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Evaluation of Resin Coated Proppants: A New Custom Method

Ekrem Alagoz[1]*, Yalcin Yaradilmis[1]

[1] *Turkish Petroleum Corporation (TPAO), R&D Department, Sogutozu Nizami Gencevi Street No:10, 06510 Cankaya, Ankara, Turkiye*

INFORMATION

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Contact
*Ekrem Alagoz
ealagoz@tpao.gov.tr

ABSTRACT

Resin Coated Proppants (RCP) type proppants are used to control proppant backflow in hydraulic fracturing operations. Negative effects of the RCP proppants used on the flowback volume and fracturing fluid have been frequently reported by operator companies. It is of great importance to understand how the resin material on which such proppants are coated behaves in during fracturing treatment conditions. In this study, it was investigated whether the resin covering the proppant surface flowed down from the proppant surface during fracturing operations. A new custom experimental method was developed to study resin behavior of RCP type proppants. In this developed method, RCP proppants were pressurized with fracing fluids, and then the changes in proppant size and loss of stickiness were recorded both by observation and by Particle Size Distribution (PSD) analyses. It was observed that the size of the RCP proppants decreased by 1-5% at 250 °F and different exposure times.

1. Introduction

In recent years, hydrocarbon production from unconventional shale formations is among the most important topics in the petroleum industry (Abes et al., 2021; Ifrene et al., 2022; Iroftiet al., 2022). The two most important technologies in production from these formations are directional drilling and hydraulic fracturing. By directional drilling, more surface area is dredged in the hydrocarbon reservoir and more of the horizontally deposited formations can be contained. The second technology, hydraulic fracturing operations, is the cracking of the reservoir rock by pressurizing fracturing fluid with high rate into the well. The conductivity of the shale formations is increased, and cracks are created that enable hydrocarbon flow (Khetib et al., 2023). In this way, oil or gas is produced from wells with respect to the stimulated reservoir volume (SRV).

Reservoir rock cracked by high pressure water during hydraulic fracturing operations and closes again after flowing back. Proppants are used to prevent this closure. The most basic task of proppants is to keep the cracks open by entering between the hydraulic crack's apertures. In this context, there are proppants made from many different materials, in different sizes, and are used according to the conditions of the well. The proppant diameter used varies between 100 mesh and 20 mesh. According to their properties, starting from sand, ceramic proppants or proppants made of bauxite materials can be used.

One type of the proppants used is RCP which is unique in keeping more proppant grains together by providing the adhesive property of the resin coated on them under reservoir conditions. Thus, the proppant crush resistance is greater, which will resist fracture closure stress. This further prevents the cracks from closing. However, it has not been tested how the resin part of the RCP behaves under reservoir conditions, or at least close conditions to reservoir. Testing whether the resin can flow down under a certain temperature and pressure will contribute to the fracturing design of the operator companies before the fracturing treatments.

2. Previous Studies

Researchers have previously studied RCP proppants (Almond et al., 1995; Burke et al., 2012; Letichevskiy et al., 2015; Songire et al., 2019; Alqam et al., 2022) by performing UCS testing. They studied fracturing fluid rheology before and after mixing the RCP to investigate its effect on proppant flow back. The findings vary on different commercial fracturing fluid additives. The difference of this study from the previous ones is that it is a method developed to test whether the resin material flows down and leave the proppant grains itself. Proppants may break and generate fines due to the fracture closure pressure they are exposed to, or they may embed into the fracture surface and cause fracture closure (proppant embedment). Considering multiple mechanisms in unconventional wells, proppants with different properties were used, and tests were carried out according to the characteristics of each (Alagoz, 2020; Alagoz et al., 2020; Alagoz and Sharma, 2021; Alagoz et al., 2022; Yaradilmis and Alagoz, 2022; Alagoz et al., 2023). There is no standard set by the API for testing RCP type proppants (Alqam et al., 2022). Therefore, a new test setup was needed.

3. Experimental Protocol

In order to test the durability of RCP proppants, a protocol was developed to simulate real field conditions (Fig. 1). The protocol consisted of several steps.

3. 1. Preparation of Frac Fluids

The fluids used in real field applications were prepared and added to separate aging cells (Table 1). These fluids were chosen to represent the typical fluids used in hydraulic fracturing operations.

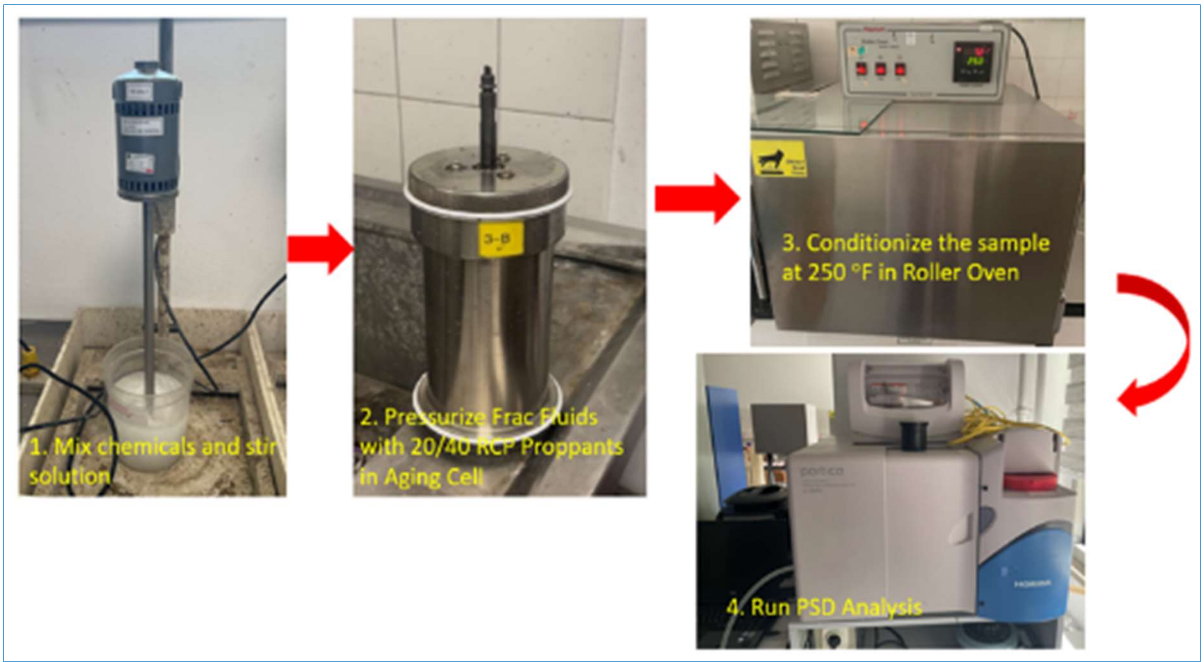

Fig. 1. Experimental setup

Table 1. Typical chemicals used in the experiments

Frac Fluid Additives	Concentration*
Biocide	0.5 gpt
Surfactant	2 gpt
Clay Stabilizer	2 gpt
Friction Reducer	3 gpt

gpt: grams per tons (for ex. 10 gpt is 1%)

3. 2. Addition of Proppants

1 gram per ton (0.1%) of 20/40 RCP ceramic proppants were added to the aging cell filled with the fracturing fluid. This proportion was chosen to represent the typical usage of proppants in hydraulic fracturing operations.

3.3. Pressurization

The mixture of fracturing fluid and proppants was pressurized at different pressures to observe the pressure dependence of the proppant durability.

3.4. Temperature Exposure

The pressurized mixture was exposed to a temperature of 250 °F (121 °C) in a roller oven to simulate the high temperatures experienced during hydraulic fracturing operations.

3. 5. Sample Removal and Drainage

The sample was then removed from the aging cell and the fluids were allowed to drain. The proppants were then patted down with paper to remove any excess fluid.

3.6. Fume Hood Placement

The sample was placed in a fume hood for 25 minutes to observe any proppants that had become stuck together. This step was designed to simulate the conditions under which proppants might become stuck together in a hydraulic fracturing operation.

3.7. Observation and Comparison

The proppants were then observed and compared to samples that had undergone different conditions. This step was designed to determine the durability of the proppants under different conditions.

3.8. PSD Analysis
PSD analysis was conducted on the proppants before and after the tests to determine any changes in the proppant size and distribution.

3. 9. Comparison of PSD Results
The PSD results were then compared to determine if there were any differences in proppant diameter before and after the tests.
Overall, this protocol was designed to simulate real-world hydraulic fracturing conditions and determine the durability of RCP proppants under these conditions. By following this protocol and conducting PSD analysis, researchers can determine if there are any changes in the proppant size and distribution, which can have implications for the effectiveness of hydraulic fracturing operations.

4. Performing Tests and Results
4.1. Observational Test Results
The observational test was performed by taking 1000 mL of fracturing liquid and separating it into three identical samples. Each sample was then mixed with 1 gram per ton (12.08 grams) of 20/40 RCP proppant. The mixture was placed in an Aging Cell and pressurized to 200 psi (1,378,951 Pa). The Aging Cell was then conditioned at 250 °F (121 °C) for 3 hours and 30 minutes in a Roller Oven.

The testing procedure is summarized in Table 2. To observe the durability of the proppant, pictures were taken before and after the test. Fig. 2 and Fig. 3 show these pictures, respectively. By comparing the pictures, any changes in the proppant's appearance, such as aggregation or breaking, can be observed.

Table 2. Testing conditions

Samples	Temperature	Pressure	Duration
Sample-1	250 °F (121 °C)	200 psi (1.3790 MPa)	3.5 hours
Sample-2	250 °F (121 °C)	700 psi (4.8263 MPa)	3.5 hours
Sample-3	250 °F (121 °C)	700 psi (4.8263 MPa)	17 hours

It is important to note that this was an initial test to determine the effect of pressure and temperature on the durability of RCP proppant. Further tests should be performed to determine the proppant's durability under a wider range of conditions. These tests can be used to optimize the use of RCP proppants in hydraulic fracturing operations, ensuring their effectiveness in enhancing oil and gas recovery.

Observations have shown that the RCP proppant samples tend to come together and stick to each other in the wet state when placed on a sieve. This is due to the resin on the proppant, which acts as a binder and helps to hold the particles together. However, the extent to which the resin can perform its job is limited.

After drying the samples in an oven, the bonds that the RCP proppant samples form with each other can be seen more clearly. Fig. 4 provides a visual representation of these bonds, which are formed due to the resin on the proppant. It is important to note that the strength of these bonds can vary depending on the pressure, temperature, and other conditions under which the RCP proppant is used. This can lead to increased oil and gas recovery and reduced costs associated with hydraulic fracturing operations.

Fig. 2. 20/40 RCP proppants before any tests performed

Fig. 3. 20/40 RCP proppants (wet) tested at conditions: 200 psi, 250 °F, 3.5 hours

Sample-2 was tested under more severe conditions, with a pressure of 700 psi (4.8263 MPa) and a temperature of 250 °F (121 °C) for a duration of 3.5 hours. The aim of this test was to investigate the effect of increased pressure on the resin component of the RCP proppant. The closure of fractures during hydraulic fracturing can occur due to various reasons, such as closure stress and production, and high stresses are experienced by proppants as the pressure acting on them increases. Therefore, understanding the pressure dependence of proppant characteristics is important in the context of hydraulic fracturing.

The results of the dry test conducted on Sample-2, which can be seen in Fig. 5, provide valuable insights into the behavior of RCP proppants under high pressure and temperature conditions. Analyzing these results can help researchers optimize the use of RCP proppants in hydraulic fracturing operations by identifying the pressure and temperature ranges that are most effective for enhancing fracture conductivity.

Sample-3 was tested to investigate the time dependence of RCP proppants under high-pressure and high-temperature conditions. The test was conducted at a pressure of 700 psi (4.8263 MPa) and a temperature of 250 °F (121 °C) for 17 hours. The main aim of the test was to determine whether the resin component of RCP proppants would flow down over time, and to observe any changes in the proppant particles. Interestingly, no sticked proppant particles were observed in this test, indicating that the RCP proppant did not lose its integrity or bonding strength even after being exposed to high pressure and temperature for an extended period of time.

Fig. 4. 20/40 RCP proppants (dry) tested at conditions: 200 psi, 250 °F, 3.5 hours

Fig. 5. 20/40 RCP proppants (dry) tested at conditions: 700 psi, 250 °F, 3.5 hours

Fig. 6 provides a close-up picture of the proppant grains after they had dried out, and it can be seen that Sample-3 is the darkest among all tests. It is important to note that the change in color of the proppant grains is not believed to be a result of chemical reactions. Fig. 7 shows the RCP proppant during a field fracturing operation, and it is easily recognizable among other proppants. The comparison of the color of Sample 1-3 is presented in Fig. 8, which provides a useful visual representation of the changes in color over time. These results can be useful in optimizing the use of RCP proppants in hydraulic fracturing operations, by identifying the ideal time and temperature ranges for optimal performance.

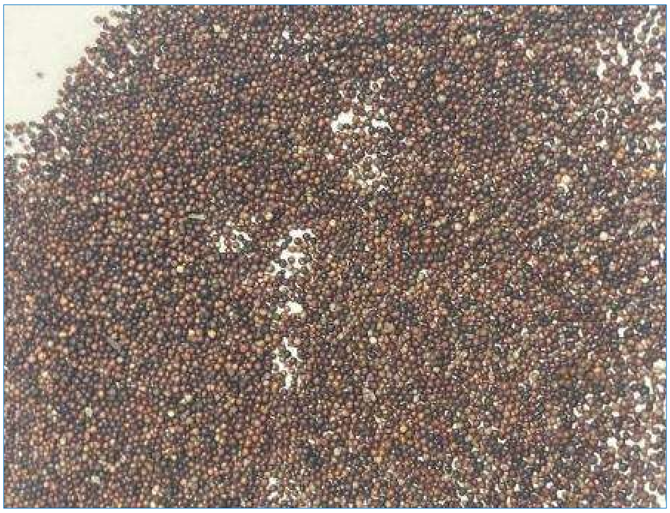

Fig.6. 20/40 RCP proppants (dry) tested at conditions: 700 psi, 250 °F, 17 hours

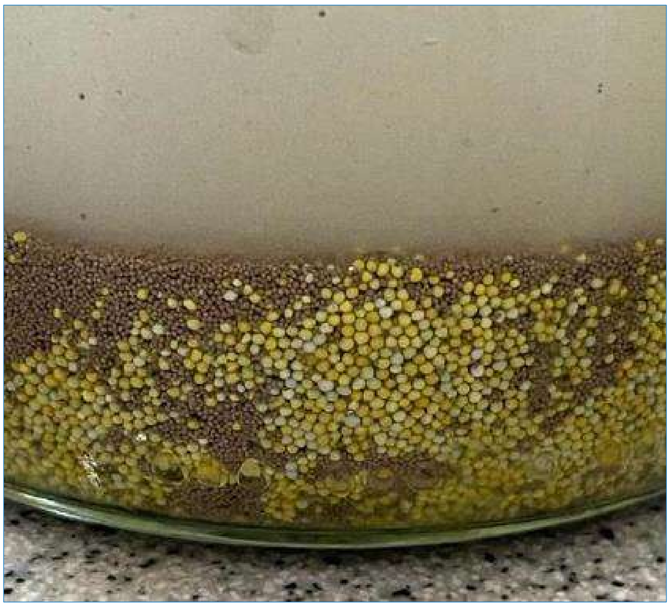

Fig. 7. Fluid sample taken during hydraulic fracturing treatment in the field

In order to accurately quantify the number of sticked proppant grains, a specific selection criteria were established where at least 3 proppant grains were chosen. This means that if only two grains were sticking together, they were not counted and considered. The resulting number of sticked proppant grains was then recorded and presented in Table 3.

This process allowed for a consistent and objective method to quantify the stickiness of the proppants, which is crucial for understanding their performance in the field.

4.2. PSD Test Results

The PSD analysis is a crucial tool used in this study to determine the size distribution of RCP proppants. The PSD analyzer measures the size of the proppants by using the Mie Theory (Mie, 1908), which considers the refraction and transmittance of light around the grain size in the medium. In the study, water is used as a base fluid for the tests, and 12.08 grams of 20/40 size RCP ceramic proppants are added to the fluid. The aim of the analysis is to detect any changes in the size of the proppants before and after the tests.

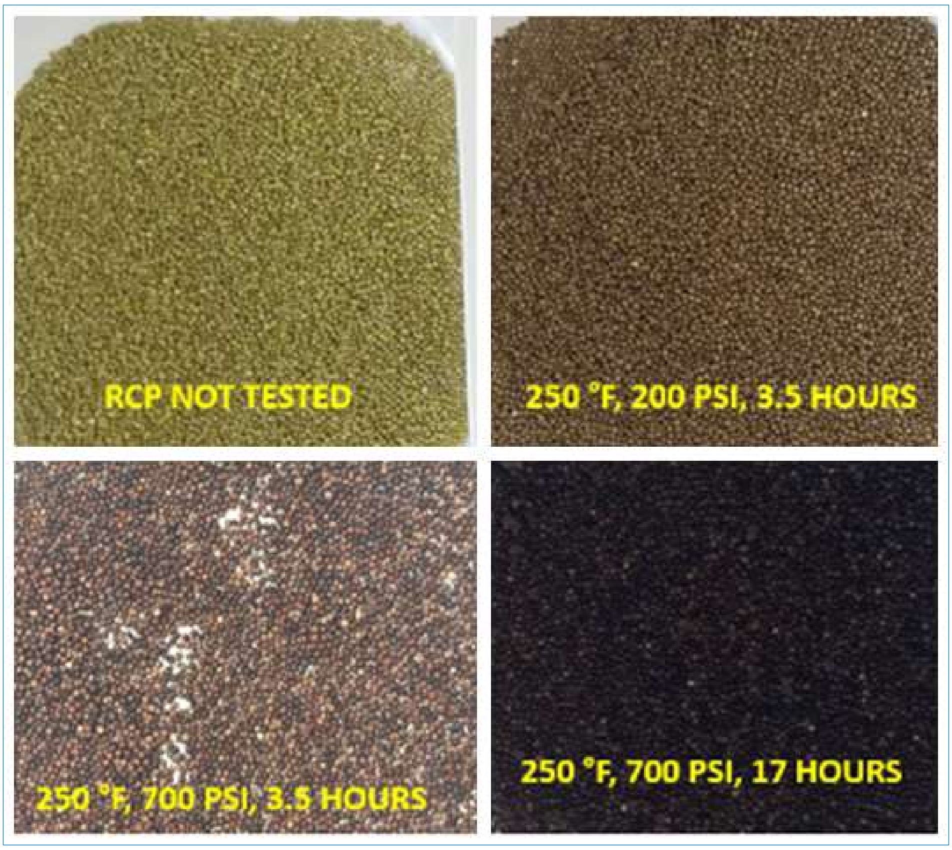

Fig. 8. Comparison among tested samples and original samples

PSD analysis is an effective method of measuring the size distribution of proppants, which is crucial for understanding their performance in hydraulic fracturing operations. The Mie Theory used in the PSD analyzer takes into account the optical properties of the medium, which ensures accurate measurement of the proppant size. By analyzing the size distribution of the RCP proppants before and after the tests, the study aims to identify any changes that may occur in the size of the proppants due to the test conditions.

Table 3. Quantifying proppant pack among samples

Test Names	Conditions	Count
Sample-1	250 °F, 200 psi, 3.5 hours	43
Sample-2	250 °F, 700 psi, 3.5 hours	35
Sample-3	250 °F, 700 psi, 17 hours	0 “zero”

Typical PSD results graph is shown in Fig. 9. Some of the elements can be explained as follows before proceeding the PSD result Interpretation.

4.2.1. Transmittance (R) and (B)

The percentage of the red laser and blue led power passing through the sample. While red laser measures the relatively bigger particles, blue led is more sensitive to smaller particle sizes such as powdered samples.

4.2.2. Refractive Index (R) and (B)

Real and Imaginary refractive index of samples for red and blue light sources. The refractive index of a substance is a coefficient that shows how slowly the light or other electromagnetic waves traveling in that substance travel compared to the light traveling in space.

4.2.3. Ultra Sonic

Controls whether particles can be broken by sound waves. The magnitude of 7 is used to check for RCP proppants in these tests.

The study aimed to determine how the conditioning process affected the resistance of RCP proppants. To measure this, the median dimensions of the proppants were analyzed using a PSD device, and ultrasonic sound waves with a magnitude of 7 were applied. The amount of diameter reduction was taken as an indicator of the weakening of the proppants' strength.

The results, presented in Table 4, Column 3, showed that Sample 3 had the highest diameter reduction compared to the other samples. This indicates that the 700 psi (4.8263 MPa) and 17 hours conditioning conditions caused the most significant weakening of the proppants' strength. Overall, the study highlights the importance of considering the effects of conditioning on the performance of RCP proppants in hydraulic fracturing operations.

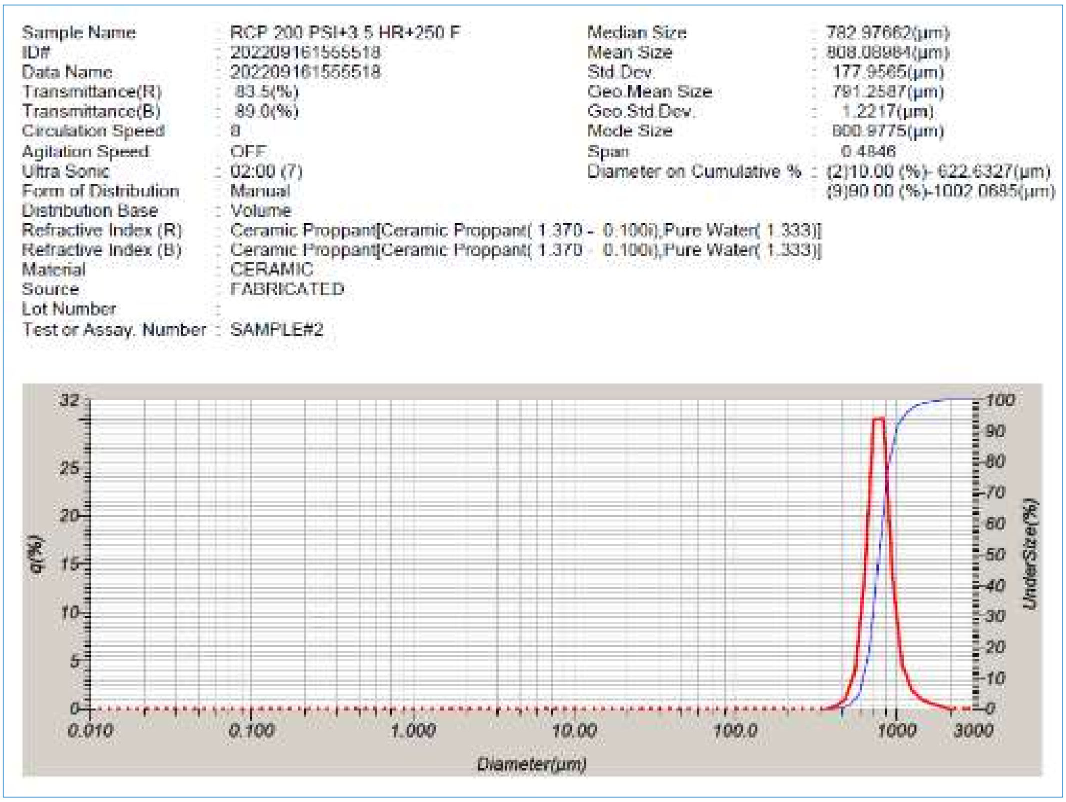

Fig. 9. Sample results of PSD analyzer

Table 4. PSD test results

Test Names	Conditions	Effect of ultrasonic waves (%)
RCP sample	Not Tested	0.10
Sample-2	250 °F, 200 psi, 3.5 hours	0.65
Sample-2	250 °F, 700 psi, 3.5 hours	0.20
Sample-3	250 °F, 700 psi, 17 hours	4.01

5. Conclusion

An experimental protocol was established to study resin durability of RCP Proppants. This protocol involves preparing fracturing fluid composition, exact recipe used in the field, pressurize the fluid with initial proppant loading 0.5 ppg (59.91 kg/m^3) and expose the sample in the oven at 250 °F temperature for various time schedule. The method allows us to observe the bond of RCP proppants and weight loss percentage of those proppants. These outputs give us an idea of how much of the RCP works in the reservoir conditions.

Test results show that:

RCP ceramic proppants has not been durable in all testing conditions. Generally, RCP lost 5% of its weight after 17 hours exposed to the 250 °F.

Temperature dependence has not been investigated as the RCP samples used in these experiments has the limit for that. Any temperature above 250 °F will damage proppant itself. Considering the Sample-1 observational results, temperature kept constant.

During the tests, pressure has not been increased after 700 psi. The reason for that is Sample-3 has shown no sticked proppant grains and no harsher conditions is needed to test RCP ceramic proppants.

The color of proppant particles gets darker when the conditions becomes harsh.

Sound waves tests through PSD showed that RCP proppant strength will experience 0-5 % reduction while exposed by pressure and temperature.

Proposed designed tests can be modified at any given field conditions and proppant type.

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