Evolution of a Defect in a 2D Wet Foam

Atef AbdelKader, E.A. Dawi

Abstract—We experimentally investigate the evolution of long-time effect of a single topological defect in a two-dimensional wet foam. The single defect is inserted in a hexagonal lattice. As the time passes, the disorder initially grows due to the coarsens of the foam of the defect. This long time scale behavior is in a good agreement with the recent simulations. Unlike the results of our previous work, a peak was observed in the disorder cluster. The latter qualitatively support simulations of alike conditions in 2D froth.

Keywords: Disorder, Foam, Froth, Growth, Second moment

I. INTRODUCTION

Soap froths are considered as an interesting examples of 2D cellular structures. Recently, physical properties as well as evolution of such structures have been the subject of increasing scientific attention [1, 2, 3]. The controversy concerning the long-time behavior of the soap forth has been known for long in literature [4]. Smith et. al. early experiments [5] performed on froths with small number of bubbles revealed that average area of bubbles denoted as $<a>$, increases with $\alpha = 1$ as $<a> \approx t^{\alpha}$. Besides, a tendency towards fixed distribution of number of sides and relative areas has been observed by Smith. Subsequent data analysis by Smith with large number of bubbles has been a subject of study made by Aboav et al. [6]. Aboav et al. found that the value of α is equal to 2. Furthermore, no stable limiting distribution is reported. The outcomes of the latter simulations can be represented in terms of several statistical measures of the cellular structure [7].

Within his study of the evolution of an isolated defect in a hexagonal network, Levitan has already defined the set of bubbles around the defect as a cluster having at least one non-hexagonal neighbor [8]. Much attention has been paid to how the number of the bubbles in the cluster depends on time and the topological distribution of the cluster. It has been found that the number of the bubbles in the cluster grew similarly to a power law, $n_c \sim t^{\alpha}$. Moreover, Levitan had challenged the quality that the dynamics of the scaling state is independent of the initial condition. By using the so-called mean-field treatment, Levitan already inferred that the long-time topological distribution function is essentially different for single-defect initial hexagonal lattice.

The importance of the second moment of the topological distribution μ_2 has already been pointed by Weaire [9]. The latter hasn't been identified within the Leviton's paper [8]. It is mentioned that $\mu_2(t)$ has a peak when the evolution starts from rather ordered initial conditions [3], [10]. Weaire [10] reported that this peak is inconsistent with the existence of a steady limit of the topological distribution for the cluster as obtained by the analysis of the "area" model, indicated in Levitan's work [8].

Jiang et al. [11] and co-authors evolved initially special condition; that is a single large grain in a perfectly hexagonal lattice. Co- authors identified the disordered cluster to initially consist all grains with a minimum of one non-hexagonal neighbour, revealing a large central grain with surrounded grains boundary around it. In addition, authors claimed that the central grain grew in a such faster way than that of the grains within its boundary. Furthermore, the grains outside the cluster is reported to remain unchanged. That means as disorder propagates outward in the pattern; the large grain seemingly grows at the same rate. The diameter of the cluster is found to grow linearly. Besides, co-authors claimed that the total area of the cluster and the diameter could be determined by the large center grain. Their conclusion reveal that the average area of the grains in the cluster boundary is constant. Finally, Jiang et al. found that the topological distribution tail of the function, P(n), extends towards larger n values however, the peak appears to stay at n value correspond to 6 due to the cluster definition. Statistical analysis of disordered cluster has already shown the divergence of topological distribution with the time; however, Levitan et al. found that the distribution of topological classes in the cluster converges eventually to a stationary form. Authors found that μ_2 of the cluster was dominated by the linear growth of the large grain. The latter is found to be consistent with the results obtained by Aboav et al. [12]. On the other hand, $\mu_2^{/}$ (μ_2 of the boundary) fluctuated around fixed value of about 0.7 while the topological distribution was kept constant.

II. EXPERIMENTAL METHODS

Our proposed simulations concern 2D dry froth. Even though, production of nearly dry 2D froth is visible, [13], ordering of such forth is considered as nearly impossible. We adopted the principle of the Bragg's bubble raft in our studies, which is presumed to allow the formation of 2D ordered foam. Thus, as to obtain bubbles, we have used a hexagonal frame as shown in Figure 1.

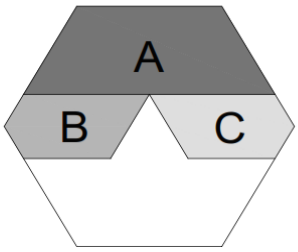

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Figure 1. A diagram indicating procedures for producing defect. First, perfectly ordered bubbles is made in region A, B and C. Next, a single defect introduced in the gap. Finally, the remaining space is filled with bubbles, in register with those in A.

Initially, the glass cover of about 1 - 3 mm is supported above the soap solution on a metal plate, deepening into the solution. Thus, a 2D foam is formed by bubbling N_2 into the solution below this hexagonal cell via a long hypodermic needle. The bubbles are configured in a such way to be coupled to the cell wall as well as to themselves. Through systematic sweeping of the needle tip, and as the bubble lines form, it is possible with extended practice, to create perfectly 6-fold coordinated lattice within the hexagonal cell comprising ~ 3000 bubbles of about 2 mm in diameter. The big bubble which is introduced as defect is initiated by interrupting the process when the hexagonal hole is half made. Injection of the big bubble is made by using a syringe, forming a topological defect, and afterwards the lattice is completed around it. Usually, in average one or two dislocations are observed. These dislocations enjoy non-zero Burgers vector as dislocation character. However, the dislocations could move towards themselves and/or alternatively towards the direction of the big bubble until it eventually vanishes.

Thus far, the 2D foams produced are, in practice, wet, however, we propose that to some extent, its behavior could reflect some aspects of the 2D foam generic evolution, which is already found in the simulations.

III. RESULTS AND DISCUSSION

In the current study, we have explored the behavior of some cluster statistics, the combination of the center bubble and the cluster boundary such as the topological distribution and their second moment, the area and number of bubbles. Figures 2a - 2b show the single defect evolution in a perfect regularly hexagonal lattice. Initially, only a single large bubble is presented; (Figure 2a).

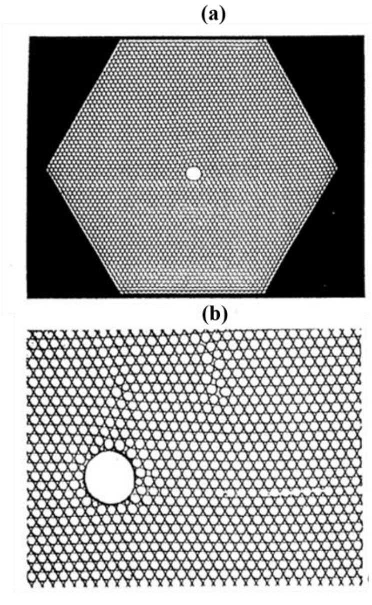

Figure 2. Images of growing foam that comprises an initial central bubble. (a) 2D foam as formed (t = 0). (b) t = 25 h.

Figure 2b shows the disorder as it grows around the big bubble. As can be seen, small size differences in ordered bubbles lead to coarsening of time scales of the order of days. We have used a certain liquid that let us to run the experiment for a longtime before the cluster enters into this coarsening-induced disorder. This gives us the chance to study the disorder of the cluster for a long time to be able to follow on the evolution of the cluster. Different experiments with central bubbles having the same number of sides were created, and followed over a longtime. These experiments with same central bubbles in the same conditions have similar rate of growth with time.

All experiments display a linear relationship between total bubbles number within the cluster n_c and time. Next, we use the number of bubbles in the cluster n_c and/or number of neighbors of the center bubble n_b, as measure of the relative time to allow us to compare our results findings with Jiang et al simulations. It is observed experimentally that the bubbles number in cluster n_c and the number of neighbors of the center bubble n_b both grew with time. A definite linear relationship between n_c and n_b is well established (Figure 3).

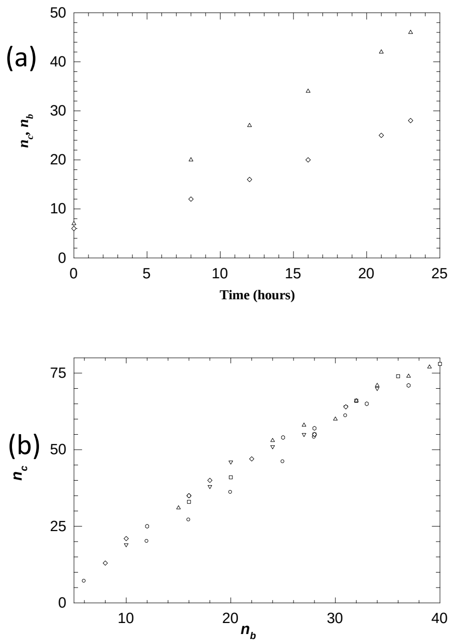

Figure 3. Number of bubbles including the cluster n_c and number of defect's neighbors n_b versus time (a), Number of bubbles including the cluster n_c versus number of defect's neighbors n_b (b), respectively.

This relationship supports the fact that large bubble grows at initially similar rate to the disorder propagation outward in the pattern. Figure 4 shows the topological distribution of the bubbles belonging to the cluster. Error bars in all distributions are the same. It can be seen from the graph that topological distribution function denoted as P(n) gets wider and wider. This indicates that n grows with time (the cluster became more disorder). Finally, P (n) reached to stationary form.

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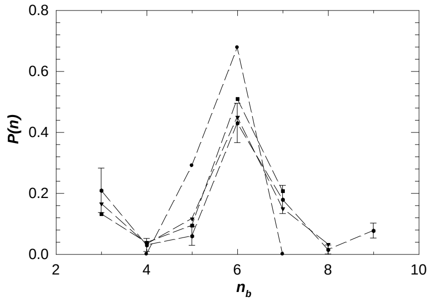

Figure 4. Topological class distribution P(n) for evolving foam comprising a single defect.

Figure 5 indicates that the second moment of the topological distribution (μ_2) grows linearly with number of sides of the center bubble (n_b) to a high value where the peak appears clearly at a certain number of bubbles inside the cluster.

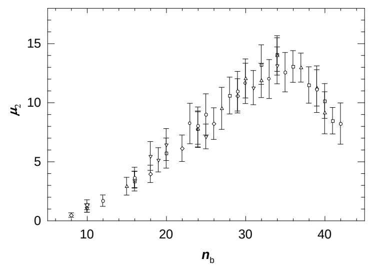

Figure 5. The relation between (μ_2) of the cluster with n_b as different foams evolve.

The diverging values of μ_2 reported in our results clearly support the values attained in simulations [11]. If the large bubble in the center of the second moment is excluded from the rest of the cluster (the boundary), the peak of $\mu_2^{/}$ appears clearly to be saturate at a low value comparing with μ_2 but still in agreement with the simulations (Figure 6).

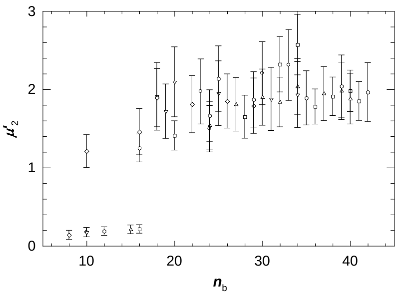

Figure 6. The evolution of the second moment of the boundary ($\mu_2^{/}$).

Our main attention will be only paid to the cluster, cluster boundary and finally to the center bubble areas. The relations between the area of the cluster, boundary area and the center of the bubble area A_b were plotted against n_c and n_b as in Figures 7, 8 and 9, respectively.

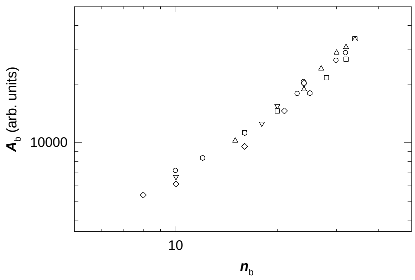

Figure 7. The variation of the area of the defect A_b with n_b as different foams evolve.

Figure 7 shows that area of the cluster grew as function of the bubble number within cluster denoted as n_c. The same result was obtained when we plotted cluster boundary area and the center bubble area with n_c, Figures 8 and 9, respectively.

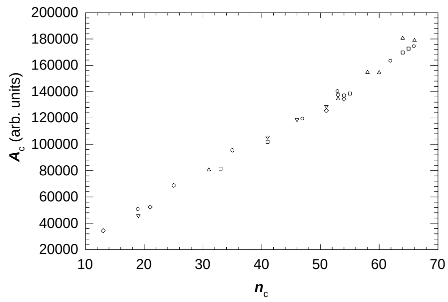

Figure 8. Variation of the cluster area (A_c) with n_c as different foams evolve.

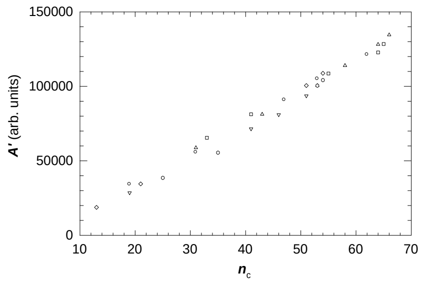

Figure 9. Variation of the boundary area ($A^{/}$) with n_c as different foams evolve.

The large center bubble thus chiefly determines the total cluster area. By normalizing the average bubble area in the boundary to that in ordered areas of the foam at the same age, the average area of the bubbles in the cluster boundary is found to approach constant value. This average normalized area is 0.90 ± 0.05, (Figure 10) which is very close to the value in Jiang simulations [11].

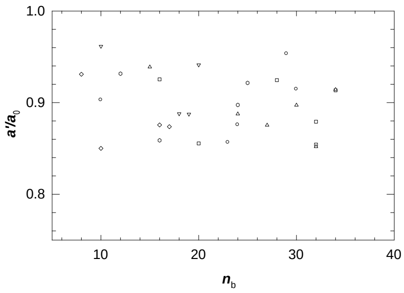

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Figure 10. The variation of area per bubble in boundary with n_b as foam evolves. The data fluctuate about a constant value.

IV. CONCLUSIONS

We have experimentally studied the growth of single defect in a hexagonal lattice. Different experiments with central bubbles having same number of sides were evolved. The time was used as a measure of n_c or n_b. The above-mentioned results show that the large bubble grows at similar rate as cluster disorder is propagating outwards in the pattern. Accordingly, the topological distribution function is extending towards larger n_b values. On the other hand, μ_2; the second moment and $\mu_2^{/}$ grow linearly with the bubbles number within the cluster and the peak clearly appeared in both cases. The area of the cluster A_c and the cluster boundary area $A^{/}$ both grew as function of the bubbles number n_c and with the number of neighbors of the central bubble n_b. Finally, the results of the bubbles average area in the cluster boundary seemingly to fluctuate about stable value.

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