（様式 3）

国際共同研究事業
令和２（2020）年度実施報告書

2021-OIST-RSD-0034

令和 3 年 3 月 31 日

独立行政法人日本学術振興会理事長　殿

[代表者所属機関・部局]
学校法人沖縄科学技術大学院大学学園
マイクロ・バイオ・ナノ流体ユニット
[職・氏名]
教授・シェン エイミー（公印省略）

１．プログラム名　スイスとの国際共同研究プログラム（JRPs）

２．研究課題名

（和文）微粒子運動解析に基づくソフトマテリアルのスケール依存アクティブマイクロレオロジー

（英文）Scale-dependent active microrheology of soft materials by studying driven motion of microbeads

３．共同研究実施期間（全採用期間）

令和元年 10 月 1 日 ～ 令和 4 年 9 月 30 日(3 年 0 ヶ月)

４．研究参加者（代表者を含む）

(1) 日本側参加者　5　名　　　(2) 相手国側参加者　2　名

５．主要な物品明細書（一品又は一組若しくは一式の価格が 50 万円以上のものを購入した場合は記載）

物品名	仕様 型・性能等	数量	単価(円)	金額(円)	設置研究機関名	備考
High Speed Camera	Phantom VE0640L mono	1 式	1,593,465	1,593,465	沖縄科学技術大学院大学	別財源と合算購入。

※本事業の委託費と他の経費とを合算使用する際は、合算使用した旨を備考欄に記載した上で、金額は本事業の委託費で負担した額のみ記載してください。

※再委託先/共同実施先における支出である場合は、備考欄にその旨を記載してください。

７．渡航実施状況

（１）当該年度に相手国又は相手国以外の国を訪問した日本側参加者（委託費から支出した出張のみ記載。相手国以外の国における用務先には下線を付すこと。）

氏名	旅行期間*	用　　務 （用務先・用務内容）
計　　　名（延べ人数）		

＊　旅行期間の欄の記入例：「6 月 10～19 日」（旅行開始日～旅行終了日）

（２）当該年度に受入れた相手国側参加者

氏名	旅行期間*	用　　務 （用務先・用務内容）
計　　　名（延べ人数）		

＊　旅行期間の欄の記入例：「6 月 10～19 日」（旅行開始日～旅行終了日）

８．研究実施状況

※当該年度実施計画書の「5．本年度実施計画の概要」の内容と対応させつつ、当該年度の研究の実施状況を簡潔に記載してください。再委託又は共同実施を行った場合は、それぞれの研究の実施状況がわかるように記載してください。

※年度途中で当初計画を変更した場合にはその内容及び理由も記載してください。特に、各費目の増減が研究経費の 50%（この額が 300 万円を超えない場合は 300 万円）に相当する額を超えた場合は、変更理由と費目の内訳を変更しても研究の遂行に支障がなかった理由を記載してください。

During FY2020, due to the pandemic, we focused on investigating flows of yield stress fluids and colloidal suspensions inside benchmark microfluidic platforms in OIST, Japan. Our results led to two journal publications (more details below). In addition, we also collaborated with Professor Frank Scheffold's group from University of Fribourg, Switzerland remotely on the project titled "Microrheological Analysis of the Entanglement Properties for Polyelectrolyte Solutions", which was a part of the main project and its experimental part was performed by Dr. Atsushi Matsumoto. We used the diffusing wave spectroscopy (DWS) technique to characterize the material properties of polyelectrolyte solutions. Since Prof. Scheffold's group pioneered DWS technique, they worked with us closely on programming and data analysis after we collected experimental data in Japan. We are in the process of writing a manuscript to summarize these results and plan to submit this work in June 2021.

Project 1: Transition between solid and liquid states of yield-stress fluids under purely extensional deformations

The stress-induced transition from solid to liquid state is commonly referred to as "yielding." Experiments and simulations conducted under pure extension provide fundamental information on the behavior of yield-stress materials and demand an overhaul of the current standard theory in order to account for material deformation in the solid-like state prior to yielding and flow.

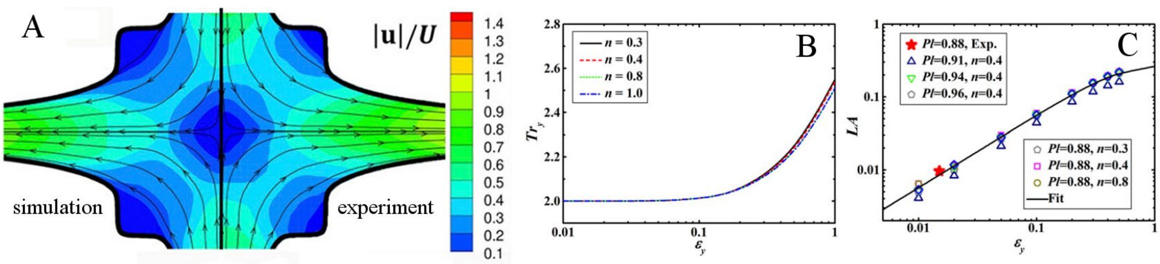

FIG. 1. (A) comparison between flow velocity fields for an EVP fluid in an extensional flow apparatus obtained by numerical simulation (left) and by experimental measurement (right). (B) Yield stress Trouton ratio (Tr_y) as a function of the yield strain (ε_y), showing strong departure from the theoretical value of $Tr_y = 2$ for $\varepsilon_y > 0.1$ (C) The yield strain can be deduced from a local asymmetry parameter (*LA*) measured from the velocity field in extensional flow.

We report experimental microfluidic measurements and theoretical modeling of elastoviscoplastic

(EVP) materials under steady, planar elongation. Employing a theory that allows the solid state to deform, we predict the yielding and flow dynamics of such complex materials in pure extensional flows. We find a significant deviation of the ratio of the elongational to the shear yield stress from the standard value predicted by ideal viscoplastic theory, which is attributed to the normal stresses that develop in the solid state prior to yielding. Our results show that the yield strain of the material governs the transition dynamics from the solid state to the liquid state. Finally, given the difficulties of quantifying the stress field in such materials under elongational flow conditions, we identify a simple scaling law that enables the determination of the elongational yield stress from experimentally measured velocity fields.

Project 2: Effects of Shearing and Extensional Flows on the Alignment of Colloidal Rods

Cellulose nanocrystals (CNC) can be considered as model colloidal rods and have practical applications in the formation of soft materials with tailored anisotropy. Here, two contrasting microfluidic devices are employed to perform an experimental quantification of the role of shearing and planar extensional flows on the alignment of a dilute CNC dispersion. Characterization of the flow field by microparticle image velocimetry is coupled to flow-induced birefringence analysis to quantify the deformation rate–alignment relationship. The deformation rate required for CNC alignment is 4× smaller in extension than in shear. The birefringence signal rising from the CNC alignment in shear and extension can be scaled on a single master curve using a Péclet number that accounts for the shear and extensional viscosity of the solvent fluid, respectively. Based on this simple scaling relationship, it is possible to anticipate the alignment of rigid colloidal rods under purely extensional deformation by knowing the respective alignment profile in a shearing flow that is more accessible via multiple rheo-optical techniques. Quantification of the differences between shearing and extensional kinematics at aligning colloidal rods establishes coherent guidelines for the manufacture of structured soft materials.

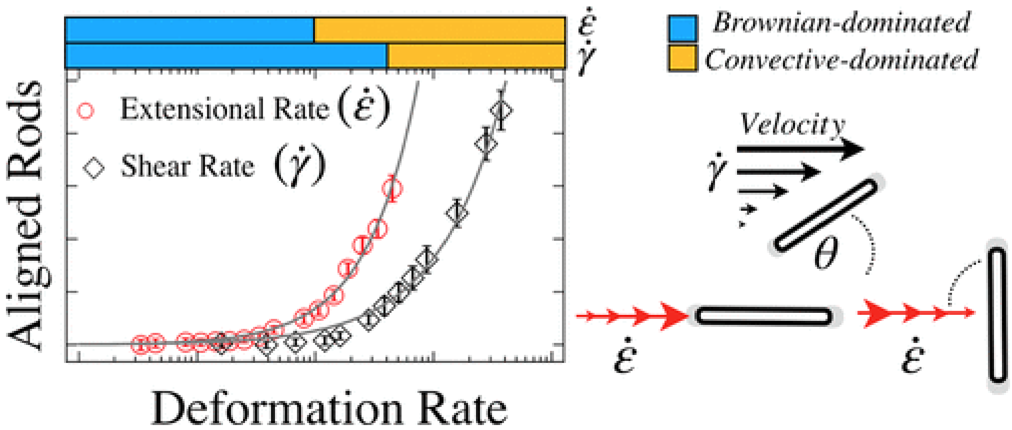

Fig. 2 (Left) Number of aligned rods vs. deformation rate. (Right) Schematic of the effect of the shear and extensional rate on the orientation angle of a colloidal rod.

９．研究発表（当該年度の研究成果）〔**雑誌論文**〕　計（　３　）件　　うち査読付論文　計（　３　）件

通番	共著の有無*1	論文名、著者名等*2
1		S. Varchanis, S. J. Haward, C. C. Hopkins, A. Syrakos, Amy Q. Shen, Y. Dimakopoulos, and J. Tsamopoulos, Transition between solid and liquid state of yield-stress fluids under purely extensional deformations, *PNAS*, 117: 12611-12617 (2020)
2		Cameron C. Hopkins, Simon J. Haward and Amy Q. Shen, Tristability in viscoelastic flow past side-by-side microcylinders, Physical Review Letters, 126 (5), (2021).
3		Vincenzo Calabrese, Simon J. Haward, and Amy Q. Shen, Effects of Shearing and Extensional Flows on the Alignment of Colloidal Rods, Macromolecules, (2021). https://doi.org/10.1021/acs.macromol.0c02155

〔**学会発表**〕計（　２　）件　　うち招待講演　計（0）件

通番	共著の有無*1	標題、発表者名等*2
1		Stylianos Varchanis, Cameron C. Hopkins, Amy Q. Shen, John Tsamopoulos, Simon J. Haward, Asymmetric flows of complex fluids past confined cylinders: A numerical study, Virtual International Congress on Rheology, Brazil, December 2020.
2		Amy Q. Shen, Novel glass microfluidic devices for probing flow instabilities of complex fluids, Virtual International Congress on Rheology, Brazil, December 2020.

〔**図　書**〕　計（　０　）件

通番	共著の有無*1	題名、著者名等*2
1	None	

*1　相手国側参加者との共著（共同発表）がある場合は○、相手国側参加者との共著であり謝辞等に事業名を明記している場合は◎と記入。

*2　当該発表等を同定するに十分な情報を記載すること。例えば学術論文の場合は、論文名、著者名、掲載誌名、巻号や頁等、発表年（西暦）、学会発表の場合は標題、発表者名、学会等名、発表年（西暦）、著書の場合はその書誌情報、など（順番は入れ替わってもよい）。相手国側参加者との共著となる場合は、著者名が複数であっても省略せず、その氏名を記入し下線を付すこと。

*3　足りない場合は適宜行を追加すること。