

**NON-DENDRITIC CRYSTALLIZATION OF METALS – POSSIBLE CAUSES**

**ABSTRACT.** The paper examines possible causes of degenerate dendrite formation during the non-dendritic crystallization of metals, specifically the Al-Si alloy (A356). The study includes experiments with model systems and numerical simulations. It was found that such morphologies may arise due to anisotropy reduction, transitional processes, or forced growth conditions. During experiments on directional crystallization and changing growth conditions, both classical and splitting dendrites were observed. It was concluded that gradients created by intensive melt shearing might lead to the formation of degenerate dendrites.

**KEYWORDS:** degenerate dendrites; non-dendritic crystallization; aluminum alloys; directional crystallization; anisotropy

In experiments connected with the study of rheocasting methods for Al-Si alloy (A356) besides “classic dendrites” (Fig. 1, a) were found morphologies demonstrating more or less splitting of structure elements (Fig. 1, b – d).

Such structure retains some “dendrite features”, therefore we entitled them as degenerate dendrites. Possible reasons for its appearance are discussed further.

It is known that regular dendrites form spontaneously by growth in a preferential direction ( $\langle 100 \rangle$  for cubic symmetry), that reflects crystallographic anisotropy. For growth in other directions, anisotropy had to be “overcome” due to some circumstances. It seems that such circumstances can be reduction of anisotropy, transition processes and forced conditions.

**Reduction of anisotropy.** The formation of splitting patterns in the absence of anisotropy was demonstrated widely in numerical modelling. As concerns Al-based alloy [1] declares the possibility of splitting pattern formation as a consequence of alteration of preferential growth direction due to increase of Zn content for Al-Zn alloy. For verification of such ability for Al-Si alloy, the experiments on crystal growth in concentration gradient were performed.

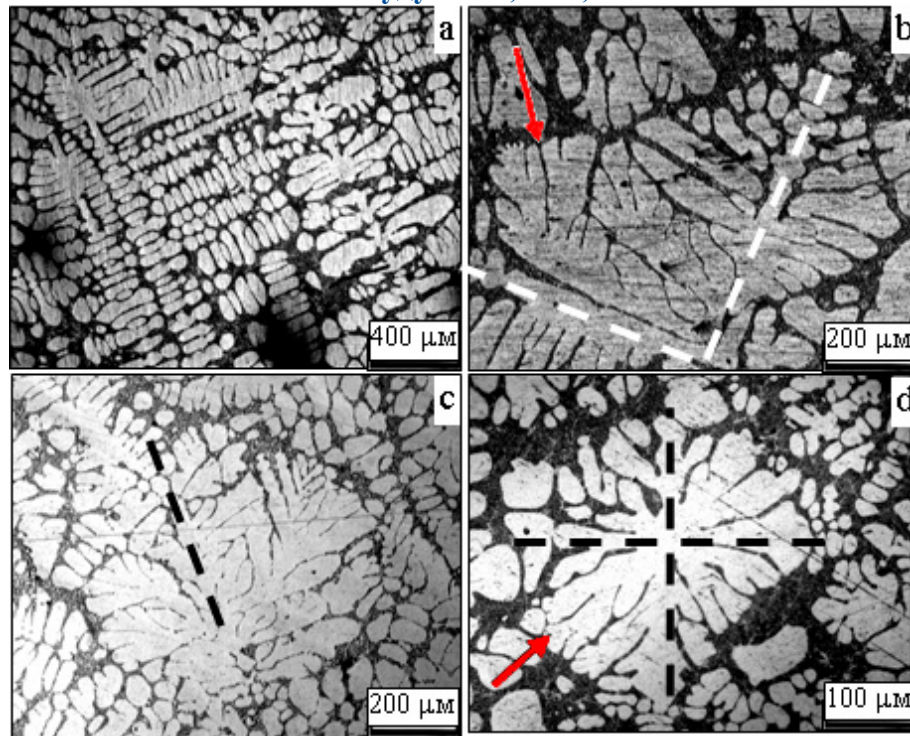


Fig.1. a – classic dendrite; b, c, d – splitting patterns. Dashed lines mark “dendrite stems”. Arrows on b) and d) indicate splitting elements for comparison with Fig. 6 d), h)

A complex cylindrical sample from two parts – pure Al and Al-Si eutectic was fabricated. The sample in the crucible was melted fully and then directional crystallization took place, so Al dendrites grow in the eutectic region, Fig. 2.

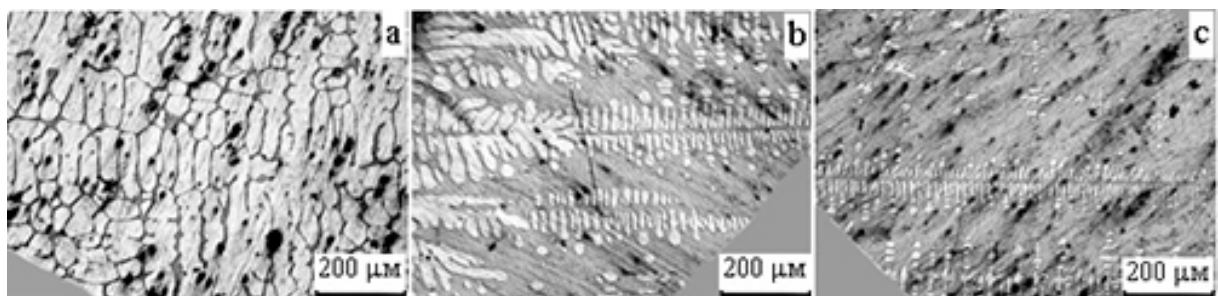


Fig. 2. Al-dendrites grow in eutectic region: a – Al region, b – transitory region, c – eutectic region

As it can be seen from the figure, dendrites continuously grow throughout the whole sample, and no changes of preferential growth direction or splitting were observed.

**Transition processes.** Relatively transition processes it must be noted that in real casting growing crystal is surrounded with neighboring, so transition processes from one stationary growth state to another can be not completed and the structure of casting will fix just transition stage. Concerning the possibility of splitting morphology formation as the result of such processes, we take into account two moments.

At first, in [2] appearance of non-dendrite splitting patterns is associated with two-stage crystallization – formation of dendrites, which are partially melted, and the final structure is the result of loss of stability and further growth of fragments of different shares. To verify this hypothesis experiments with partial melting and further growth of camphene-10 wt.% salol alloy were carried out, Fig. 3

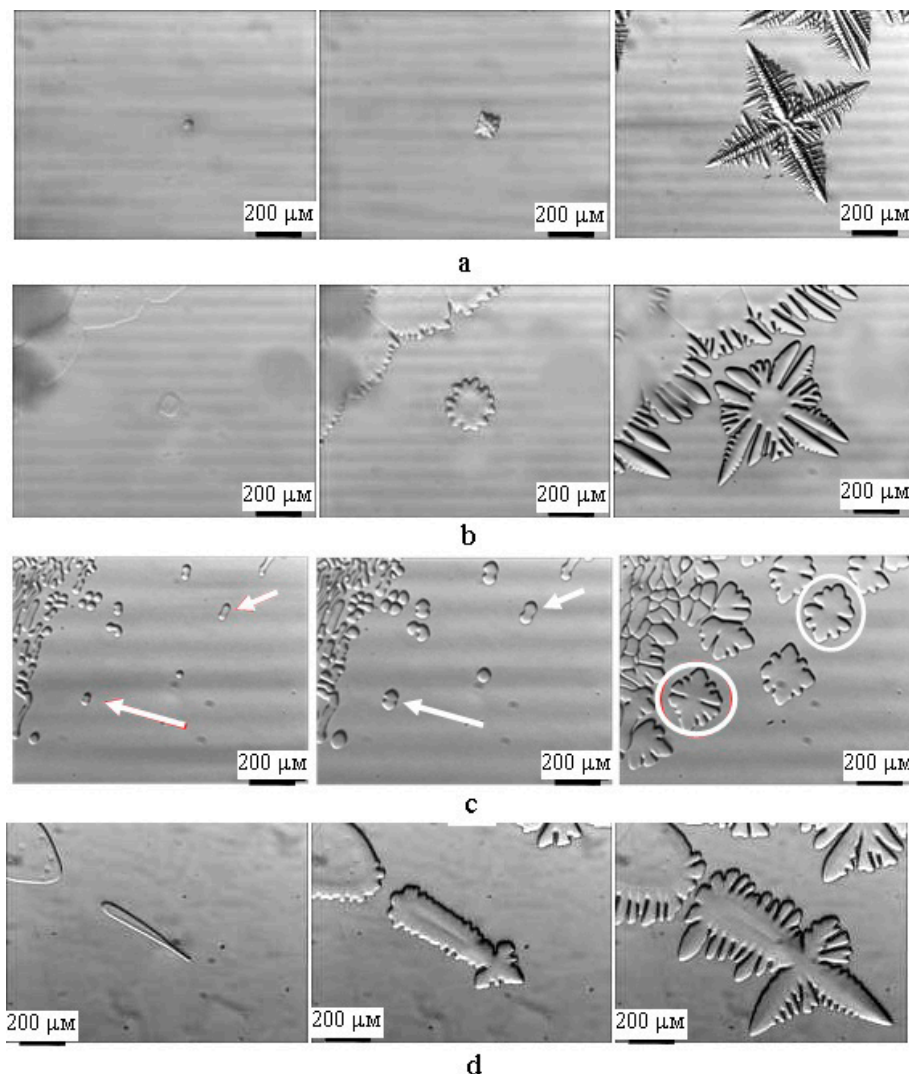


Fig. 3. Consequence stages of the growth of fragments: row a – seed crystal less than critical size; row b – rounded seed crystal a little more than critical size. See the duplex dendrite structure; row c – small elongated seed crystal. See dumbbell-like structure; row d) – large elongated seed crystal

During the melting of initial dendrite, different types of fragments were formed. Depending on the shape and size of fragments further growth formed different but regular dendrite structures.

At second, one of the possible reasons for formation of irregular splitting morphology can be the deceleration of the growth. Background for such suggestion are results of Trivedi [3]. It was pointed out that at least for directional solidification abrupt reduction of growth rate resulted in a transient process accompanied with the splitting of the pattern, see Fig. 4 b), c).

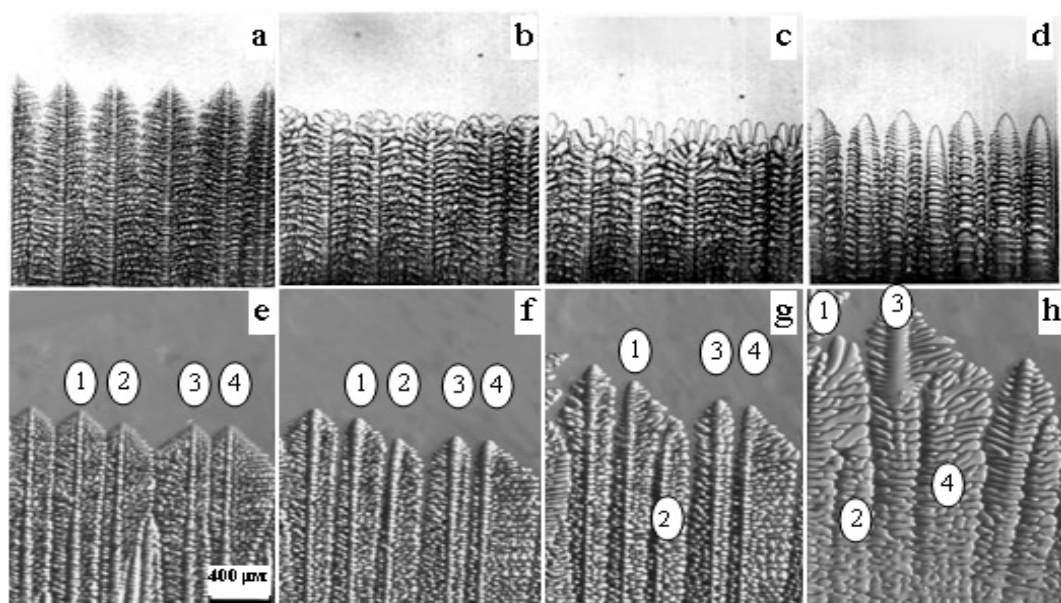


Fig. 4. Changes of growth morphology due to reduction of growth rate: a – d – data from [1]. Directional solidification of SCN-based alloy; e – h – reduction of supercooling from 2,2 °C to 0,6 °C. Camphene-based alloy

We made experiments with a reduction of growth rate by abrupt reduction of supercooling from 2,2 °C to 0,6 °C. As shown in Fig. 4 e) – h), no splitting took place during the transition. “Thickening” of dendrites took place by suppression of neighbors. Multiple dendrites are the result of the large size of the seed crystal, see Fig. 3, d.

**Forced conditions.** Relatively forced conditions, “constrains” crystal to grow in non-preferential direction, growth of succinonitrile – 2 wt. acetone alloy was studied in a thin gap (20 μm) between parallel glass slides as well as its directional



solidification with different orientations of seed crystal relatively direction of thermal gradient.

As shown in Fig. 5 c), d) as dendrite as splitting patterns can exist depending on the orientation of the seed crystal relatively to the plane of the slide. The last pattern looks like rather as a result of percolation than crystal growth.

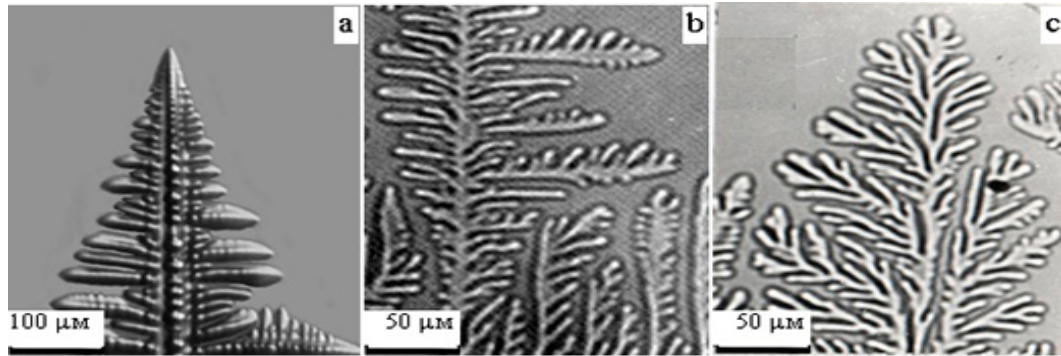


Fig. 5. Various morphologies: a – unconstrained dendrite growth, b – dendrite pattern in the gap, c – splitting pattern in the gap

For growing of crystals in non preferential direction installation for directional solidification was used, which permits to rotate cuvette with seed crystal relatively direction of the imposed thermal gradient, which was 40 °C/sm. It was found that for rate 6 μm/s, Fig. 6, e) – h), structure elements (dendrites) were growing in preferential direction  $\langle 100 \rangle$  independently from orientation of seed crystal, while for rate 3 μm/s structure elements tilted to thermal gradient direction and formed splitting patterns similar to those for degenerate dendrites (compare marked with red arrows structures on Fig. 6, c, d and Fig. 1, b, d).

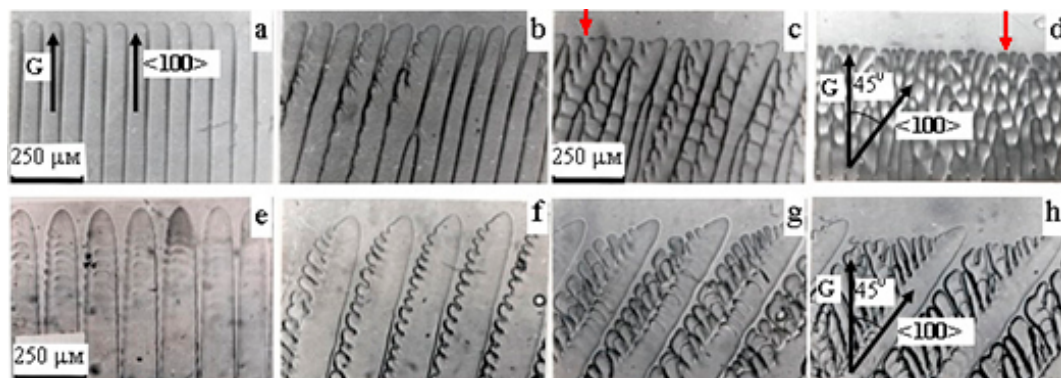


Fig. 6. Directional solidification. G – direction of thermal gradient. Angle between G and  $\langle 100 \rangle$  direction is 0° for a), e); 15° for b), f); 30° for c), g) and 45° for d), h). Rate of growth is 3 μm/s for a) – d) and 6 μm/s for e) – h). Arrows on c) and d) indicates splitting element to compare with Fig. 1.

So, analogy in morphologies put forward the question relatively analogy of “forced conditions” in both cases. Back to the rheocasting process (producing degenerate dendrites), it must be noted that its essential feature is the intensive shearing of the melt. Thereby it seems that flow incoming on solid-liquid interface generates some gradient. Due to this locally crystal is growing along this gradient (not in a preferential direction) and some “directional solidification” takes place.

#### References:

1. Orientation selection in dendrite evolution / *T. Haxhimali, A. Karma, F. Gonzales, M. Rappaz* // *Nature Materials*. – 5, – P. 660-664 (9 July 2006). doi:10.1038/nmat1693 Article
2. *Flemings M. C., Yurko J.A., Martines R.A.* Semi-solid forming – our understanding today and its implications for improved processes // Symposium in Honor of Wilfred Kurz, Charlotte, NC, USA, March 14-18, 2004.- P. 3-14.
3. *Somboonsuk K., Trivedi R.* Dynamic studies of dendritic growth // *Acta metallurgica*. – 1985. – Vol. 33. – № 6. – P. 1051-1060.



**АНОТАЦІЯ.** У статті розглянуто можливі причини утворення дегенеративних дендритів у процесі недендритної кристалізації металів, зокрема Al-Si сплаву (A356). Дослідження включають експерименти з модельними системами та числове моделювання.

Встановлено, що такі морфології можуть виникати через зменшення анізотропії, перехідні процеси або примусові умови зростання. Під час експериментів з направленою кристалізацією і зміною умов росту спостерігались як класичні, так і розщеплені дендрити. Зроблено висновок, що градієнти, створені під час інтенсивного перемішування розплаву, можуть бути причиною утворення дегенеративних дендритів.

**КЛЮЧОВІ СЛОВА:** Дегенеративні дендрити; недендритна кристалізація; алюмінієві сплави; направлена кристалізація; анізотропія.