Experimental study on repair of fractured rock mass by microbial induction technology

Rugao Gao, Yilin Luo and Hongwei Deng

Article citation details
R. Soc. open sci. 6: 191318.
http://dx.doi.org/10.1098/rsos.191318

Review timeline
Original submission: 31 July 2019
Revised submission: 25 October 2019
Final acceptance: 29 October 2019

Review History
RSOS-191318.R0 (Original submission)

Review form: Reviewer 1

Is the manuscript scientifically sound in its present form?
Yes

Are the interpretations and conclusions justified by the results?
Yes

Is the language acceptable?
Yes

Do you have any ethical concerns with this paper?
No

Have you any concerns about statistical analyses in this paper?
No
Recommendation?
Accept with minor revision (please list in comments)

Comments to the Author(s)
Article deals with an important issue of repairing fractured rocks by using Bacillus pasteurii composites. The repairing effect of microbial materials on fractured sandstone is analysed by means of nuclear magnetic resonance (NMR) and unconfined compression-shearing equipment. Authors were successful in using the analytical and testing methods. However, some comments need to be rectified:
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2. Please include error bars in Figures 5, 7 and 8.
3. In section 4 (Mechanism of MICP repairing fractured rock), please extend the discussion and explain more on the influence of calcium carbonate and its presence in the cemented sand.
4. Please make the annotation on SEM images clearer. Text in the images are barely read.
5. Manuscript needs proofreading. Some grammar mistakes were detected.

I would like to recommend this article for publication after authors rectify the previous comments.

Review form:Reviewer 2

Is the manuscript scientifically sound in its present form?
Yes

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Yes

Is the language acceptable?
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Do you have any ethical concerns with this paper?
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Recommendation?
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This research on MICP technology is detailed and meaningful. By combining the analysis of microstructure features with macroscopic performance, the authors present reliable results. Therefore, I suggest that this article be accepted for publication.
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6. The conclusion can be appropriately streamlined.

Decision letter (RSOS-191318.R0)

22-Oct-2019

Dear Dr Gao,

On behalf of the Editors, I am pleased to inform you that your Manuscript RSOS-191318 entitled “Experimental Study on Repair of Fractured Rock Mass by Microbial Induction Technology” has been accepted for publication in Royal Society Open Science subject to minor revision in accordance with the referee suggestions. Please find the referees' comments at the end of this email.

The reviewers and handling editors have recommended publication, but also suggest some minor revisions to your manuscript. Therefore, I invite you to respond to the comments and revise your manuscript.

• Ethics statement
If your study uses humans or animals please include details of the ethical approval received, including the name of the committee that granted approval. For human studies please also detail whether informed consent was obtained. For field studies on animals please include details of all permissions, licences and/or approvals granted to carry out the fieldwork.

• Data accessibility
It is a condition of publication that all supporting data are made available either as supplementary information or preferably in a suitable permanent repository. The data accessibility section should state where the article's supporting data can be accessed. This section should also include details, where possible of where to access other relevant research materials such as statistical tools, protocols, software etc can be accessed. If the data has been deposited in
an external repository this section should list the database, accession number and link to the DOI for all data from the article that has been made publicly available. Data sets that have been deposited in an external repository and have a DOI should also be appropriately cited in the manuscript and included in the reference list.

If you wish to submit your supporting data or code to Dryad (http://datadryad.org/), or modify your current submission to dryad, please use the following link: http://datadryad.org/submit?journalID=RSOS&manu=RSOS-191318

• Competing interests
Please declare any financial or non-financial competing interests, or state that you have no competing interests.

• Authors’ contributions
All submissions, other than those with a single author, must include an Authors’ Contributions section which individually lists the specific contribution of each author. The list of Authors should meet all of the following criteria; 1) substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content; and 3) final approval of the version to be published.

All contributors who do not meet all of these criteria should be included in the acknowledgements.

We suggest the following format:
AB carried out the molecular lab work, participated in data analysis, carried out sequence alignments, participated in the design of the study and drafted the manuscript; CD carried out the statistical analyses; EF collected field data; GH conceived of the study, designed the study, coordinated the study and helped draft the manuscript. All authors gave final approval for publication.

• Acknowledgements
Please acknowledge anyone who contributed to the study but did not meet the authorship criteria.

• Funding statement
Please list the source of funding for each author.

Please ensure you have prepared your revision in accordance with the guidance at https://royalsociety.org/journals/authors/author-guidelines/ -- please note that we cannot publish your manuscript without the end statements. We have included a screenshot example of the end statements for reference. If you feel that a given heading is not relevant to your paper, please nevertheless include the heading and explicitly state that it is not relevant to your work.

Because the schedule for publication is very tight, it is a condition of publication that you submit the revised version of your manuscript before 31-Oct-2019. Please note that the revision deadline will expire at 00.00am on this date. If you do not think you will be able to meet this date please let me know immediately.

To revise your manuscript, log into https://mc.manuscriptcentral.com/rsos and enter your Author Centre, where you will find your manuscript title listed under “Manuscripts with Decisions”. Under "Actions," click on "Create a Revision." You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript and upload a new version through your Author Centre.
When submitting your revised manuscript, you will be able to respond to the comments made by the referees and upload a file "Response to Referees" in "Section 6 - File Upload". You can use this to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the referees. We strongly recommend uploading two versions of your revised manuscript:

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2) A separate electronic file of each figure (EPS or print-quality PDF preferred (either format should be produced directly from original creation package), or original software format);
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4) Included the raw data to support the claims made in your paper. You can either include your data as electronic supplementary material or upload to a repository and include the relevant doi within your manuscript. Make sure it is clear in your data accessibility statement how the data can be accessed;
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Reviewer comments to Author:

Reviewer: 1
Comments to the Author(s)

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Author's Response to Decision Letter for (RSOS-191318.R0)

See Appendix A.

Decision letter (RSOS-191318.R1)

29-Oct-2019

Dear Dr Gao,

I am pleased to inform you that your manuscript entitled "Experimental Study on Repair of Fractured Rock Mass by Microbial Induction Technology" is now accepted for publication in Royal Society Open Science.

You can expect to receive a proof of your article in the near future. Please contact the editorial office (openscience_proofs@royalsociety.org and openscience@royalsociety.org) to let us know if you are likely to be away from e-mail contact -- if you are going to be away, please nominate a co-author (if available) to manage the proofing process, and ensure they are copied into your email to the journal.

Due to rapid publication and an extremely tight schedule, if comments are not received, your paper may experience a delay in publication.

Royal Society Open Science operates under a continuous publication model (http://bit.ly/cpFAQ). Your article will be published straight into the next open issue and this will be the final version of the paper. As such, it can be cited immediately by other researchers. As the issue version of your paper will be the only version to be published I would advise you to check your proofs thoroughly as changes cannot be made once the paper is published.
On behalf of the Editors of Royal Society Open Science, we look forward to your continued contributions to the Journal.

Kind regards,

Lianne Parkhouse
Editorial Coordinator
Royal Society Open Science
openscience@royalsociety.org

on behalf of Dr Maria Charalambides (Associate Editor) and R. Kerry Rowe (Subject Editor)
openscience@royalsociety.org

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Author’s reply: We have modified the introduction and added some of the latest references.

2. Please include error bars in Figures 5, 7 and 8.

Author’s reply: We have modified these figures, and we have added error bars in Figure 5 and Figure 7. Figure 8 shows the stress-strain curve of the test piece, which mainly reflects the peak intensity change under different conditions. This is a relatively straightforward result, so the error bars are not added.
Fig. 5 Statistics of Average permeability and its decline percentage of rock samples

Fig. 7 Statistics of uniaxial compressive strength of rock samples

Fig. 8 Stress and strain curves of rock samples in different periods
3. In section 4 (Mechanism of MICP repairing fractured rock), please extend the discussion and explain more on the influence of calcium carbonate and its presence in the cemented sand.

Author's reply: We have supplemented this section as follows:

![Composition analysis before experimental processing](image1)

![Composition analysis after experimental processing](image2)

From the comparative analysis of the composition of the cemented sand before and after the test, the XRD spectra of the sand mixture processed by MICP test can detect obvious peaks of calcium carbonate, which indicates that a considerable amount of calcium carbonate is produced during the test. The calcium carbonate formed by MICP has a high degree of bonding with the geotechnical material, and the depth of the bonding layer can reach the micron level. Calcium carbonate is not only a filler between the pores of the soil, but also a good cementing object. The soil particles are bonded together and a layer of calcium carbonate protective film is deposited on the surface of the rock to improve the durability of these materials. The reinforcement effect is achieved by reducing the void ratio and permeability coefficient of the soil and increasing the strength.

4. Please make the annotation on SEM images clearer. Text in the images are barely read.

Author's reply: We have re-edited the images and text in them.
5. Manuscript needs proofreading. Some grammar mistakes were detected.

Author’s reply: We have revised some of the contents of the manuscript based on the comments.

I would like to recommend this article for publication after authors rectify the previous comments.

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This research on MICP technology is detailed and meaningful. By combining the analysis of microstructure features with macroscopic performance, the authors present reliable results. Therefore, I suggest that this article be accepted for publication.

1. The contents of Table 1 need to be revised.

Author reply: Modified

| Table 1 Experimental grouping |
|-----------------------------|
| No. of group | Cultivating time (d) | No. of rock samples | Average wave velocity ($\times 10^3$ m/s) | Standard deviation |
|---------------|----------------------|---------------------|------------------------------------------|--------------------|
| A             | 0                    | A-1, A-2, A-3       |                                          |                    |
| B             | 7                    | B-1, B-2, B-3       |                                          |                    |
| C             | 14                   | C-1, C-2, C-3       |                                          |                    |
| D             | 21                   | D-1, D-2, D-3       | 1.15                                     | 0.015              |
| E             | 28                   | E-1, E-2, E-3       |                                          |                    |
| F             | 35                   | F-1, F-2, F-3       |                                          |                    |
| G             | 42                   | G-1, G-2, G-3       |                                          |                    |
2. The author should supplement the parameters of the water used in the test to provide support for the reliability of the test results.

Author’s reply: We have supplemented this section as follows:
The water used in the leaching experiment is tap water, which was sealed in plastic buckets prior for further analysis. The pH of the test water is 7.45 and the COD value is 15.04. There is little harmful substance in it.

3. Page 6, Fig. 4 should be changed to Fig. 5

Author reply: Modified

4. The author should explain why the correlation between strength and porosity is analyzed.

Author’s reply: We have supplemented this section as follows:
In the MICP test, the repair effect of calcium carbonate can reach the micron level. This effect can be used to improve the strength by filling the cracks and pores inside the rock and soil. NMR can visually show the porosity change of the rock mass, and the actual effect of the MICP can be more accurately expressed through the correlation analysis with the intensity gain.

5. Porosity studies are meaningful for the repair of microscopic structures. Please supplement the test principle of nuclear magnetic resonance equipment.

Author’s reply: We have supplemented this section as follows:
NMR technique is based on the interaction between magnetic field of hydrogen nuclei and external magnetic field. Under the influence of static magnetic field and alternating magnetic field, the H proton in water-saturated specimens will release energy, which is called NMR signal. The transverse relaxation time T2 distribution can be obtained through the difference of the signals, which directly reflects the variation features of rock pore structure. Distribution of pore fluids is controlled by pore structure of the rock samples. The presence of different pore fluids can be measured by nuclear magnetic resonance system, which is the basis for evaluating the pore structure by NMR T2 spectrum.

6. The conclusion can be appropriately streamlined.

Author’s reply: We have made some changes to this section.