Review History for "Proppant-Induced Opening of Hydraulically Created Fractures"

A.P.S. Selvadurai *2019*

Review Round 1

Reviewer A

It is not clear what problem the authors are actually solving since the boundary conditions do not look correct to me. Indeed, the proppant area is assumed to be under compressive load. Yes it is, but it is irrelevant since the proppant is assumed infinitely stiff, otherwise its elastic parameters will be introduced. Then the obvious boundary condition, assuming that the proppant part of the crack is just sitting on the proppant, would be the displacement discontinuity equal to the proppant thickness. In other words the object considered does not seem to be a crack despite the reference to Griffiths crack.

The manuscript presents a solution of some problem which does not seem to be relevant to the hydraulic fracture field. I cannot recommend the manuscript for publication.

Reviewer B

This is a very well articulated work, attempting to unify several aspects of the hydraulic fracturing process. To my knowledge it is the first time that a model is suggested to capture fracture generation in the presence of suspended particle-rich fluids as well as the interaction between proppants and rock formation. The authors provide analytical solutions to the formulated problems, the manuscript is easy to follow and the results are extremely useful for the community. I suggest accepting the manuscript as it is. My only criticism, if I had to have one, is that the introduction is a bit too long in its present form. Maybe the authors could consider reducing it and relegating all the information in the rest of the sections? But again, this is really minor and a matter of taste. The work is solid, round, and very well presented.

Reviewer C

In this paper, the author(s) obtain an elegant analytical solution for the equilibrium length of a Griffith crack remotely subjected to uniform compressive normal stress and supported by a rigid rectangular inclusion. Based on the analytical solution, a closed-form formula is obtained for the length of the "zone of separation" on either end of the inclusion. The author(s) provide a well-written and in-depth discussion on the practical applications of the investigated problem towards the modelling of partially-propped hydraulic fractures. Before the paper can be accepted for publication, the author(s) must modify the manuscript adequately to address the following comments:

1) Can the author(s) comment on the influence of the “zone of separation” on the increase in oil or gas production at the wellbore? Is this a marginal or substantial effect?

2) The similar problem was examined using the distributed dislocation technique in the following paper:

Khanna et al (2014) Effect of residual opening on the inflow performance of a hydraulic fracture. Int J Eng Sci, 74:80-90.

Can the author(s) provide any comparison of their analytical solution against the semi-analytical solution obtained in the above paper? The authors might also find the above paper helpful when addressing comment (1).

3) p. 5 line 90-99: It is worth mentioning that the approach developed by author(s) and other contributors was also extended in the following paper:

Kotousov et al (2014) On a rigid inclusion pressed between two elastic half spaces. Mech Material, 68: 38-44.

4) On p. 6, lines 125-126, the author(s) mention that the effect of proppant consolidation on the opening of partially-filled fractures has not been investigated previously in the literature. The authors must amend this text and discuss recent developments in this area, including the importance of this problem towards the Channel Fracturing technology. Some recent examples include:

Bortolan Neto et al. (2015) Conductivity and performance of hydraulic fractures partially filled with compressible proppant packs. Int J Rock Mech Mining Sci, 74:1-9.

Khanna et al. (2017) Residual opening of hydraulic fractures created using the channel fracturing technique. Int J Rock Mech Mining Sci, 100:124-137.

Khanna et al. (2018) On the Application of the Channel-Fracturing Technique to Soft Rock Formations. SPE J (pre-print). doi: 10.2118/194202-PA

5) Experimental studies utilising typical rock and proppant combinations have demonstrated that the depth of proppant embedment in the rock can be comparable to the particle diameter. The author(s) should deeply discuss the validity of Eq. (26) in the situation when the proppant embedment effect is significant, and also when the proppant pack comprises of multiple layers rather than a single layer.

6) p. 13, Conclusion section: the author(s) must further discuss how their new analytical solution contributes towards the existing body of research in this area. They can refer to the papers mentioned in this review, as well as references within those papers.

Author’s Response

To Reviewer A

The reviewer seems to make some comments, which are difficult to decipher.

1. The manuscript is not presenting the “...solution to some problem”. It presents a solution to a specific problem involving the interaction between the elastic media and the proppant that leads to a separation zone that is determined through the solution to mixed boundary value problems in plane strain elasticity.

2. The halfspaces simply do not sit on the proppant; the interaction between the proppant and the compressed elastic halfspace regions results in a separation zone the dimensions of which are unknown and needs to be determined through the analysis of the mixed boundary value problems.

3. The caption of Figure 1 refers to a Griffith crack, is perhaps misleading and the author has corrected this inconsistency. In the revised version, this is replaced by a ...”planar separation zone”, which conveys the correct terminology.

To Reviewer B

The author appreciates the very positive comments of the reviewer and with his/her permission would like to retain the introduction in the present form to preserve the continuity of the presentation. Also, a number of papers that have recently appeared in the literature, notably by newcomers to the field, seems to be completely ignorant of the important work done by leading researchers at the start of this research area. The purpose of the lengthy introduction is to set the record straight.

To Reviewer C

The author appreciates the very positive comments of the reviewer and for drawing attention to the additional references, which are relevant and informative.

Before the paper can be accepted for publication, the author(s) must modify the manuscript adequately to address the following comments:

Reviewer's comment C1

1) Can the author(s) comment on the influence of the "zone of separation" on the increase in oil or gas production at the wellbore? Is this a marginal or substantial effect?

Author's reply C1

This is an important question and relevant from the point of view of the rationale for initiating hydraulic fracture and maintaining the fracture in an open condition through the use of proppants. The oil or gas production is related to the aperture width, which can vary with the position along the aperture. The techniques for estimating the effective fluid conductivity in variable aperture settings have been dealt in the literature and these references are included.

Reviewer's comment C2

2) The similar problem was examined using the distributed dislocation technique in the following paper:

Khanna et al (2014) Effect of residual opening on the inflow performance of a hydraulic fracture. Int J Eng Sci, 74:80-90.

Can the author(s) provide any comparison of their analytical solution against the semi-analytical solution obtained in the above paper? The authors might also find the above paper helpful when addressing comment (1).

Author's reply C2

The article cited by the reviewer is germane to the scope of the paper and hence added to the list of references. An extensive comparison between the results of the elementary approach proposed in the paper and the semi-analytical approach proposed in the additional references is should be relegated to a separate study.

Reviewer's comment C3

3) p. 5 line 90-99: It is worth mentioning that the approach developed by author(s) and other contributors was also extended in the following paper:

Kotousov et al (2014) On a rigid inclusion pressed between two elastic half spaces. Mech Material, 68: 38-44.

Author's reply C3

The reference has been included since it contains citations to other useful articles.

Reviewer's comment C4

4) On p. 6, lines 125-126, the author(s) mention that the effect of proppant consolidation on the opening of partially-filled fractures has not been investigated previously in the literature. The authors must amend this text and discuss recent developments in this area, including the importance of this problem towards the Channel Fracturing technology. One recent example is:

Bortolan Neto et al. (2015) Conductivity and performance of hydraulic fractures partially filled with compressible proppant packs. Int J Rock Mech Mining Sci, 74:1-9.

Author's reply C4

The comment has been amended and the reference is included

Reviewer's comment C5

5) Experimental studies utilising typical rock and proppant combinations have demonstrated that the depth of proppant embedment in the rock can be comparable to the particle diameter. The author(s) should deeply discuss the validity of Eq. (26) in the situation when the proppant embedment effect is significant, and also when the proppant pack comprises of multiple layers rather than a single layer.

Author's reply C5

In the study presented, the author considers a relatively elementary problem of a a fracture being generated in a single medium. The extension of the methodology to include multiple layers is best addressed through the modelling of the domain either as a layered medium or a transversely isotropic elastic medium. Such extensions are possible but best left for future investigations.

Reviewer's comment C6

6) p. 13, Conclusion section: the author(s) must further discuss how their new analytical solution contributes towards the existing body of research in this area. They can refer to the papers mentioned in this review, as well as references within those papers.

Author's reply C6

The new analytical study gives a compact result that takes into account, the governing stress state, the development of a separation region, the effective dimensions of the granular proppant and the failure strength of a grain. These aspects have not been addressed in the literature and should provide a suitable additional dimension to the study of the proppant fracture interaction problem. This comment is included in the revisions.

Review Round 2

Reviewer A

1) It is still not clear what problem the authors are actually solving. The Abstract says that "The paper examines the problem of the open configuration created when a hydraulic fracture fluid containing a granular proppant is introduced into the fracture." This means that the authors consider the stage of fracture development.

2) The fracture obviously produced by the internal pressure, so it is this pressure which opens the crack. Proppant my not even be in contact with the crack faces at this stage. The stage of contact of proppant and crack surfaces is the stage of removal the fracturing fluid, that is the beginning of the (e.g. petroleum) production stage. In this case the fracture gets closed by the external (in situ) compression. So where is this compression in the model proposed? In reality it is the magnitude of the compression which determines the contact. By the way, the contact which does not have to be continuous contrary to what assumed by the model. Furthermore, the separation zone is obviously due to the proppant particle size preventing the particles to come close to the crack tip rather than the proppant failure stress.

3) The authors assume that the proppant area is in the failure state simultaneously everywhere. Is this realistic?

The actual model is presented is equations (18) - (26). The rest is a selective retelling of fracture mechanics textbooks, which makes one wonder what the reason for this was.

In the reviewer's opinion the manuscript:

1) Confuses different stages of hydraulic fracturing.

2) Misses the crucial player - the in-situ compression.

3) Proposes a model which is irrelevant to reality as the mechanism of creation of the separation zone is different.

4) The assumption of uniform proppant fracturing is too strong. In reality the proppant may not fracture at all, at least this is how the particles are selected as proppant fracturing reduces production.

5) Half of the manuscript is filled with textbook matter, sometimes irrelevant.

I cannot recommend the manuscript for publication.

Reviewer C

Reviewer's comment C5

5) Experimental studies utilising typical rock and proppant combinations have demonstrated that the depth of proppant embedment in the rock can be comparable to the particle diameter. The author(s) should deeply discuss the validity of Eq. (26) in the situation when the proppant embedment effect is significant, and also when the proppant pack comprises of multiple layers rather than a single layer.

Author's reply C5

In the study presented, the author considers a relatively elementary problem of a a fracture being generated in a single medium. The extension of the methodology to include multiple layers is best addressed through the modelling of the domain either as a layered medium or a transversely isotropic elastic medium. Such extensions are possible but best left for future investigations.

Response to author comment on C5

In the above, my intention was not for the authors to examine (or discuss) the more complicated problem involving multilayered or transversely isotropic rock. I was referring to the inadequacy of Eq. (26), which only considers one of three dominant mechanisms of loss of fracture opening. The first mechanism, as correctly identified by the author, is the crushing of the proppant. The second mechanism, which was ignored in this study, is the localised crushing of the rock at the contact zone (i.e. inelastic indentation of the rock by the proppant particles). Finally, third mechanism, also ignored, is the rearrangement and tighter packing of the proppant particles between the fracture walls. The author assumes a so-called "proppant monolayer" rather than a "proppant pack – comprising of multiple proppant layers". The mechanisms of proppant "embedment" and proppant pack consolidation are entirely ignored in the paper, despite the detailed introduction section. My suggestion to clearly state something like Eq. (26) describes only one of many mechanisms of fracture closure and is only valid when there is a proppant monolayer and the strength of the rock is far greater than the strength of the proppant. Of course, the author can use a more refined language to discuss this matter.

Author's Response

I have included a comment in the concluding remarks to address the request of reviewer 3.