TECHNOLOGY ENABLING INNOVATION

SILICONE TECHNOLOGIES DIVISION
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New Highly Thermally Stable Flexible Heater Compound
Arlon's 427CR (UL-Recognized Flexible Heater Compound)

Conclusion and Summary

Arlon's next generation 427CR silicone compound delivers the best thermal stability of any flexible heater material available on the market. The new 427CR compound retains critical physical properties such as elasticity longer than competitive materials during field operation. This is true for short term thermal exposure up to 320°C and for long-term thermal aging up to 220°C. Test results presented in this application note demonstrate the superiority of 427CR vs. a relevant, high-quality benchmark – Arlon's leading UL-recognized silicone compound. This benchmark compound has a long record of successful service in the flexible heater industry, but the test results clearly show that 427CR has superior thermal stability.

Introduction

The purpose of this application note is to describe the benefits of Arlon's new highly thermally stable flexible heater compound. The superior thermal aging resistance of the 427CR compound has been proven through long term property retention during accelerated thermal aging. Long term thermal stability with good tensile strength and dielectric strength retention has been validated through a UL746B program, Polymeric Materials - Long Term Property Evaluations. The 427CR compound also shows superb short term resistance to excessive crosslinking, which leads to retention of flexibility in extreme thermal environments. Stability of adhesion strength through high temperature exposure, as fit to an Arrhenius plot, further demonstrates thermal stability. Thermal aging analysis of key material properties places the 427CR compound best in class.

Most silicone flexible heater substrates lose a large percentage of their initial post cured tensile strength, elongation, dielectric strength, and bond strength at elevated temperatures, especially at temperatures over 200^{o}C. Silicone inherently has superb thermal oxidative stability. But, at extreme temperatures, silicones lose flexibility and strength. This occurs because of the excess energy being absorbed by the silicone from extreme temperature exposure. There are two main processes that cause the thermoxidative breakdown at temperatures between 200-350^{o}C. Firstly, excessive crosslinking can take place, which will cause the silicone to lose its flexibility and become brittle. Secondly, pendant groups on the silicone polymer backbone can volatilize off the silicone compound, which can result in a loss of key physical properties. Finally, oxidation of the silicone forms silicon oxides [1]. Arlon's new 427CR flexible heater compound is designed with thermo-oxidative stability in mind so coated substrates remain flexible. The 427CR compound and coated flexible heater substrates do not deteriorate as easily as the competition at higher temperatures, which results in minimum loss of key properties at temperatures in excess of 200°C.

Thermal Endurance

Thermal stability is a key characteristic of silicone flexible heater substrates due to their function as primary insulation for heating elements. Arlon offers silicone coated fabrics and films rated for long term service up to 220^{o}C. The materials maintain functionality with intermittent thermal exposure up to 320^{o}C.

Silicone flexible heater substrates must retain key material properties of tensile strength, elongation, dielectric breakdown strength, and adhesion strength at these elevated temperatures over long operation periods. The 427CR compound and coated substrates have been tested by Underwriters Laboratories and received a Relative Thermal Index (RTI) of 220°C/220°C (Electrical/Mechanical rating) under the UL Card E54153. The

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electrical RTI is associated with the critical insulating property of dielectric breakdown strength. The mechanical strength (Mechanical without Impact) RTI is associated with critical mechanical strength and structural integrity focuses on ultimate tensile strength. The Electrical and Mechanical RTI ratings were developed over a 1.5 year accelerated aging program with UL, in a systematic process to validate the high temperature stability of the 427CR compound and its associated calendered substrates [2].

Flexibility Retention

The photographs below demonstrate flexibility retention for the 427CR compound versus the benchmark – Arlon's leading UL-recognized flexible heater compound. Both ASTM slab samples were exposed to 300°C for 24 hrs. After aging, the 427CR compound sample can be easily folded 180 degrees without fracture (**Photo I**). After identical aging, the benchmark material has become brittle and splits when folded (**Photo II**).

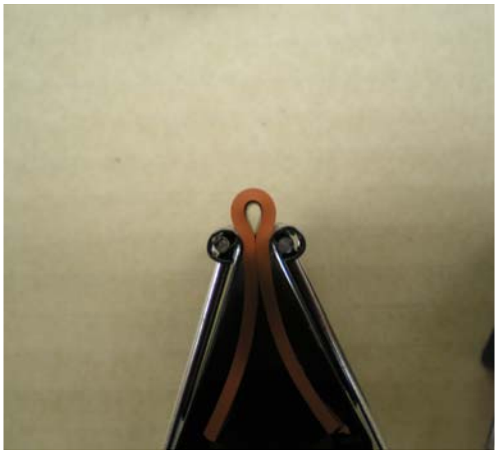

Photo I – 427CR
After 24 hr @ 300ºC

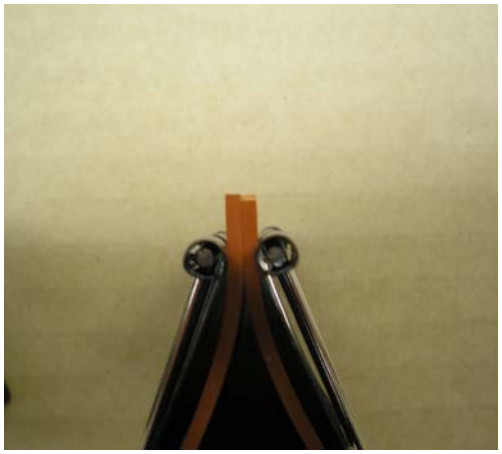

Photo II – Benchmark Material
After 24 hr @ 300ºC

Short Term Resistance to Excessive Crosslinking

Most silicone compounds begin to excessively crosslink at temperatures higher then 200°C, which leads to a loss in tensile strength and elongation. Arlon's new 427CR compound will retain these key properties better at higher temperatures than other silicones. The charts below show how Arlon's new thermally stable flexible heater compound has better tensile strength and elongation retention compared to the benchmark material. Chart 1 shows that Arlon's new thermally stable compound does not lose tensile strength during short term exposure to temperatures over 250°C. The 427CR product retains over 95 percent of its tensile strength when exposed to temperature over 250°C for up to one week and has virtually no loss in tensile strength when subject to 320°C for 24 hours.

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PERCENT TENSILE STRENGTH RETENTION

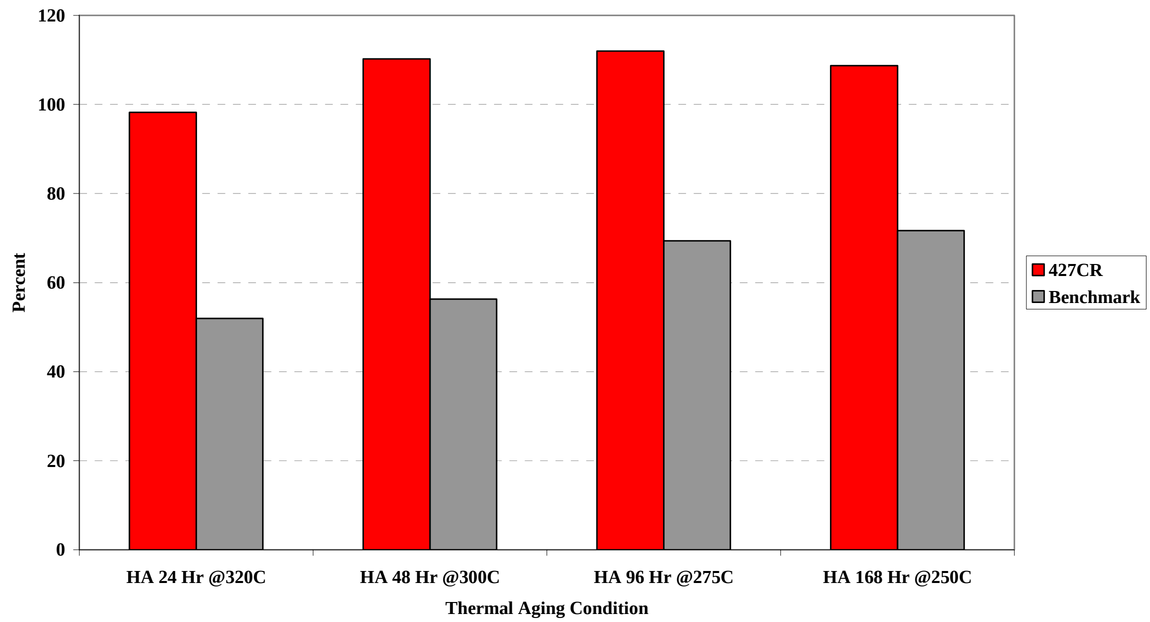

Chart 1

Chart 2 highlights how the 427CR compound retains over 30 percent of its initial elongation after 24 hours at 320^{o}C . The competition retains less than 15% or its original elongation for this same thermal exposure period.

PERCENT ELONGATION RETENTION

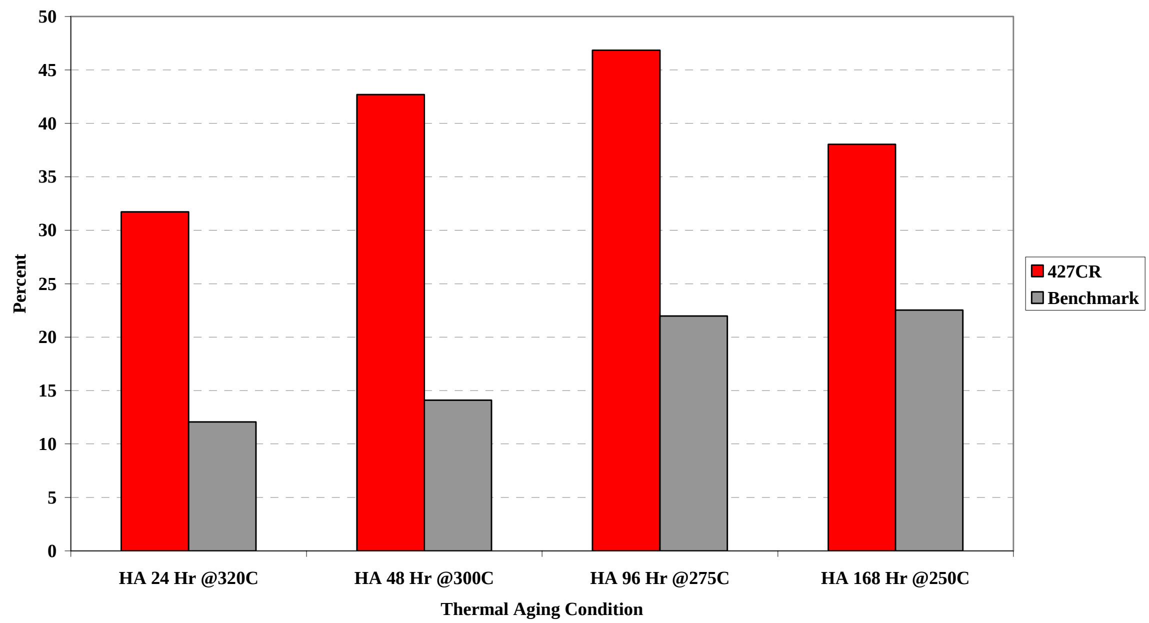

Chart 2

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Arlon's 427CR compound clearly has a higher retention of elongation and therefore will remain flexible when subject to aggressive thermal spikes compared to the benchmark silicone compound.

The short term thermal aging study was performed on molded ASTM slabs to show how Arlon's 427CR compound can handle extreme temperature spikes much better than the benchmark material. The 427CR compound retains its tensile strength and elongation better than the benchmark and therefore retains greater elasticity or flexibility. This is critically important because as silicone products start to lose flexibility, micro cracks can form, leading to field failures in final products.

Adhesion Strength Longevity

The 427C compound shows excellent retention of fabric adhesion at elevated temperatures. A ply adhesion strength of 1.5 pounds force per inch width was chosen as "end of life" to compare compound adhesion to fiberglass fabric (427CR vs. the benchmark). Chart 3 shows the time to "end of life" for calendered ply adhesion coupons at various temperatures. The chart fits the results to an Arrhenius plot. The 427CR compound maintains cohesive failure at high temperatures and retains its level of adhesion strength longer.

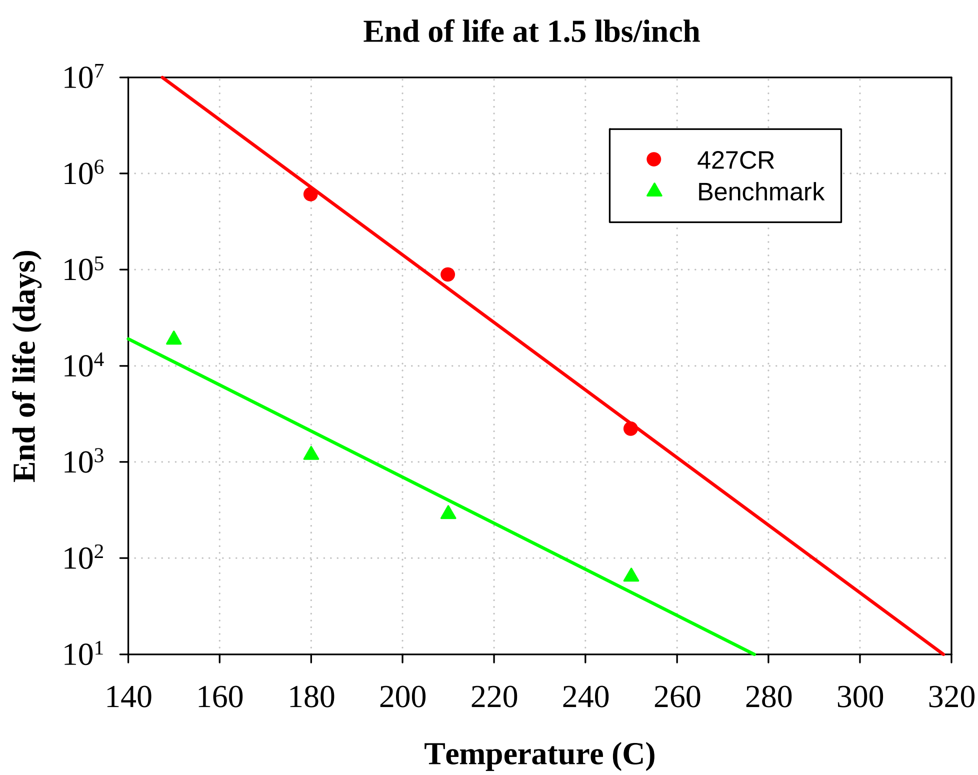

Chart 3
(Based on Side 1 to Side 1 ply adhesion coupons
built from 55##9R028 constructions)

Chart 3 demonstrates that the 427CR based calendered substrates have extended operational life as judged by adhesion strength stability between 140°C and 320°C. Chart 3 can be read by choosing a temperature on the x-axis, moving vertically until intersecting either regression line, and then moving horizontally until intersecting the y-axis, which is the "end of life" in days. For example, at 220°C, the "end of life" of the 427CR

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calendered substrates is an amazing ~30,000 days compared to ~225 days for the benchmark. Since this study isolates the kinetics of polymer thermal aging (aerobically) and uses an arbitrary "end of life" value, the regression lines should be used with caution. But, with any interpretation, it is clear that overall bond strength longevity of 427CR calendered substrates is superior to the benchmark product.

Another method of comparing the 427CR to the benchmark is a single thermal aging cycle comparison. Chart 4 shows the 427CR and benchmark material aging at 210°C.

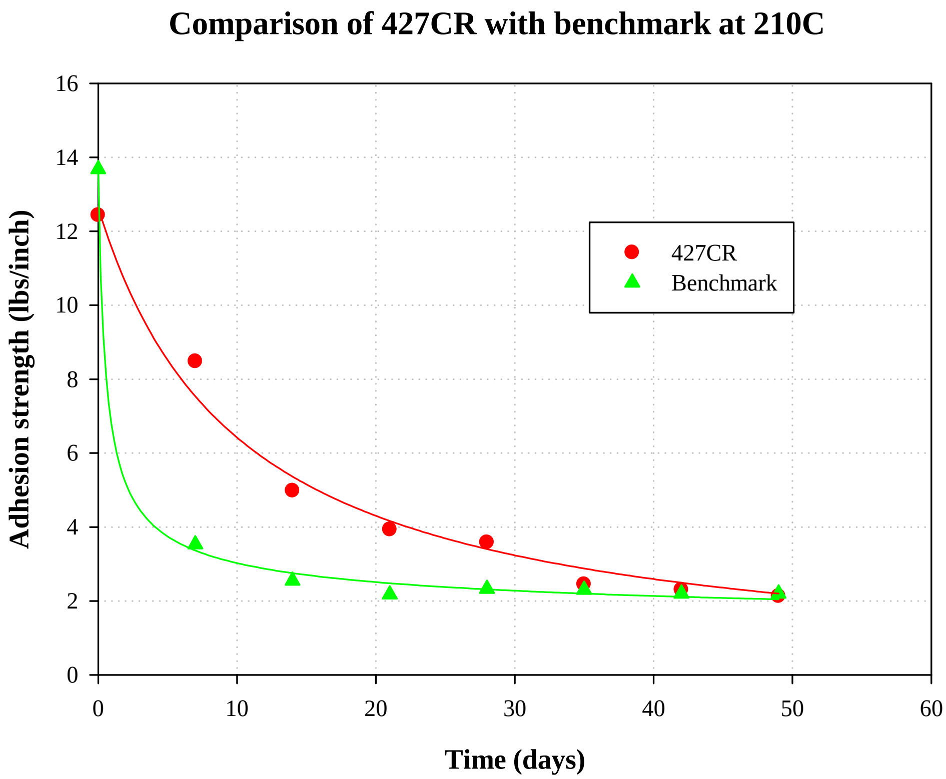

Chart 4

The chart shows the rapid decay in the benchmark's bond strength at 210°C. In only a day at temperature, the 427CR based substrate has superior bond strength.

Long term adhesion strength of the 427CR compound to Stainless Steel 304 and Alloy 600 is also considered excellent compared to the benchmark. The superior polymer thermal stability of 427CR leads to a more stable silicone to foil bond when compared to the benchmark.

Process Considerations for Bulk Compound and Calendered Substrates

Chart 5 shows the cure kinetics of the 427CR compound and can be used as a reference for processing calendered substrates. As the 427CR product cures, and polymer crosslink density increases, the Monsanto R100 Rheometer torque also increases. A torque reading of approximately 70 lbs-in is considered is considered a fully crosslinked polymer. Less than 5 minutes is required to reach completion at all of the cure temperatures in Chart 5.

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427CR Temperature Vs. Cure time Rheo charts

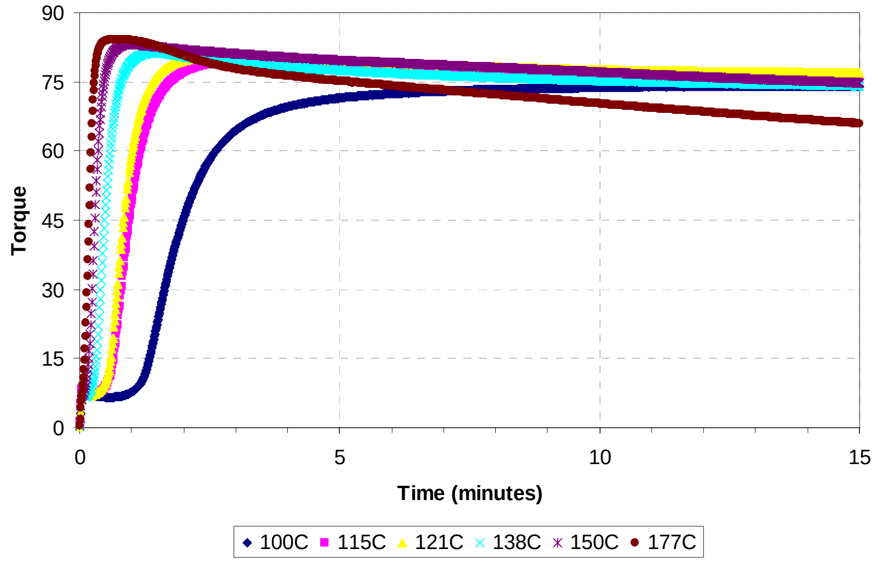

Chart 5

Arlon recommends the following process parameters for building laminates from flexible heater substrates calendered with the 427CR compound:

- Platen Press Lamination (Uncured Silicone to Uncured Silicone)
  - Temperature: 121°C
  - Pressure 50 psi
  - Time: 5 minutes

- Vacuum Bag Lamination (Uncured Silicone to Uncured Silicone)
  - Temperature: 121°C
  - Pressure : 14.7 psi
  - Time: 5 minutes
    - Notes:
      - Laminate entrapped air must be completely removed
      - Substrate surfaces must be completely mated
      - Time equals the time that the polymer is at temperature

- Platen Press Lamination (Uncured Silicone to Primed Foil)
  - Temperature: 100°C
  - Pressure: 50 psi
  - Time: 15 minutes

- Vacuum Bag Lamination (Uncured Silicone to Primed Foil)
  - Temperature: 100°C

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- Pressure: 14.7 psi
- Time: 15 minutes
  - Notes:
    - Laminate entrapped air must be completely removed
    - Substrate surfaces must be completely mated
    - Utilize proper press pads in a platen press process
    - Time equals the time that the polymer is at temperature

- Recommended Foil Prime Coat:
  - Application method: Pneumatic spray or lint free rag wipe
  - Primer: 2:1 vol --- Anhydrous Isopropanol:DC2260
    - Note: Primer ratio is subject to change based on application method
  - 30 minute hydrolization step, at 23°C and 50% RH, after priming

- Recommended Laminate Post Cure:
  - Oven is vented and mechanically circulating
    - Air exchange rate: ~ 2 cubic feet of fresh air per minute per pound of silicone.
  - Laminate thickness < 0.060” = 2 hr at 204°C
  - Laminate thickness 0.060” to 0.150” = 4 hr at 204°C
  - Laminate thickness > 0.150” (Subject to evaluation)

Calendered Substrate Availability

The 427CR compound can be purchased as bulk compound, CP-427R, or in a calendered construction, ex, 51276R015.

Flexible heater substrate part number (GG)(##)(C)(CO)(TTT)

(GG) Two digit code identifying the substrate [51] = Style 7628 fiberglass
(##) Two digit code identifying the silicone rubber compound [27] = 427CR compound
(C) One digit code identifying the product construction [6] = Cured Side 1 & Uncured Side 2
(CO) One or two letter(s) identifying the product color [R] = Red
(TTT) Three digit code identifying the overall product thickness in mils [015] = 0.015”

Compatability With Other Arlon Silicone Compounds

Lastly, 427CR coated flexible heater substrates are compatible with many of Arlon’s current flexible heater substrates, and laminates can be effectively built mixing products. Excellent adhesion can be achieved when laminating calendered substrates, whether an uncured to uncured or a cured to uncured laminate combination is used:

(GG)58(C)R(TTT) to (GG)27(C)R(TTT): 121°C, 50 psi, 15 minutes.
(GG)57(C)R(TTT) to (GG)27(C)R(TTT): 177°C, 50 psi, 15 minutes.
(GG)60(C)R(TTT) to (GG)27(C)R(TTT): 121°C, 50 psi, 15 minutes.

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References

[1] Dvonic, P.R. (2004) High Temperature Stability of Polysiloxanes, Silicon Compounds: Silanes and Silicones, Gelest Catalog 3000-A pp. 419-431

[2] QMFZ2.GuideInfo Plastics – Components, UL Online Certification Directory (2007) Retrieved on September 7, 2007 from http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/showpage.html?&name=QMFZ2.GuideInfo&ccnshorttitle=Plastics++Component&objid=1073827223&cfgid=1073741824&version=versionless&parent_id=1073827222&sequence=1

Note

The data presented in this document represent typical values.
The data should not be used to write, or in place of, material specifications.
The data presented do not ensure fitness for use in any particular application.
Arlon recommends that the customer confirm fitness for use in their finished product design.