YIDDISH Vol 11 Issue 03,July 2021
ISSN NO: 0364-4308

An example of the casing of a shale gas well collapsing during volume fracturing

B Mahesh[1], N.Siva Prasad[2],
Assistant Professor [1,2],
Mail Id : bitraguntamaheshkumar@gmail.com, sivaprasad.n@visvodayata.ac.in,
Department of Mathematics,
PBR VISVODAYA INSTITUTE OF TECHNOLOGY AND SCIENCE,KAVALI.

Abstract

Normal completion stimulations are rendered difficult during the volumetric fracturing operation of shale gas due to a high rate of casing failures. This article presents studies using numerical simulation and rock mechanics to tackle this challenge. It is discovered that the macroscopic mechanical strength of the rock in the Longmaxi Formation decreases most at a crack angle of 45 and steadily decreases to 8 fractures. Based on the elasticity modulus ratio, yield strength ratio, and compressive strength ratio—0.70, 0.71, and 0.68, respectively—this paper develops the shale gas well X201 finite element model. Subsequently, during the fracturing process, the secondary development achieves the dynamic modification of the rock mechanical characteristics. By contrasting the simulated computation of casing deformation with the field multi-arm caliper logging data, the accuracy of the model and approach used in the article is confirmed. The process of casing failure is elucidated, furnishing a theoretical foundation for averting casing failure resulting from hydraulic fracturing.

Keywords: multi-arm caliper logging, finite element analysis, secondary development, shale gas fracturing, and casing failure.

Introduction

Volume fracturing is a new technology that can ‘‘shatter’’ the reservoir, form complex crack networks, and create ‘‘artificial’’ permeability. Crack initiation in the technology is realized by shearing, breaking, and slipping. This technology breaks through the traditional mode of crack percolation theory and significantly shortens fluid flow distance. It has stimulated unconventional oil and gas production greatly and been widely applied to the transformation of rock layer with higher brittleness. Meanwhile, it adopts the staged multi-cluster perforation.1 The proposal of ‘‘volume transformation technology’’ subverts the classic fracturing theory.[2]

Compared to conventional fracturing, volume fracturing is characterized by excessive stimulated stages, large fracturing volume, and high injection capacity inthe operation process. The technique breaks up reservoirs into pieces and forms complicated fracture networks, which degrades the mechanical properties offormation rock much larger than the convention fracturing. There will exist complicated mechanical behaviours such as shear, leap, and slip around the casing string, which makes casing more prone to failure. In the development of China shale gas, frequent collapses and deformations of casing prevent the bridge plug from setting in the very place. The effect of fracturing operation is mitigated as a result, and the running of subsequent tools gets harder. Along with it, construction costs are increased and the construction becomes tougher, making it difficult to ensure the wellbore integrity of gas well and bringing a big risk for subsequent production operations.[1,3–8]

In order to reveal the mechanism of casing failure in the volume fracturing process, this article analyzes the typical well X201 with casing failure in the ChangningWeiyuan national demonstration zone of shale gas. Through a large number of rock mechanical experiments and numerical simulation experiments, the effect of crack angle and crack number on rock mechanical properties and its effect on casing failure in the volume fracturing process are studied. Moreover, a comparative analysis is conducted with the field multi-arm caliper imaging tool (MIT) logging curve of casing failure section in X201 well.

Analysis on the change of rock mechanical properties during volume fracturing

Basic data of X201 well

Located in Yibin, Sichuan Province, X201 is in the east wing of the top Middle Ordovician Shangluochang nose uplift in Changning anticline structure. The target layer is a part of Long maxi Formation in Silurian.

X201 is a vertical shale gas well with measured depth (MD) of 2542 m. Completion is conducted with F139.7 mm 3 L10.54 mm casing with steel grade P110. IBC (Isolation Scanner, post-casing imager) cementing quality evaluation is good without significant channelling. According to logging data, elasticity modulus of the formation is 13–46 GPa, and average Poisson's ratio is 0.23 at 2200–2550 m; the minimum horizontal stress is 45–50MPa, and the maximum horizontal stress is 50–70MPa, as shown in Figure 1.

Volume transformations are conducted twice at 2400– 2525 m in the well. The fracturing fluid is injected directly into the formation through the casing, and the two-stagedamount is 1953.5 and 1239.9 m3 , respectively. The detailed fracturing parameters are shown in Table 1.

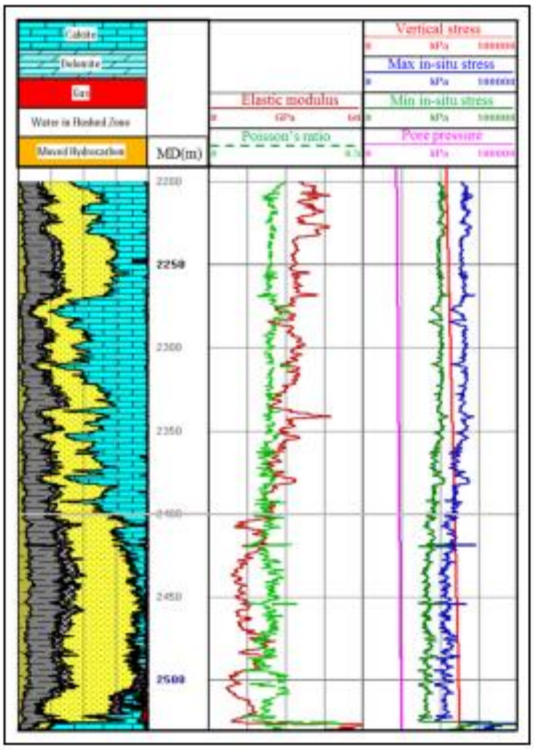

Figure 1. Interpretation of rock mechanical parameters and in-situ stresses in X201.

Sticking occurs when the gauge tool (F114 mm) is run to make a wiper trip at 2441.6 m after two fracturing operations. Then, casing deformation failure may have occurred. MIT logging is subsequently conducted to perform an accurate inspection of the inside of casing, and it is found that serious casing deformation occurs near 2441 m. Casing deformation cannot be effectively prevented by simply increasing steel grade and wall thickness. It is initially thought that casing deformation failure may be caused by the degradation of fissured rock mechanical properties and the redistribution of near-well gestures field after the volume fracturing.

Fissured rock theory Volume fracturing is to form the previous relatively intact rock in certain volume area into fissured rock withmany multiple directional cracks, which changes the macroscopic mechanical properties. According to the related theories of fracture mechanics and several fracture criteria,9,10 rock damage is characterized by the progressive degradation of rock mechanical properties, leading to material failure. The critical stress criterion of rock damage can be represented as given in equation (1)

$$\left\{\frac{\sigma_n}{\sigma_n^{\max}}\right\}^2+\left\{\frac{\sigma_s}{\sigma_s^{\max}}\right\}^2+\left\{\frac{\sigma_t}{\sigma_t^{\max}}\right\}^2=1 \qquad (1)$$

Rock damage is assumed to initiate when the maximum nominal stress ratio (as defined in the expression above) reaches a value of 1.

 Vol 11 Issue 03,July 2021
ISSN NO: 0364-4308

A scalar damage variable, d, represents the overall damage in the material. It initially has a value of 0. If rock damage evolution is modelled, d monotonically evolves from 0 to 1 upon further loading after the initiation of damage. The elasticity modulus and compressive strength are affected by the damage according to equations (2) and (3).

The linear degradation criterion of elasticity modulus is

$$E = (1 - d) \times E_0 \qquad (2)$$

The linear degradation criterion of compressive strength is

$$\sigma_c = (1 - d) \times \sigma_{c0} \qquad (3)$$

The formula to calculate the damage factor d is

$$d = \frac{\delta_m^f \times (\delta_m^{\max} - \delta_m^0)}{\delta_m^{\max} \times (\delta_m^f - \delta_m^0)} \qquad (4)$$

From equations (1)–(4), it is shown that rock is continuously damaged due to new cracks formed infissured rock during the volume fracturing process, resulting in such mechanical properties' degradation as the elasticity modulus, compressive strength, and so on. However, the complexity of fracture networks formed by volume fracturing makes it hard to obtain relative damage parameters. Hence, there is no quantitative representation model for mechanical properties' degradation. In order to solve this problem, this article carried out rock mechanical experiments, aiming at the Long maxi Formation where casing failure occurred frequently. Macroscopic numerical simulations based on Voronoi diagram were also conducted to analyze the change law of macroscopic mechanical properties during volume fracturing process.

Study on the change of fissured rock mechanical properties after volume fracturing

Volume fracturing aims to increase the transformation volume of shale gas reservoirs to the utmost extent and to form more complex crack networks. It significantly increases flow conductivity of reservoirs on one hand and divides the intact rock before fracturing into several small portions on the other. Mechanical properties, including elasticity modulus and strength, varied after fracturing and the original mechanical condition of casings changed. This article aims to study the effect of the formation with complex crack network on rock mechanical properties in the volume fracturing process. Therefore, the model was established with macroscopic numerical simulation method based on the Voronoi diagram. The quantitative relationship of the effect of different crack angles and the number of rock mechanical properties was analyzed.[3,11–16]

Effect of crack angle on the rock mechanical properties. Cracks with different angles are formed in the rock in the volume fracturing process. To obtain the effect of crack with different angles on rock mechanical properties, the finite element (FE) model was established, as shown in Figure 3. The numerical experiments of the effect of a single crack under different angles on rock mechanical properties were conducted. Wherein areas of different colours are randomly generated Voronoi diagrams, representing different particle regions in the rock whose elasticity modulus, Poisson's ratio, cohesion, and internal friction angle are 22645MPa, 0.22, 15MPa, and 43, respectively (as obtained in the triaxial compression experiment above). The FE model is a square (a= 100 mm) and the crack is 25 mm long. The bottom AB is constrained, and the confining pressure st is set as 53MPa. Load (pc= 300MPa) is imposed on the top edge with linear loading of 100 steps.

Vol 11 Issue 03,July 2021
ISSN NO: 0364-4308

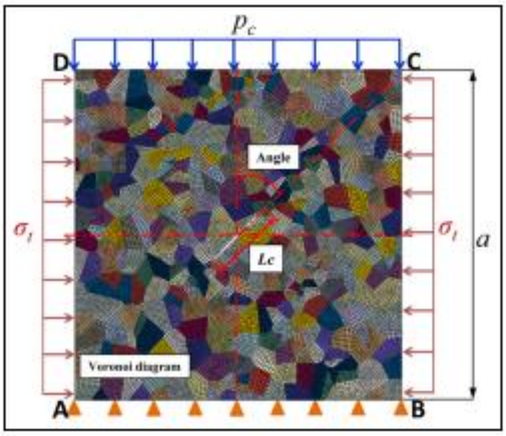

Figure 3. Finite element model of crack angle on rock mechanical properties.

According to the FE model shown in Figure 3, numerical simulation experiments for different crack angle u (0°, 15°, 30°, 45°, 60°, 75°, and 90°) were conducted, respectively, with the same method of data extraction as the triaxial compression experiment. The engineering stress–stain curves with different crack angles are shown in Figure 4, where the vertical axis represents stress (stress=pc) and the horizontal axis represents strain (strain=Dd/d).

From Figure 4, it can be known that there are three stages in the failure process of rock mass: elasticity stage, yield stage, and failure stage. Compared to the results of triaxial compression test in Figure 2, the stress–stain curve of numerical simulations without cracks in Figure 4 is the same as that of the test basically. When the single crack in the rock is $L_c$long, there is varying change of stress–strain curves in different degrees. When u equals 90°, the stress–strain curve substantially coincides with the one without cracks, indicating that the crack basically does not influence the rock strength. When 0 is 0°, the stress–strain curve is slightly lower than that without cracks and has a smaller amplitude of variation by contrast. When u is 45°, the stress–strain curve drops most drastically compared to that without cracks, indicating minimum rock strength. When u is other value, the stress–stain curve for a single crack is between that without cracks and the one when u is 45°.

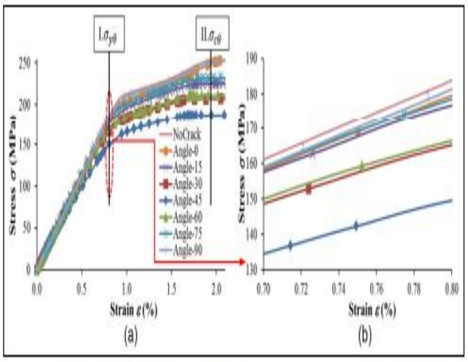

Figure 4. Stress-strain curves of rock under different crack dip angles: (a) stress-strain curve and (b) yield strength.

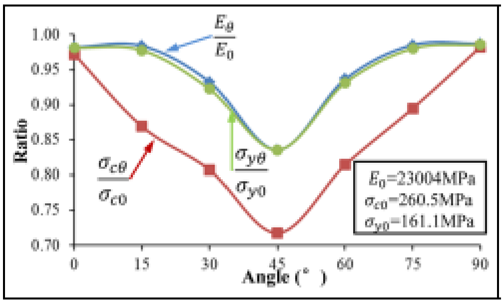

Figure 5. Curve of crack dip angle on rock mechanical properties.

similar trend, and the variation amplitude of compressive strength is the most obvious. When the crack angle u is 45°, the ratios of elasticity modulus, yield strength, and compressive strength show a minimum value. They are 0.84, 0.83, and 0.72, respectively. This shows a significant effect of crack angle on the rock mechanical properties. Comparison with the previous researches verifies the reliability and accuracy of the established FE model.[11,15]

Effect of the number of crack on the rock mechanical properties. Many cracks are formed in the rock mass in the volume fracturing process. In order to obtain the effect of the crack number on the rock mechanical properties, the ultimate minimum strength of fissured rock based on the study of the single crack was studied. The numerical experimental model for the rock mass with multiple cracks at the angle u of 45 was established, as shown in Figure 6.

The material mechanical parameters, crack attribution, boundary conditions, and loads are the same with that of the FE model in Figure 3. Numerical simulation experiments for cracks with different number n (1, 2, 3, 4, 5, 6, 7, 8, 9, 16, 32, and 64) were conducted, respectively, and stress–stain curves with different cracknumbers are shown in Figure 7. The symbols syn and scn are the variables depended on the crack number n, representing the yield strength and the compressive strength with different crack numbers. Through the comparative analysis, the stress–stain curves show varying degrees of reduction as the crack number increases. The stress–stain curve of the rock mass is significantly lower when n is 2 than that when n is 1, indicating a great amplitude vibration. The stress–stain curve keeps a lower level when n is 3; however, the amplitude is smaller than before. When n is more than 8, the stress–strain curve substantially coincides, indicating basically no change in rock strength. The rock strength is reduced to the limit. When n is 64, the yield strength syn and the compressive strength scn are close to 115.7 and 176.7MPa, respectively.

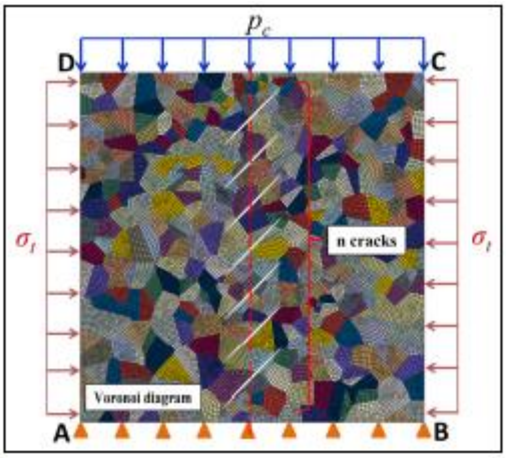

Figure 6. Finite element model of crack number on rock mechanical properties.

Conclusion

In this article, aiming at the effect of complex crack networks on rock mechanical properties in the volume fracturing process, the model was established with macroscopic numerical simulation method based on the Voronoi diagram, and the quantitative relationship of the effect of different crack angles and the number of rock mechanical properties was analyzed.

Through a large number of rock mechanical experiments and numerical experiments, this article obtained the quantitative relation between the macroscopic mechanical strength of rock and the macroscopic characteristics of crack in fissured rock mass. It is found that rock mechanical properties reduce most when the angle of single crack in Longmaxi Formation is 45; rock mechanical strength tends to be stable when the crack number is more than 8. The numerical simulation for casing failure during the volume fracturing was conducted, and the obtained mechanism of casing failure is elliptical deformation of casing section. Oversize ovality leads to sticking of subsequent run tools. Comparison with the field MIT logging data verifies the effectiveness of the method used in this article and the accuracy of calculations.

Increasing wall thickness is more effective to improve the resistance to ovality than increasing steel grade. In addition, the reasonable spacing design of volume fracturing can also help solve casing deformation failure.

References

1. Lian Z, Yu H, Lin T, et al.A study on casing deformation failure during multi-stage hydraulic fracturing for the stimulated reservoir volume of horizontal shale wells. J Nat Gas SciEng 2015; 23: 538–546.

2. Wang H, Liao X and Ding H. Monitoring and evaluating the volume fracturing effect of horizontal well. J Nat Gas SciEng 2015; 22: 498–502.

3. Chen Z, Wang Z and Zeng H. Status quo and prospect of staged fracturing technique in horizontal wells. Nat Gas Ind 2007; 27: 78–80.

4. Hossain MM, Rahman MK and Rahman SS. Volumetric growth and hydraulic conductivity of naturally fractured reservoirs during hydraulic fracturing: a case study using Australian conditions. In: Proceedings of the SPE annual technical conference and exhibition, Dallas, TX, 1–4 October 2000, paper no. SPE 63173.Moskva, Russia: SPE.

5. Tang Y, Wang G, Li Z, et al. Practice and understanding on multiple crack volume fracturing in open hole horizontal well section of Zone Su53. Oil Drill Prod Technol 2013; 35: 63–67.

6. Yang Q, Liu H, Yan J, et al. Multi-Stage horizontal fracturing in casing for low permeability reservoirs. In: Proceedings of the SPE Asia Pacific oil and gas conference and exhibition, Jakarta, Indonesia, 22–24 October 2013, paper no. SPE 166671.Moskva, Russia: SPE.

7. Yu H, Lian Z and Lin T. Finite element analysis of failure mechanism of casing during shale gas fracturing. China Petrol Mach 2014; 42: 84–88.

8. Brantley SL, Yoxtheimer D, Arjmand S, et al. Water resource impacts during unconventional shale gas development: the Pennsylvania experience. Int J Coal Geol 2014; 126: 140–156.

9. Camanho P and Davila D. Mixed-mode decohesion finite elements for the simulation of delamination in composite materials. Report NASA/TM-2002-211737, June 2002, pp.1–37. Washington, DC: National Aeronautics and Space Administration.

10. Turon A, Camanho P, Costa J, et al. A damage model for the simulation of delamination in advanced composites under variable-mode loading.Mech Mater 2006; 38: 1072–1089.

11. Li Y and Yao C. Simulation of rocks containing two coplanar numerical fissures under uniaxial compression non-persistent. Water Resour Power 2014; 32: 127–130.

12. Yao C, Jiang Q, Shao J, et al. A mesoscopic numerical model for simulation of rock fracturing. Chin J Rock MechEng 2013; 32(Suppl. 2): 3146–3153.

13. Ghazvinian E, Diederichs M and Quey R. 3D random Voronoi grain-based models for simulation of brittle rock damage and fabric-guided micro-fracturing. J Rock MechGeotechEng 2014; 6: 506–521.

14. Liu C, Liu H, Zhang Y, et al. Optimal spacing of staged fracturing in horizontal shale-gas well. J Petrol SciEng 2015; 132: 86–93.

15. Yao C, Li Y, Jiang Q, et al. Mesoscopic model of failure process of interlayered rock under compression. Chin J Rock MechEng 2015; 34: 1–10.

16. Zhang D, Zhang L, Guo J, et al. Research on the production performance of multistage fractured horizontal well in shale gas reservoir. J Nat Gas SciEng 2015; 26: 279–289.