The 'Yield Stress Myth?' Paper – 21 Years On

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Abstract:
Consideration is given to the reaction to Barnes and Walters' 4-page '*The yield stress myth?*' paper published 21 years ago. It has been cited approximately 180 times since then, as either a standard reference for 'yield stress' papers, or to disagree with its sentiment that yield stresses do not actually exist, but are a useful approximation. The references that cite the paper are categorized and commented on.

Zusammenfassung:
Überlegungen über die Reaktion auf den vierseitigen Artikel von Barnes und Walther "The yield stress myth?" werden angestellt, der vor 21 Jahren publiziert wurde. Er wurde seither ungefähr 180 Mal zitiert, entweder als Standardreferenz für Artikel über Fließspannungen oder als Gegenmeinung zu seiner These, dass Fließspannungen gar nicht existieren, aber eine nützliche Näherung darstellen. Die Referenzen, die diesen Artikel zitieren, werden kategorisiert und kommentiert.

Résumé:
Nous donnons de l'attention à la réaction à l'article de 4 pages de Barnes et Walters, «Le mythe de la contrainte seuil?», publié il y a 21 ans. Il a été cité à peu près 180 fois depuis lors, soit comme une référence standard pour les articles traitant de la contrainte seuil, soit pour communiquer un désaccord avec son sentiment que les contraintes seuils n'existent pas réellement, mais sont une approximation utile. Les références qui citent cet article sont catégorisées et commentées.

Key words: yield stress, controlled-stress rheometers

1 INTRODUCTION

In many countries around the world, it was the custom in former days to look upon the twenty-first birthday of a person as a 'coming-of-age', i.e., a transition from adolescence to adulthood. It has now been twenty-one years since Barnes and Walters' provocative 4-page paper was published with the challenging – but somewhat guarded – title '*The yield stress myth?*' [1]. Since its publication the paper has been cited approximately 180 times (ISI Web of Knowledge) in the open literature, so that, in many ways, it too has now truly 'come-of-age'. It was therefore thought worthwhile to mark this occasion by a short memoir.

2 THE THESIS PRESENTED IN THE PAPER [1]

With the advent of better and better controlled-stress rheometers, with their increased ability to apply lower and lower stresses and measure lower and lower shear rates, it became obvious that what appeared to be a yield stress in many non-Newtonian liquids was in fact only an extrapolated value obtained from fairly high shear rates. In a later paper* [2] Barnes expanded the idea by means of many examples that showed that even at very low shear stresses 'everything flowed' (hence the $\pi\alpha\nu\tau\alpha\ \rho\epsilon\iota$ in that paper's title), even if this continuous deformation was very slow, i.e., creep. The range of solid-like 'creeping' materials was shown to extend from metals, through ceramics to solid polymers and rocks and minerals. However, the real argument with respect to yield stress was for those structured liquids that flow *readily* at high shear stress, but *appear* to have a critical stress below which *no* flow takes place. Roberts, Barnes and Carew [4] gave numerous examples of such fluids and showed that they could be quite adequately described as having a yield stress suitably and variously defined but nevertheless they still flowed below this value, albeit very slowly. Figure 1 shows this behaviour schematically.

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existed. 'Theory and modelling' covers those areas where a flow model was used which incorporated a yield stress, using the model to predict flows in complex geometries. The 'measurement' papers cover those efforts to measure yield stress, which obviously depends on its nature. 'Experimental' lists those papers that examined flows experimentally and invoked the idea of a yield stress to describe the results. The 'chemical or process engineering' publications have to do with industrial or near-industrial situations where, like the 'experimental' section, the idea of a yield stress is used to describe the observed flow of the materials of interest. Typical in this context is the picture of non-Newtonian flow as a cavern, where the dimensions of the cavern are dictated by the value of the yield stress [17].

Quite a number of systems that have been associated with yield stresses are polymeric in nature. Concentrated suspensions are very non-Newtonian and have often been described as having yield stresses. Geo-physical flows include muds, lavas and mineral suspensions, and all these have, from time to time been described as having yield stresses. Biological flows such as blood circulation have been described using a yield stress, as have quite a number of biologically derived thickening materials. 'Foams' and other surface dominated systems obviously appear to have a yield stress and a number of flow models have been used to predict its value.

6 ENGINEERING SITUATIONS

There are a number of practical flow situations where there is no visible or noticeable continuous movement, i.e., flow below the yield stress. Among these are:

- 'dead' spots and zones
- plug flow
- cavern flow

However, in a number of other papers published since the original one, the present author has been careful to state that the use of a yield stress as a *very useful mathematical convenience* to define *part* of a flow curve has never been in dispute, but that the simplistic definition of a physical parameter is not tenable, i.e., that there is no flow below the defined yield stress.

Of course it depends on what one means by 'flow'. If we extend the definition to 'observable or visible flow', then I would have no argument at all with such a proposition and we could all agree! As most mathematical uses of viscoplastic theories are actually used to predict such 'observable or visible flow', usually for engineering purposes with short timescales, then it is worthwhile investigating what are the best kinds of theories that incorporate yield stresses: slump tests for concrete or chocolate thickness in coating machines being typical examples. For instance, for all practical purposes in shear-rate terms we mean the stress at ~ 10^{-2} s^{-1}, this being the lowest shear rate that one could visually detect during normal observation in engineering (or even consumer) situations.

However, experimentalists who measure creep below the yield stress are able to provide data that is useful over very long time scales, such as shelf life of months or years, as for instance when the physical stability of a multiphase liquid or paste is important.

7 CONCLUSION

Is a yield stress a ***c***onvenient ***f***iction or a ***c***oncrete ***f***act; a ***p***hysical ***c***onstant or a ***p***ragmatic ***c***oncept? Well it depends! Dr. Cyril E. M. Joad (1891 - 1953) - sometime head of the department of Philosophy and Psychology at Kirkbeck College, London University - usually began his answers in the 1950s BBC Television's 'The Brains Trust' with the phrase - '*Well, it depends on what you mean by* ...', and so it does in the *yield stress* debate! For instance, it could be defined as something like 'that critical stress below which there is no flow ...', however if the words *observable or visible* are inserted between the words no and flow, then there would be no argument at all with such a proposition and all could agree!

Whatever else one might say about the reaction to the '*Yield stress myth?*' paper, one thing is sure – there has been a lot of thinking going on about the subject of yield stress. This alone fully satisfies the original authors, even if others come to different conclusions following their thoughts, for Thomas Jefferson said 'difference of opinion leads to enquiry, and enquiry to truth'.

All the remarks made here refer to steady-state flow conditions, but it should be noted that for typical materials covered here, their behaviour is heavily overshadowed by thixotropic effects [18] that greatly complicate the situation,

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e.g., start-up flows, etc. [19 - 21]. It should also be noted that apart from the 'physical' assertion made here that 'everything flows', mathematicians have long been using a 'regularization' technique to model the flow of yield stress fluids, which introduces a very high but finite viscosity at low stresses, see [22].

FOOTNOTES AND REFERENCES

* This paper [2] appears - along with two other of this author's papers - in Kröger's list [4] of the top 10 Landmark Paper Index articles for 1999 – 2004 and was one of the 'Top 20' most downloaded paper from the Journal of Non-Newtonian Fluid Mechanics in 2006.

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