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Effect of Elevated Temperatures on Fiber Glass Composite Pipes used for Geothermal Well Completions

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ABSTRACT

Geothermal well fluids may pose high corrosive loads on the casing and tubing used to complete the well. Recent developments in composite pipe manufacturing process, that allows the reduction of fabrication costs have pushed the composite pipes to enter on the market of well completion. Although high temperature may not be favorable to the implementation of composite pipes in high enthalpy geothermal wells applications, low enthalpy geothermal wells, especially those where the fluid temperature is lower than 150°C have considered the use of fiber glass reinforced composite pipes.

This paper shows the experiments performed on several fiber glass composite pipes to understand its response to thermal cycles and the results found show that thermal cycling may reduce the pipe strength with up to 10%. The tests have been carried out for a time frame of 3 weeks, and some samples have been continuously heated, while others have been heated for 8 hours and left to cool for 16 hours.

The samples' mechanical properties have been measured using a modified pipe crushing test, which allow the use of short samples. All together we believe that our experiments, will help better understand the use of composite pipes in geothermal well completions.

1. INTRODUCTION

By definition, a composite material represents a product made up of 2 or more constituent materials, with different physical and chemical properties. The purpose of combining the properties from different materials is to give to the end-product special attributes, e.g. good mechanical properties whilst maintaining a small weight. Since these materials were implemented with resounding success in other industries, as telecommunications, and aerospace, the petroleum industry is moving forward to implementing them with good results in fabrication of drill pipes, tubing, casing, marine risers, tanks and pipelines.

Geothermal applications of tubular face many challenges due to the highly corrosive environment, and energy efficiency requirements. In response to that, alternative solutions to carbon steel have been studied and implemented with promising results ranging from corrosion resistant alloys to titanium (Teodoriu and Falcone, 2009). Geothermal applications of fiberglass have been proven to be very efficient in terms of reducing maintenance due to good corrosion resistance, strong mechanical properties and good pressure rating, as presented by Rafferty (1989) and Tong (2019). The energy efficiency increases as well by using this type of materials, which have a low thermal conductivity, therefore preserving the heat of the thermal agent, minimizing heat loss in the adjacent formations. Wilkes and Childs (1992) have presented the use of fiberglass as a thermal insulator, which reduces the natural convection up to eliminating it. The validation of fiberglass application in geothermal wells has been achieved in Bonneuil-sur-Marne geothermal district heating site, as presented by Ungemach and Antics (2018).

Fiberglass is a composite material made up of 2 basic constituents, the fibers, which are winded to an epoxy resin matrix. The glass fibers offer the end-product good mechanical strength, and the epoxy matrix offers good corrosion resistance and elastic properties. Yuan and Goodson (2004) highlighted that the degradation of fiberglass could take place due to temperature variations, as the constituent materials dilate and contract in different proportions, resulting in a weakening of the interfacial cohesion between the constituents, which translates into an overall reduction of the mechanical strength.

Figure 1 displays the SEM view of a fiberglass sample in which lack of interfacial cohesion has been found, due to manufacturing flaws. Other flaws could represent micro-pores due to air bubbles intrusion during epoxy solidification. These defects are susceptible to cause further damage to the material in addition to thermal effects, as they could represent fractures propagation centers which could lead to material failure at smaller loads than expected.

Corrosion resistance of fiberglass makes it cost-effective in saving bactericides, corrosion inhibitors and maintenance costs, enhancing tubular lifetime and providing in the same time less pressure loss through friction and less heat loss through material thermal conductivity, as presented in Table 1. Another property that makes fiberglass suitable for geothermal wells is the elasticity, which offers the capacity to accommodate changes in length due to temperature variations, therefore simplifying well completion design, whilst maintaining the integrity of the tubular.

However, since fiberglass products for wellbore applications are relatively new, their long term performance has not been fully understood, and therefore our research is trying to answer to some of these questions.

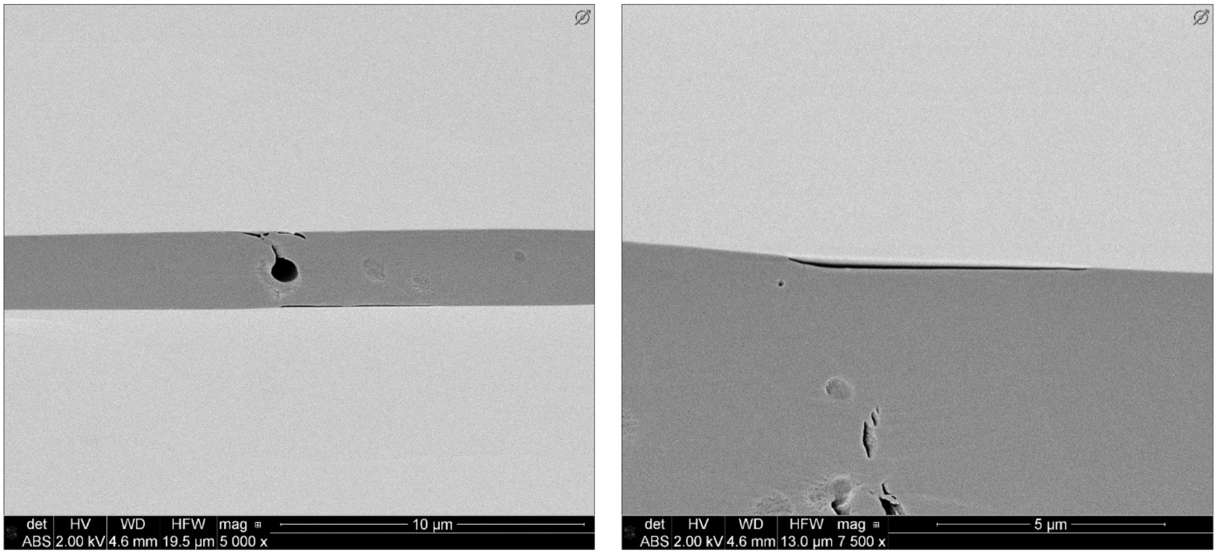

Figure 1. Manufacturing imperfections of fiber glass samples used in this paper

Table 1. Thermal conductivity for materials used in geothermal applications

Material type	**Thermal conductivity *Btu in / (h ft^2 °F)***
Fiberglass (Epoxy)	2.8
Ductile iron	240
Carbon steel 1 %C	297.6
Steel - Chrome, 5% Cr	277.2
Steel - Chrome Nickel, 15% Cr, 10% Ni	132
Steel - Chrome Nickel, 20% Cr, 15% Ni	104.76

2. EXPERIMENTS AND RESULTS

In order to test the influence that temperature has over the fiberglass composite tubular, as to proposing them as pertinent solutions for geothermal wells implementation, a series of experiments have been conducted. The pipe has been sampled in circular shape and subjected to temperature loading by submersion in a hot bath with distilled water, preset to 60 °C to simulate the heating and cooling conditions. The experiment took place over a 3 weeks period, 3 of the samples being subjected to thermal cycles – 8 hours of thermal loading with 16 hours of cooling down, whereas one sample has been continuously exposed to the same temperature of 60°C. The 60°C temperature have been selected, as it is considered to be the temperature at which heat distortions may occur for common resins. Although geothermal wells may face higher temperatures, a 60°C condition may exists when the surface casing is made of fiber glass materials. Some other geothermal wells have used fiber glass tubing up to 90°C conditions, in low temperature geothermal wells.

In order to quantify the effect of temperature over the material strength, a pipe-crushing setup has been used, while the unexposed sample was tested both using the crushing device as well as the standard tensile testing procedure for reference. The device consists of a hydraulic press which records the force at which the plastic deformation occurs, as shown in Figure 2. This force is then corrected by considering the thickness of each sample. A force versus displacement measurement is shown in Figure 3. The almost linear behavior can be observed until the maximum force is reached followed by an abrupt force decrease. The maximum force is then used to characterize the sample resistance. All linear portions of the 5 tests are shown in Figure 4 whereas an interesting behavior is observed: after first thermal cycle, the tested sample after first cycle seems to be stronger as the original not exposed sample. Although this variation is small, it has been considered not being influenced by the measurements error. The results presented in Figure 5 show a decrease in the material strength with up to 10% for the sample which has been continuously exposed to temperature. This decrease could be explained by a more intense thermal degradation of the epoxy matrix rather than the weakening the interface between the 2 constituents, as previously mentioned. The mechanisms through which temperature affects the epoxy are known as the hygrothermal degradation – the infiltration of moisture in the epoxy with the effect of weakening the structure, as presented by Karbhari (2019) and the hydrolytic degradation, through which water is absorbed and bonded to the polymer structure, causing other components of the matrix to leach, resulting in a mass loss, as presented by Krauklis et al. (2003). These drawbacks of the fiberglass do not make it suitable for high enthalpy geothermal applications, as the effects mentioned are accelerated by temperature, but makes it a reliable technical solution for use in low enthalpy geothermal wells, both for injectors and producers.

Figure 2. Pipe-crushing testing setup

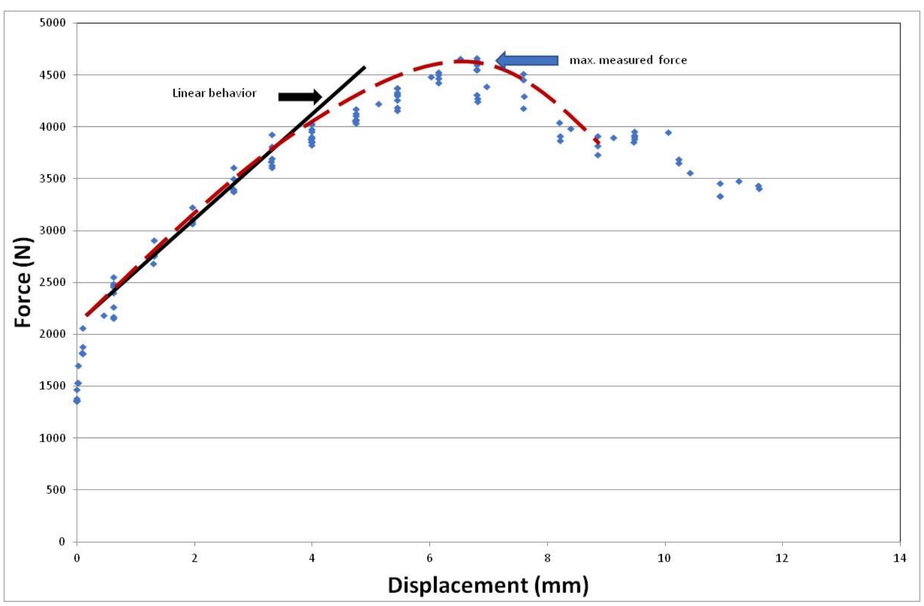

Figure 3. Example Force - Displacement Chart of sample 3

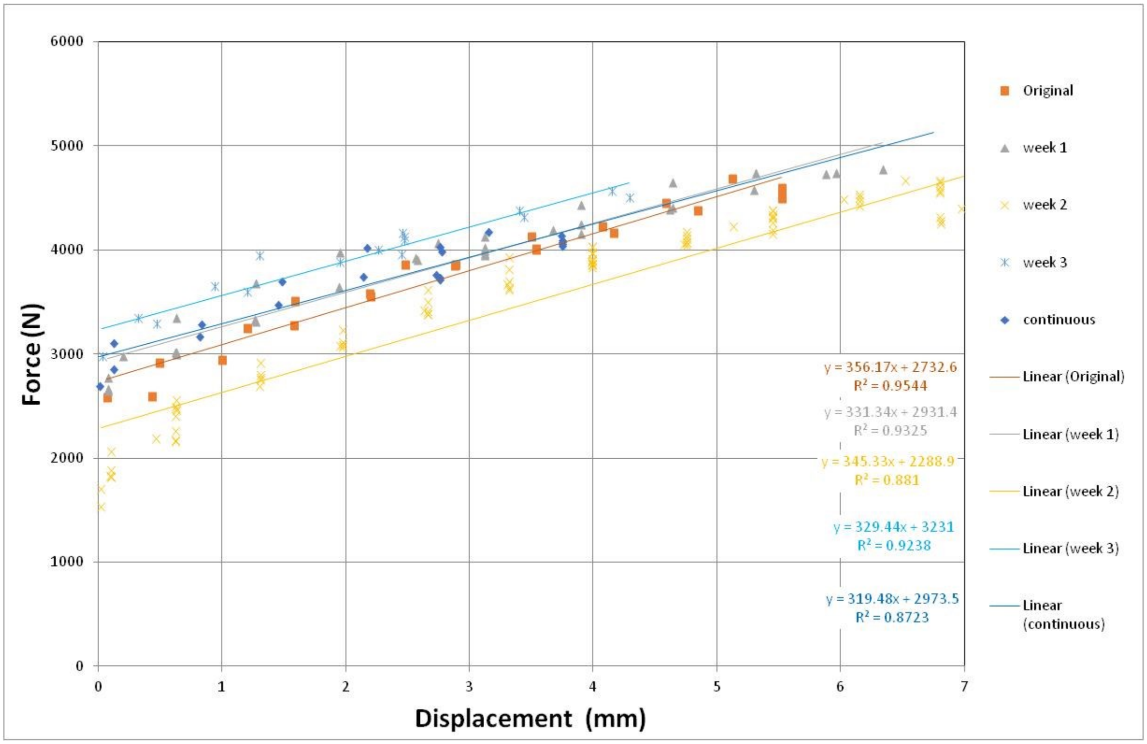

Figure 4. Linear portion of the Force - Displacement Chart for all samples

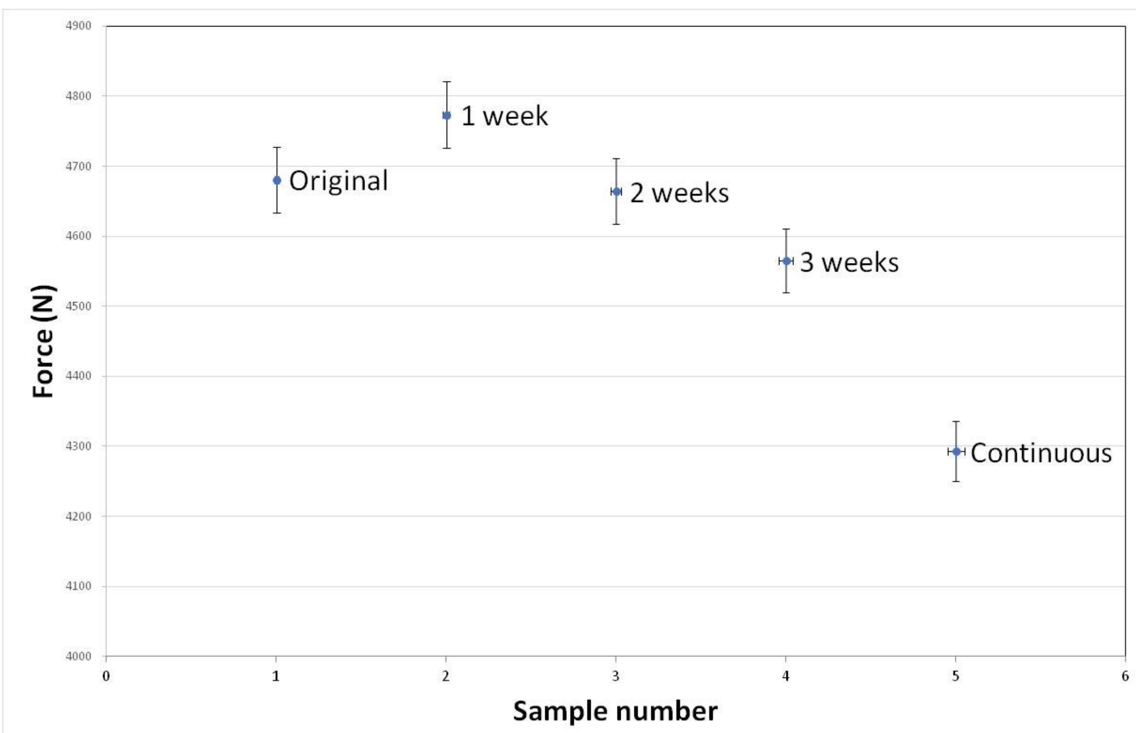

Figure 5. Thermal loading influence on fiberglass composite pipes showing a slight decrease of the mechanical properties with time

3. DISCUSSIONS

A very interesting characteristic obtained through experiments was the slight increased of sample strength after the first cyclic test. Diniţă et al. (2019) have shown that depending of the medium at which the samples are stored at elevated temperature, the ultimate tensile strength may increase after 24 hours by 3 to 5%. Our data shows an increase of about 2 % in hot water.

The importance of the experimental work presented above lies in the possibility to further predict the composite pipe strength over time. Figure 4 shows a decrease of the force vs. displacement slope over time at temperature exposure which indicates a change in E-modulus of the material.

Although our experiments are not necessary representative for all market available composite pipe, the samples we have tested show a clear thermal degradation of mechanical properties, which actually was also shown by other researchers (Shokry, 2014, Diniţă et al., 2019). Although we agree that our data is limited at this stage, we have performed an extrapolation of our results as shown in Figure 6. The data shows that the composite pipe exposed continuously at 60°C may lose its strength after approximately 36 weeks of continuous exposure, while a similar pipe exposed to thermal cycles will fail after 47 weeks. Since our tests was a crushing test, the above results will apply only to the composite pipe crushing resistance.

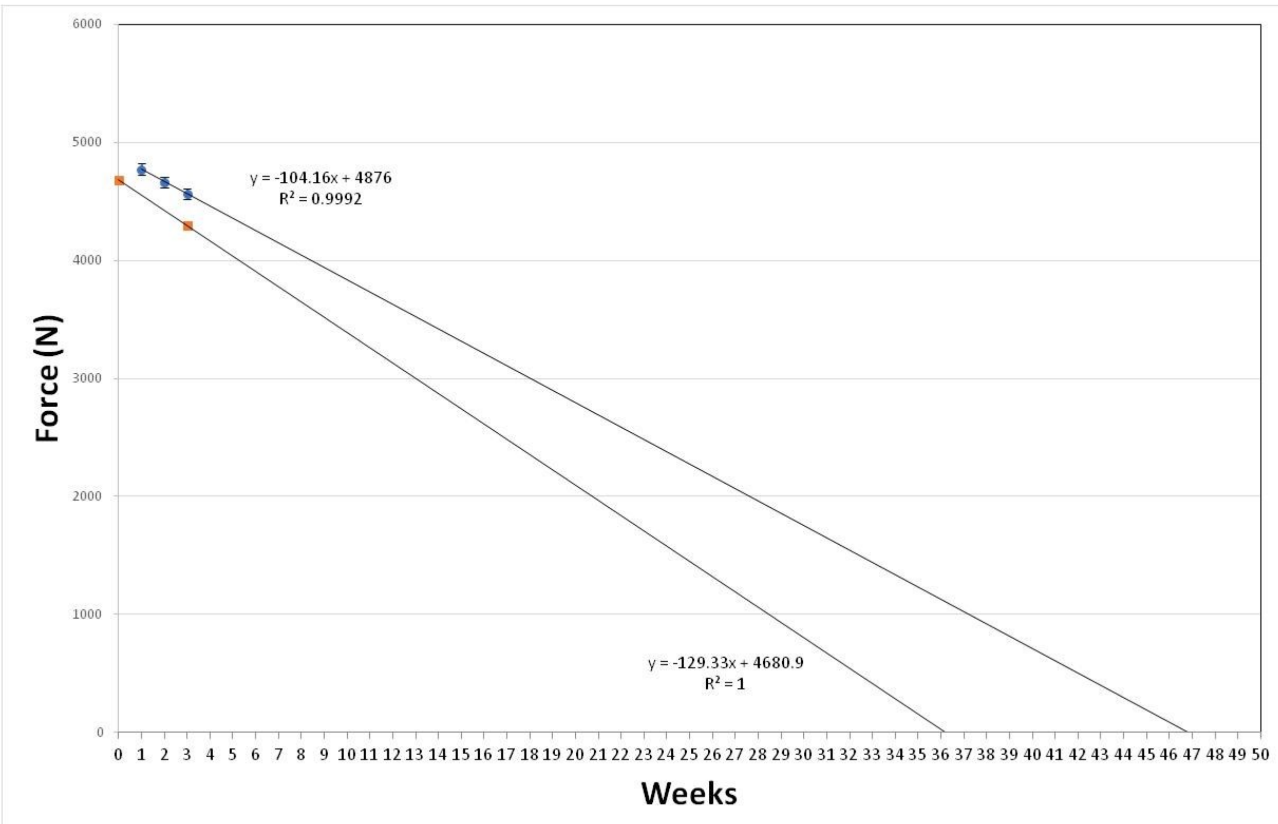

Figure 6. Thermal loading influence on fiberglass composite pipes showing the estimate time to failure for crushing resistance

4. CONCLUSIONS

Designing the completion of low enthalpy geothermal wells by the help of fiberglass composite tubular is proving to be a very simplistic and optimistic approach in order to minimize well intervention, save costs related to corrosion prevention and complex devices to accommodate tubular length change.

In this paper authors presented an experimental study in which fiberglass composite degradation with temperature has been evaluated and quantified, by taking into consideration various scenarios which could be found throughout the lifetime of a geothermal well, whether an injector or a producer.

The scenarios follow thermal cycling and continuous exposure to temperature loading, which lead to the result that epoxy matrix degradation due to temperature decreases the strength of the material with about 10% for a 3 weeks exposure.

Extrapolating our current data, shows that the tested composite samples will only survive for about 36 weeks at continuous exposure to 60°C temperature or 47 weeks at daily cycles. However, due to limited amount of current data, the presented results should be carefully used, especially for other type or composite fiberglass systems.

At this point, long term investigations on composite fiber glass pipe are necessary to fully understand the degradation mechanism at elevated temperatures.

REFERENCES

Diniţă, A., Minescu, M., Dumitrescu, A., Teodoriu, C., and Săraru, C. Ş., Assessment of Variations in the Physico-Mechanical Properties of Fiberglass Tubing Working in Different Environments, Proceedings of the ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering. Volume 8: Polar and Arctic Sciences and Technology; Petroleum Technology. Glasgow, Scotland, UK. June 9–14, 2019. V008T11A047. ASME. https://doi.org/10.1115/OMAE2019-96283

Karbhari, V.M., Hygrothermal Effects on Transition Behavior of Carbon-FRP Composites - Proceedings of The Thirteenth (2003) International Offshore and Polar Engineering Conference Honolulu, Hawaii, USA, May 25–30, 2003, I-03-374 ISOPE Conference Paper - 2003

Krauklis, A.E., Gagani, A.I., Echtermeyer, A.T., Long- Term Hydrolytic Degradation of the Sizing - Rich Composite Interphase - Coatings 2019, 9(4), 263; https://doi.org/10.3390/coatings9040263

Rafferty, K.D., Geothermal Direct-Use Engineering and Design Guidebook Volume 12693, Issue 2 of US Department of Energy. DOE-ID, 1989- Chapter 10 - Piping Geo-Heat Center Klamath Falls, Oregon

Shokry, K.M., Effect of Temperature on Mechanical Properties of Glass Reinforced Plastic GRP, World Applied Sciences Journal 31 (7): 1341-1344, 2014ISSN 1818-4952© IDOSI Publications, 2014 DOI: 10.5829/idosi.wasj.2014.31.07.14463

Tong, C., Introduction to materials for advanced energy systems - Springer, Chicago, Il, USA ISBN 978-3-319-98001-0, © 2019

Teodoriu, C.; Falcone, G. Comparing completion design in hydrocarbon and geothermal wells: the need to evaluate the integrity of casing connections subject to thermal stresses, Geothermics journal, doi:10.1016/ j.geothermics.2008.11.006, 9 January 2009.

Ungemach, P., Antics M., Anti-Corrosion Well Concept Validated in the Paris Basin, Published July 31, 2018 GDCE18052_press release-v2, https://www.egec.org/anti-corrosion-well-concept-validated-paris-basin/

Wilkes, K.E., Childs, P.W., Thermal Performance of Fiberglass and Cellulose Attic Insulations, Conference on Thermal Performance of the Exterior Envelopes of Buildings V Clearwater Beach, Florida December 7-10, 1992, CONF-921203--3 DE92 040714

Yuan, Y., Goodson, J. Advanced Composite Downhole Applications and HPHT Environmental Challenges 04616 NACE Conference Paper - 2004