MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

SURFACE ROUGHNESS OF RAPIDLY SOLIDIFIED RIBBONS

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ABSTRACT

This work aims to study the influence of processing variables in melt spinning - which is one of the rapid solidification processes (RSP) - on the surface roughness of the ribbons produced directly from the melt.

The melt spinning is one of the recent manufacturing techniques, in which the final products - ribbons and fibers - could be produced directly by solidification of liquid alloys, thus saving all further conventional metal forming processes usually carried out.

In this investigation, a melt spinning apparatus was designed and constructed in order to produce ribbons from the melt using a rotating substrate in the form of wheel. The alloys studied were aluminium alloys with 0, 5.23, 13.46 and 33 wt% Cu.

The processing variables used were as follows: substrate linear velocity (v) ranging from 2 to 20 $m.s^{-1}$, injection pressure of the melt (P) ranging from 2.9×10^4 to 6.8×10^4 $N.m^{-2}$, substrate thermal conductivity (K) ranging from 43.3 to 386.6 $W.m^{-1}.K^{-1}$, melt superheating temperature (ΔT) ranging from 0 to 150 K, nozzle - substrate distance (H) ranging from 5 to 20 mm and nozzle diameter (d) ranging from 0.5 to 2 mm. The surface roughness (R_t) has been measured and it was correlated with the different processing variables.

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INTRODUCTION

The rapid solidification processing (RSP) is considered one of the relatively new casting processes in which a cooling rate of at least 10^4 $K.S^{-1}$ is maintained through the melt transformation from liquid to solid [1].

The melt spinning is one of the RSP recent manufacturing techniques, in which the final products - ribbons and fibers - could be produced directly by solidification of liquid alloys, thus saving all further conventional metal forming processes usually carried out.
Some examples of possible melt spinning products applications and markets are:

Among the chill methods, the processes associated with wide sheet production, have received the most commercial attention. U.S.A. and Japan have been capable of producing sheet greater than 80 mm wide in a semi-continuous manner. The unit at Allied Chemical in the U.S.A. [1], for example can run for several hours without any interruption. Since the production rate is greater than 1 kilometer per minute, this represents a considerable amount of sheet.

One of the largest, most profitable markets for ferrous fibres could well be their use in fibres concrete [2 , 3]. This material trade-marked "Wirand" concrete by the developer, Battelle Development Corp., could and probably will replace a great percentage of reinforced concrete as it is now used. In the case of Wirand, relatively small fine-diameter fibres are randomly mixed into more-or-less conventional concrete at the time of mixing. These fibres when properly spaced, serve as crack arresters and give concrete increased tensile strength, wear resistance, impact strength and spall resistance.

The same can be said about the useful using of rapidly casted ferrous fibres for tyre strengthening which may have a great commercial success due to the high rate of consumption of tyres.

Zinc ribbons directly spun from the melt have a very attractive surface which absorbs SO_2 from the atmosphere. Levels of several parts SO_2 per million can be reduced to less than 0.1 part per million by passing air containing the gas through a moderately compressed zinc-fibres filter. i.e. this type of cast-fibres is very useful in the field of pollution [4].

An immediate potential market for fibre is the replacement of powder in certain powder-metallurgy applications and so, a new fibre-metallurgy term appears. For example, beryllium powder (actually the oxide and other compounds) is highly toxic, a considerable capital investment is required for safety equipments to handle beryllium powder. In filament form, this toxicity problem is greatly reduced. One could handle the continuous cast fibre as a powder, compact it, and sinter it, with relative ease. Further more, the potential for cost savings is large [5]. Other products may also benefit by being in ribbon or wire rather than powder form. Those materials that oxidize readily or are pyrophoric in powder form would be much more easily handled in fibre form [4].

The pressed compacts of cast-fibres are stronger than powder compacts, especially when made of a strong ductile material. Such compacts will hold their shapes easily at 10% density, and will not fall apart under shock or load. Under such sever conditions, fibre compact shows little or no damage [4]. Therefore, it is probable that rolled sheets of compacted continuous aluminium fibres could readily replace lead sheets as vibrational energy absorbers, and be lighter and cheaper as well. It is also probable that such fibre sheeting would maintain its damping property over a wide range of temperatures, a performance which very few other damping materials can match. Felts and filters are, of course, other uses to which fibre compacts can be put [4].

An untested market for fibre sheeting is in armour. To defeat an incoming projectile, it is necessary not only to stop the forward movement of the projectile, but to absorb the shockwave produced in the armour itself by the impact before it can produce a spall from the opposite surface. The high damping fibre compacts may excell at this application [6 ,4].

EXPERIMENTAL PROCEDURE

In the melt spinning process, a mass is solidified continuously in a ribbon form by a rotating chill-block substrate from a pool of liquid metal or alloy falling on the substrate. In the designed apparatus, the molten metal is pushed using inert gas, through a small orifice. The metal stream falls on a rotating metallic pulley, thus forming a ribbon. Fig.(1).

Al-Cu alloys Al-pure, 5.7·13·33 wt% Cu were prepared from high purity 99.99% aluminium (german grade) and electrolytic copper using a 1 Kg capacity high purity graphite crucible. The molten metal free surface was covered using a continuous flow of nitrogen. The alloys

Al-Cu charges in the form of 50 gms rods were fed into the melt spinning apparatus which was already in operation (i.e. with hot crucible). Usually, this amount of alloy is enough to produce relatively big amount of melt spun ribbons or fibres. After complete melting, the alloy was heated to the desired superheat, then the furnace power was cut off. While the substrate was rotating, the liquid alloy was pushed to fall directly on it. The ribbons formed are collected in front of the apparatus. After each experiment, the pulley was cleaned while it was repolished using a standard silicon carbide paper of 1000 grid size after each 10 experiments.

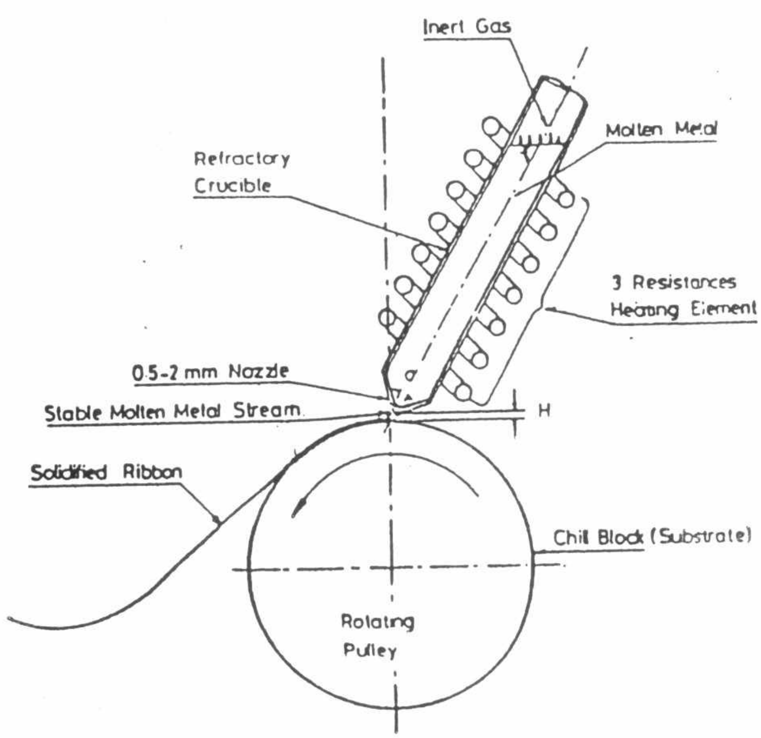

Fig. (1) A schematic diagram showing the melt

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The maximum peak to valley height (R_t) is chosen to measure ribbon surface roughness for both substrate and free sides. Measurements were made along ribbon width. Fig. (2) indicates the roughness value measured. R_t values were measured using a talysurf-4 .

Influence of v on R_t:

Fig. (3) illustrates the variation of ribbon average roughness R_t due to the increase of substrate linear velocity v. The figure includes results obtained for both the substrate-side surface (SSS) of the ribbon and the air-side surface (ASS). From the figure, the following points can be noticed:

a) R_t values for ribbon ASS are always higher than those for the SSS. This could probably be due to the high surface tension property of the aluminium alloys in general.

b) For the ribbon ASS, R_t increases sharply by increasing v up to a value ranging between 4 and 6 $m.s^{-1}$, depending on the alloy composition (4 $m.s^{-1}$ for Al, 5 $m.s^{-1}$ for Al-5.23 wt% Cu, 4.75 $m.s^{-1}$ for Al-13.46 wt% Cu and 6 $m.s^{-1}$ for Al-33 wt% Cu), where a maximum value of R_t is obtained. By further increasing of v.R_t decreases sharply till a minimum value depending on the alloy composition in the same manner. At higher values of v. R_t increases slightly again or even remains almost constant in some cases.

c) The effect of v on R_t at the substrate-side surface (SSS), is much less than that at the air-side surface (ASS). However, the set of curves indicated in fig. (3), of the SSS, for different alloys, although show a behaviour similar but weaker than that of ASS. From the results, it is clear that R_t is strongly dependent on v, especially on the ribbon air-side surface. Huang and Fiedler [7] reported that the roughness of the ribbon substrate-side surface is due to the air pockets which are trapped during the process. They proved that the air pockets distribution and size are functions of the substrate surface roughness, wetting characteristics of the alloy on the substrate material and of the substrate linear velocity. They found that the use of matte substrate wheel surface (i.e. increasing its roughness) and increasing of the wetting characteristic of the alloy on the used substrate surface (mainly the wetting angle), reduce the number of pockets obtained and assure heterogeneous air pocket distribution. With increasing the substrate linear

There is another point of view for the roughness appearence reason. Schmidt* quoted that the main reason of roughness appearing on the ribbon substrate-side surface especially in case of aluminium alloys, is the gluing tendency of the aluminium to the copper substrates, so that many small pieces of the cast ribbon are left sticking to the substrate surface after their dislocation of the ribbon surface causing that roughness as shown in fig. (4). This defect could be cancelled using chromium coated copper substrates to reduce the sticking of aluminium on its surface. Huang and Fiedler [7] used copper 1% chromium substrate and obtained good results. On the other hand, the high surface tension of the aluminium gives roughness wide waves across the ribbon width. Such defect could be cancelled by casting in vaccum or in controlled atmosphere using inert gas such as helium [8 , 9], or modifying the aluminium alloy wetting characteristic through changing its chemical composition (adding other elements).

Influence of substrate material on R_t:

Fig. (5) shows the influence of the substrate thermal conductivity (K) on ribbon surface roughness (R_t) for both ribbon substrate-side and ribbon air-side surfaces. It indicates that by increasing K,R_t slightly increases or may be considered almost constant. The relationship between K and R_t is similar to that obtained between K and ribbon average thickness (t) which indicates that R_t is dependent on t [10].

This may be due to the fact that using a substrate material of low K, the molten metal will find a longer time to spread and flatten its surfaces before its complete solidification. However, the same figure indicates that for the ribbon substrate-side surface (SSS), the obtained roughness using both the copper and steel substrates were nearly the same. For the ribbon air-side surface (ASS), the roughness values obtained using the copper substrate were higher than that obtained using the steel one. This is due to the very rapid quenching of the melt on the lower surface of the ribbon so that the substrate thermal conductivity may not have a strong effect as that produced by its original surface roughness. The figure also indicates that the difference in roughness values between both ribbon surfaces increases by increasing K. This means that in order to obtain uniform

* *Dr. I. Schmidt, werkstuff lab., Bouchoum University, West Germany, through a private contact.*

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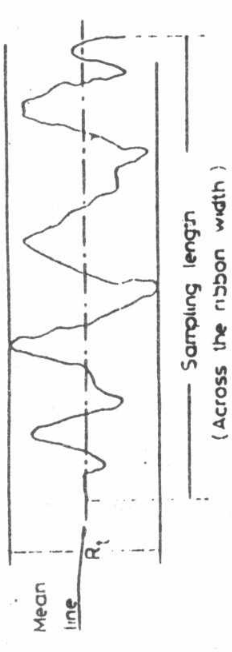

Fig. (2) Ribbon surface roughness (R_t) which was measured across ribbon width.

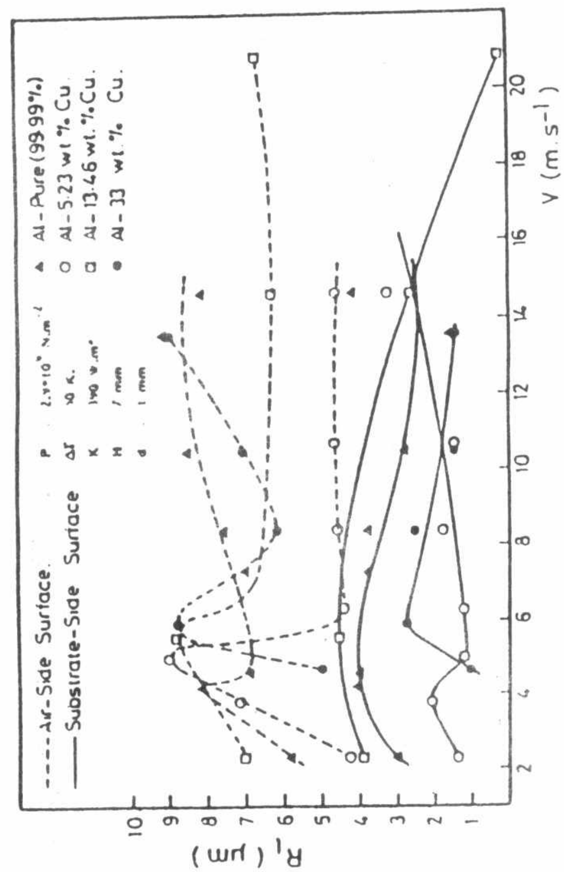

Fig. (3) Variation of ribbon surface roughness (R_t) with substrate linear velocity (v)

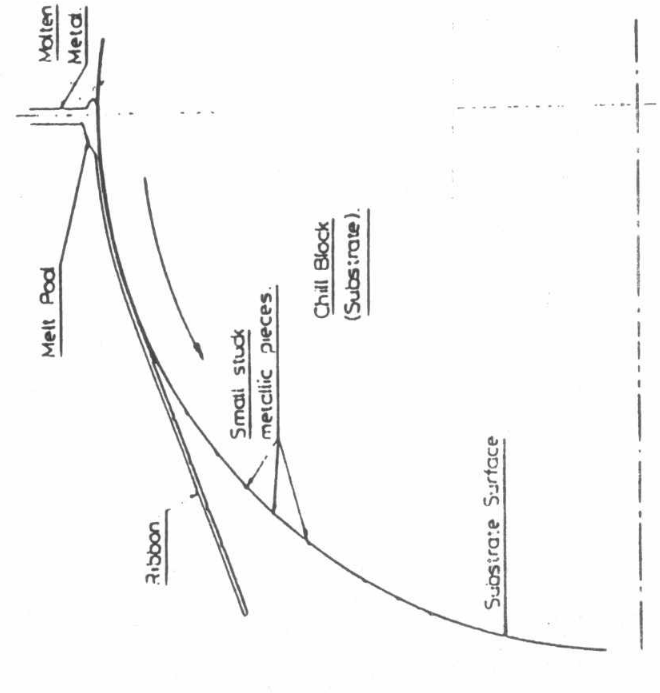

Fig. (4) Reason of roughness appeared on the ribbon substrate side surface when aluminium alloys are used with copper substrate.

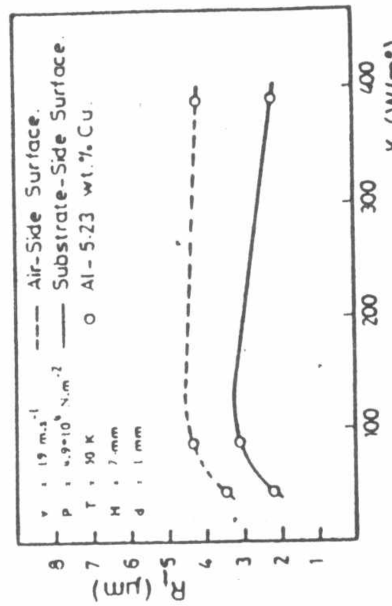

Fig. (5) Influence of substrate thermal conductivity (K) on ribbon surface roughness (R_t).

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ribbon surfaces with minimum roughness, it is better to use a substrate material of low thermal conductivitylike steel.

Influence of P on R_t: Fig. (6) shows the variation of average surface roughness (R_t) with P. The figure includes results on R_t of ribbon substrate-side surface (SSS) and ribbon air-side surface (ASS) for Al-5.23 wt% and for Al-13.46 wt% Cu alloys. For Al-13.46 wt% Cu alloy, R_t increases with increasing P up to a value of P about 4.9×10^4 $N.m^{-2}$ (0.5 $Kg.cm^{-2}$), for both the SSS and ASS of the ribbon, after which R_t decreases. This behaviour is similar to the relationship obtained between P and ribbon average thickness (t) which means that R_t is dependent on ribbon thickness [10].

Similar behaviour was observed for the ASS of the Al-5.23 wt% Cu alloy but the behaviour in the case of the ribbon substrate-side surface (SSS) was different where its surface roughness (R_t) decreases gradually with increasing P. This behaviour is similar to the relationship obtained between P and ribbon average thickness (t) which means that R_t is dependent on ribbon thickness [10].

Fig. (6) also indicates better surface quality, for both ribbon sides, for Al-13.46 wt% Cu alloy where R_t was always lower than that of the Al-5.23 wt% Cu alloy. This result may be explained since the Al-13 wt% Cu alloy exhibits a better fluidity than the Al-5.23 wt% Cu alloy. At ribbon substrate-side surface, R_t was lower than that at air-side surface due to the intimate contact with the substrate surface.

Influence of ΔT on R_t:

Fig. (7) shows the influence of ΔT on R_t. It indicates that R_t decreases by increasing ΔT for both the ribbon substrate-side surface (SSS) and the ribbon air-side surface (ASS), and also that while ΔT was increasing, the difference in roughness between the two surfaces was almost constant. The improvement in both surfaces due to increasing of ΔT may be related to the accompanying improvement of alloy fluidity. Additionally, the relationship between ΔT and R_t is similar to the relationship obtained between ΔT and the ribbon average thickness (t) [10]. This means that R_t is dependent on ribbon average thickness and that it is possible to produce a relatively smooth ribbon by increasing ΔT of the alloy. the

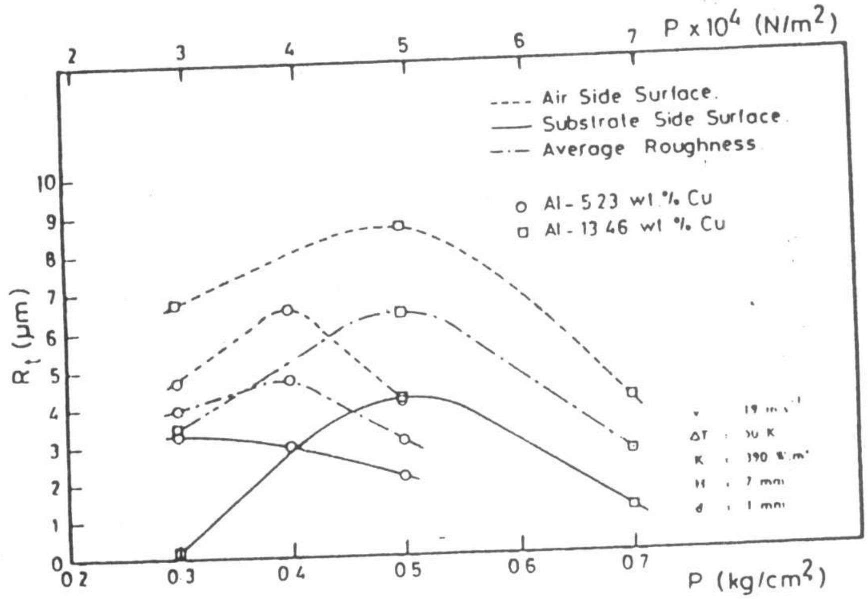

Fig (6) Variation of ribbon surface roughness (R_t) with injection gas pressure (P)

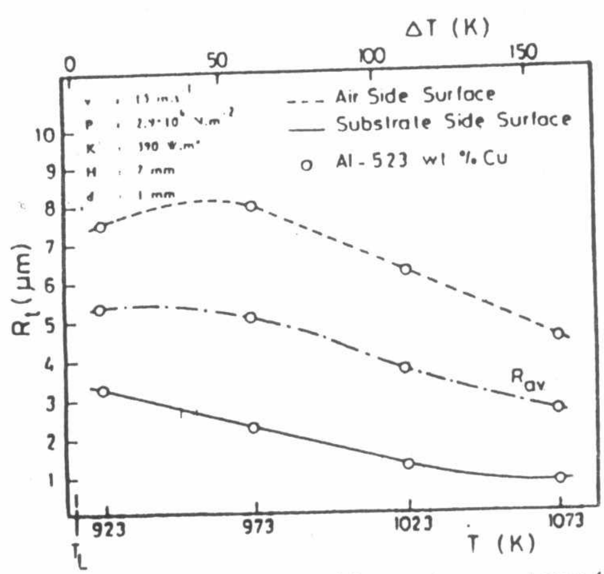

Fig (7) Variation of ribbon surface roughness (R_t) with melt temperature (T) and melt superheat (ΔT) the substrate surface plus the air pockets usually trapped under the lower surface of the ribbon [7].

Influence of H on R_t:

Fig. (8) illustrates the variation of ribbon surface roughness (R_t) with nozzle-substrate distance (H). For ribbon substrate-side surface (SSS), R_t increases by increasing of H up to a value of H = 12 mm after which R_t decreases gradually. On the other hand, for ribbon air-side surface (ASS), R_t decreases by increasing H up to a value of H = 9 mm after which R_t gradually decreases. That may be due to the change of impact force whose increase causes ribbon irregularities and splashes. The figure indicates that the best nozzle-substrate distance is H = 10 mm which results in the lowest possible average surface roughness for both sides of the ribbon.

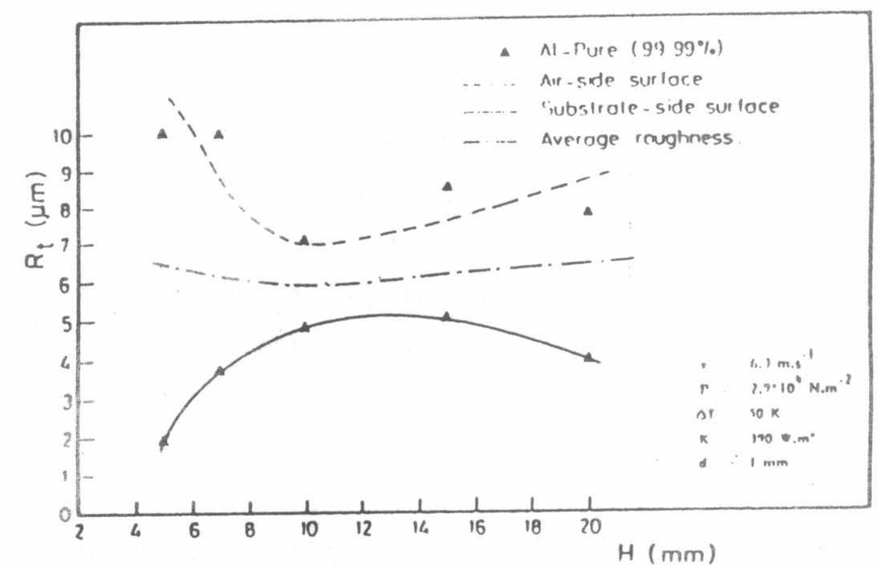

Fig. (8) Influence of nozzle - substrate distance (H) on ribbon surface roughness (R_t)

Conclusions:

From the above results and discussions, the following conclusions can be drawn:

The surface roughness (Rt) of the Al-Cu ribbons produced by melt spinning is greatly affected by the processing variables. Generally, Rt at the substrate side is less than that at the air side. The wheel velocity and injection pressure affecr Rt in such a way that there are points of maximumm Rt at certain values. Rt at air side is much more sensitive to variations in the processing variables than that at substrate side. Substrate material with low thermal conductivity and injected melt with high superheat are recommended for smoother ribbon surfaces. There is an optimum injection height at which best ribbon

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