

# The influence of graphite particles on solidification of composite suspension during flow

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## Abstract

The measurements concerning the temperature field of the composite suspension with AlMg10 alloy matrix reinforced with graphite particles during its flow in a runner-like mould cavity have been performed for the purpose of investigating the influence of the graphite particles on the solidification kinetics. Applying the derivative differential thermal analysis method, the kinetics of solidification heat release has been calculated for examined composites. The time-dependent quantity of solid phase crystallized over the period of flow has been determined on this basis. The dependence of the solid phase quantity upon the momentary length of the experimental casting has apportioned the length of the solidification zone in the casting and the critical fraction of solid phase at which the flow stops. The solidification zone is longer and the critical fraction of solid phase at the stream front is lower for composite containing 10% of graphite particles than for the one with 20% of graphite. The composite reinforced with 20% of graphite particles flows at a significantly lower rate and exhibits reduced castability as compared with the composite with 10% of graphite. It is caused by the higher solidification rate in the initial stage of the process. The obtained results allow for supposing that graphite particles intensify composite solidification by changing the kinetics of the process.

**Keywords:** casting composites, suspension flow, solidification of composites, solid phase fraction, graphite particles

## 1. Introduction

Many models of flow and solidification of metals and alloys exists in the field of the theory of crystallization depending on the assumed solidification mechanism of metal or alloy [1-3]. One of the theories says that due to the heat transmission between molten alloy and the mould the alloy begins to solidify at cavity walls as soon as it starts filling the cavity. Further flow is accompanied by further solidification from the walls towards the centre of the flowing metal stream. The stream is therefore stopped due to the reduction of the effective runner diameter in the initial section of the mould [4-5]. Some authors say that all alloys solidify in this way, while others claim that this mechanism is valid only for eutectic alloys and pure metals i.e. the melts of narrow range or

even constant value of solidification temperature. For alloys of wide range of solidification temperature they introduce another solidification mechanism. In this assumption the movement of flowing metal is stopped as a result of reaching the so-called 'critical concentration' of solid phase. Some authors state that alloys in general solidify in the mixed way and the solidification temperature range affects only the ratio of crystals solidified at the mould walls to those arising in the volume of alloy. This variety of presumed solidification mechanisms results in various criteria for determining the moment of flow stopping: reaching the critical concentration of solid phase, occurring of the temperature at which castability drops to zero value, or critical narrowing of the

mould runner. All of them, however, only partially reflect the actual phenomena occurring during flow [7]. These phenomena have not been sufficiently explained so far because they are rather complicated and hard to explore experimentally. Their complexity demands for taking into account also the surface tension, the pressure of gases evolved of the mould, friction between metal and the mould wall, and chemical reactions at the metal/mould interface [8]. Only the direct measuring of the characteristic flow parameters creates the possibility of solving such a complex problem. Nowadays it is possible thanks to the possibility of performing extremely precise measurements and recording its results with aid of computer programs. Experimental investigation in this field is really necessary, because only the measurements held under the actual conditions can give the reliable results as distinct from the more and more popular computer simulations of these processes [9-13].

## 2. Methodics of investigation

The temperature field of flowing and solidifying suspensions has been determined from measurements performed with the NiCr-Ni thermocouples placed at distance markers of the spiral castability test mould. Composite suspensions prepared by mixing method have been gravity cast at 973 K into the oil sand mould. Metal temperature at a given place of the mould has been recorded during flow of the composite suspension along the runner by means of PCL-818 computer laboratory card. This card reads and records the sensor inputs with 100 kHz frequency. Measurements have been performed for AlMg-alloy matrix composites containing 10% or 20% by volume of graphite particles. The actual cooling rate of the flowing composites has been determined by applying the derivative differential thermal analysis method. Calculating the gradient cooling rate from the formerly presented relationship [3] has allowed for finding the beginning of solidification (the liquidus temperature), supercooling and the rate of release of the heat of crystallization for the examined composites. The contribution of the released heat of crystallization to the total heat of composite solidification determines the momentary quantity of solid phase crystallized during flow and solidification. Determining the fraction of the crystallized solid phase in relation to the length of the test casting allows for establishing the crystallization zone and the 'critical concentration' of solid phase at which flow stops. Finding the location and size of the metal crystallization zone during flow found a basis for the assessment of the mechanism of metal crystallization during flow. The actual quantity of solid phase crystallized during flow should be calculated as a function of temperature in order to compare the actual solidification either with the equilibrium one or with the model cases which kinetics can be determined by computer simulations. The fraction of solid phase during crystallization is equal to the proportion of crystallization heat released at a given moment to the total crystallization heat of the alloy.

## 3. Experimental results

Figure 1 presents the change of the released crystallization heat versus time for investigated materials. The areas under the respective curves indicate the total amount of crystallization heat. Examining the obtained curve courses one can see the influence of increased quantity of graphite particles (20%) on rising the crystallization rate at initial and

final stages of the process as compared with the composite containing less amount of particles. The latter one exhibit the greatest crystallization rate in the middle period of the process. Such plot courses suggest that graphite particles actively influence the nucleation process, which is confirmed by the reduced values of supercooling during flow and solidification. The quantity of released heat of crystallization is greater for the composite with greater graphite percentage, and this indicates the greater amount of crystallized solid phase. The kinetics of the change of the crystallized solid phase amount has been presented in Fig. 2. At the initial stage of solidification the character of curves is similar for both composites. For composite containing 20% of graphite particles there is observed a greater crystallization rate in the initial stage of the process and a rapid increase of crystallization rate during its final stage immediately before the flow stop. This occurs when the crystallized solid phase fraction amounts to 12%, while for composite containing less graphite particles the flow stops at the 9% of solid phase fraction. For both composites the crystallization begins after the same time of flowing, but at different positions within the filled mould due to the various flow rates of the composites. The composite containing 20% of graphite exhibits the castability and the flow rate almost two times less than the composite with 10% of graphite.

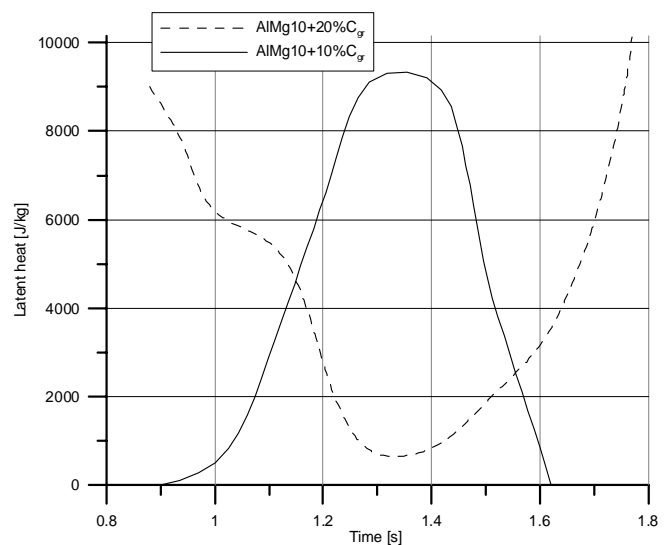


Fig. 1. Kinetics of crystallization heat release

Interesting curve courses are shown in Fig. 3 depicting the change of the solid phase amount at the stream front against the length of the spiral test casting.

The solidification zone for composite containing 20% of graphite extends over a distance of about 170 mm and is shorter than the corresponding zone for composite with 10% of graphite, which is 270 mm long. The character of changes of the solid phase quantity in such a zone is similar for both cases and therefore the similar mechanism and kinetics of crystallization can be supposed. A characteristic reduction of solid phase growth rate can be seen in the middle region of crystallization zone for composite with higher graphite fraction. This points out to the phenomenon of moving the floating crystals with the metal stream during flow which results in rapid increase of the solid phase

amount in the end zone of the casting and swift stopping of flow. The uniform increase of the quantity of solid phase crystals is observed within the beginning and the end regions of the crystallization zone. The composite containing less amount of graphite exhibits the greatest rate of solid phase growth in the middle region of the crystallization zone, what can indicate occurring of the volume crystallization mechanism in the entire zone. This is associated with the greater cooling rate. The total amount of the solid phase in the crystallization zone is equal to the area beneath the presented curves.

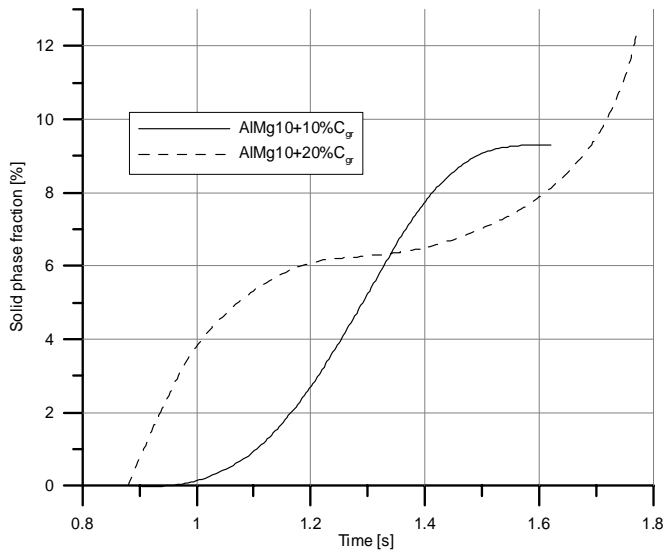


Fig. 2. Change of solid phase quantity during composite solidification

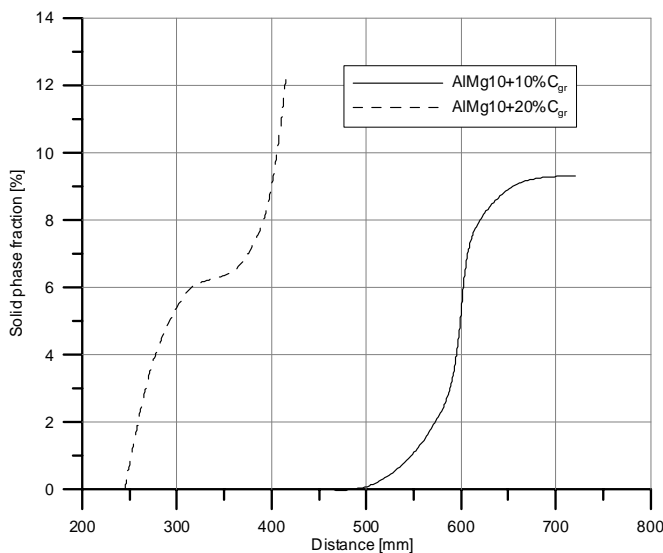


Fig. 3. Solidification zone during flow of composites

Fig. 4 shows temperature function against the change of the solid phase percentage for both examined composites. The presented plots agree with the above described Figure 3. The fact that the maximum crystallization rates of the examined composites occur at different temperatures results from different supercooling values during flow. An increase of graphite fraction in composite causes the reduction of supercooling during the solidification process thus bringing the actual process kinetics nearer the model case of crystallization with full or partial mixing. The crystallization kinetics for composite with 10% of graphite particles exhibits a deviation from such model cases due to the relative high supercooling of metal.

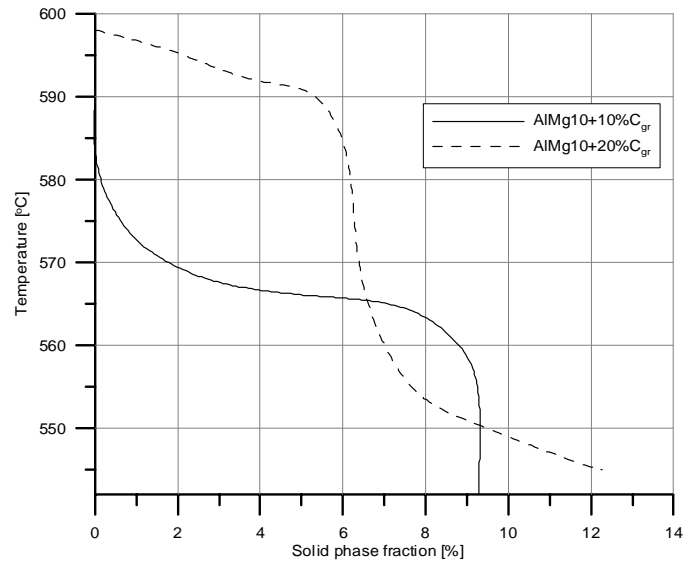


Fig. 4. Temperature function against solid phase percentage in solidifying composites

## 4. Conclusions

The performed measurements concerning the temperature field of the investigated composite suspensions during their flow in the mould runner have allowed for complex assessment of flow and solidification characteristics. It is worth emphasizing that the course of supercooling changes for the composite suspension, as well as the kinetics of the crystallization heat release and changes of crystallized solid phase quantity have been determined as functions of different variables. The particularly interesting result is determining the solidification zone of flowing metal and changes in the amount of solid phase in such a zone. The character of changes of a function like this is a basic argument enabling formulation of the description of the crystallization mechanism occurring during composite flow and the influence of graphite particles on this process.

An increase in quantity of graphite in composite results in the change in kinetics of crystallization heat release, increasing the release rate in the initial and final stages of flow and solidification. Graphite particles generally do not influence the

character of changes in quantity of crystallized solid phase in respect of time or distance, although some differences have been found. The observed differences in kinetics of the solid phase growth points out to the possibility of graphite influence on the crystallization mechanism. An increase in quantity of graphite particles in a composite affects its rheological properties by slowing down the flow rate and reducing the cooling rate. The possible nucleation-promoting influence of graphite along with the reduced cooling rate cause the decrease of matrix alloy supercooling. As a result the crystallization rate enhancing is observed in the initial stage, and the increased quantity of solid phase crystals along with the relatively high temperature and flow rate of the alloy create the advantageous conditions for floating (transportation) of crystals towards the metal stream front, what causes the quick growth of their concentration and rapidly stops the flow.

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