-to-metal coupling system adequate to sustain mechanical function of a drill pipe/casing protector in the desired environments was not possible. A different strategy was then suggested by Regal that used a prototype cage that was designed and fabricated with four longitudinal reinforcing ribs across the circumferentially slotted ribs of the cage skeleton. The longitudinal ribs were equally spaced circumferentially and provided an additional internal mechanical lock for the rubber body of the protector. Subsequent radial testing at progressive side loads proved the mechanical lock to be inadequate, with complete rubber separation from the cage occurring at approximately 2320 lbs. side load, less than 30 minutes into the test. Extensive in-house testing on conventional protectors indicates that radial loads of 4500-5500 lbs. can be sustained for 8 to 12 hours without evidence of failure.

Project personnel met to discuss the laboratory test results and it was recognized that there was a difference between results obtained under laboratory conditions and those expected under widely variable, but possibly less severe actual field conditions. It was decided to proceed, even with unacceptable adhesion indicated by lab test results, to mold a series of full scale prototypes, specifically 4-1/2" I.D. x 6-3/4" O.D. drill pipe protectors, sampling each of the identified candidate elastomer

compounds and utilizing the TY-PLY BN/Megum V12588 coupling system. This was accomplished on production machinery, although *considerable scaling and modification of procedures was required* before acceptable control parts could be produced. This modification consisted primarily of adding a bake-on step of 15 minutes at 250°F to the TY-PLY primer coat before application of the V11588 adhesive, and also increasing the shot blast profile on the surfaces prior to priming. The prototypes were press cured for 90 minutes at 90°F and then oven post cured for 1 hour at 350°F, 5 hours at 400°F and 16 hours at 450°F. After cooling, the parts appeared to have excellent adhesion to the stainless steel cages, similar to the adhesion obtained during initial laboratory tests.

These prototypes were used to determine product performance in comparison to existing data compiled on conventional drill pipe/casing protectors when tested under ambient temperatures and fluid conditions. In-plant rotational tests were conducted at a 4050 lb side load while the part was immersed in a fresh water bath. Temperature of the fresh water reached 120°F after 6 hours of rotation. After removal, the part showed relatively little surface wear and no evidence of debonding from the metal cage structure. The protector was then placed back into the oven and subjected to an additional 16 hours of circulating air heat this time at 500°F (first heat). After cooling, the protectors were reinstalled on the test machine and rotated for another 6 hours under the same load conditions. Again, upon removal, the protectors showed no evidence of debonding and the protector surface indicated very little wear, having glazed to a very glossy, polished finish. After the second 16 hour heating (third run) at 500°F some differences appeared. The results were as follows:

No. 818L - Cage structure fractured 3-1/2 hrs. into third run. Some debonding evident, no visible wear on O.D.

No. 819L - Heat cracks appeared after second heat, rubber failed one (1) hour into third run. Some debonding evident. Very little wear (less than .015").

No. 821L - Higher proportion of heat cracks after second heat, rubber appeared visibly deteriorated. Failed one (1) hour into third run, substantial rubber failure with debonding, substantial wear was also observed.

The protector wear tests were conducted per A.P.I. Specification 7J, Section 3, which specifies a minimum run time under these load conditions of 6 hours. All three candidate prototypes survived beyond this requirement and reinforced the findings that the three compounds were suitable for protector applications with the 818L compound performing exceptionally well. The collective opinion of project personnel indicates that this compound has definite potential for other products in oilfield and geothermal applications with lower temperature regimes.

Following the results of these tests, an evaluation was made to determine if the adhesion failure experienced in the environmental testing of the lab specimens was because of the test conditions being

too extreme. Using similar specimens and controls, the temperature of the environment was reduced in increments of 50°F. A constant pressure and time was maintained for each test. A second series was tested, reducing the heat time for each temperature increment by 12 hours. The tests were halted at 400°F and 12 hours of heat time since the results did not improve. All specimens exhibited totally unsatisfactory adhesion even at the lower temperatures and shortened duration. The tests were conducted in both brine and saturated steam.

CONCLUSIONS/RECOMMENDATIONS

The elastomeric compounds developed and tested under this program are capable of performing downhole in a geothermal well drilling environment. However, as understood at the onset of this program, a chemical bonding system capable of equally withstanding such a harsh environment is absolutely essential to the dynamic function of any drill pipe/casing protector.

No such coupling system is currently available from commercial suppliers although the TY-PLY BN / Megum V12588 bonding system demonstrated the best potential for improvement. The incentives necessary for commercial suppliers to perform research and develop such a system do not exist primarily because of the limited market in the geothermal industry. Perhaps, under the auspices of the various program offices dealing with renewable energy production and conservation for the U.S. DOE, further research and development activity could be encouraged with adequate funding .

The final activity in this project was planned in collaboration with the Geothermal Drilling Department of UNOCAL in Santa Rosa, California; specifically Mr. Thomas Haas, Regal manufactured six prototypes of the 4-1/2" x 6-3/4" drill pipe protector molded from the experimental compound 818L. These were sent to UNOCAL for evaluation in a downhole environment at the discretion of Mr. Haas. Included with the six prototypes were three conventional protectors to use as control specimens in the same wellbore environment. Due to a slowdown in geothermal drilling activity, these second generation prototype protectors have not yet been tested in the field environments.

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