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Research Article

Experimental Investigations on Mechanical Properties of AZ31/Eggshell Particle-Based Magnesium Composites

N. Ramanujam,[1] S. Muthukumaran,[2] B. Nagesawara Rao,[3] M. Ramarao,[4] Amol L. Mangrulkar,[5] K. S. Ashraff Ali,[6] L. Pugazhendhi,[7] and Mebratu Markos[8]

[1]*Department of Mechanical Engineering, E.G.S. Pillay Engineering College, Nagapattinam 611002, Tamilnadu, India*
[2]*Department of Mechanical Engineering, University College of Engineering Panruti, Panruti, Tamil Nadu, India*
[3]*Department of Mechanical Engineering, VFSTR, Vadlamudi, Guntur 52213, Andhra Pradesh, India*
[4]*Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai 600073, Tamilnadu, India*
[5]*Department of Mechanical Engineering, Rajiv Gandhi Institute of Technology, Mumbai 400053, India*
[6]*Department of Mechanical Engineering, C. Abdul Hakeem College of Engineering & Technology, Vellore 632509, Tamil Nadu, India*
[7]*Department of Mechanical Engineering, Chennai Institute of Technology, Chennai 600059, Tamilnadu, India*
[8]*Department of Mechanical Engineering, College of Engineering, Wolaita Sodo University, Ethiopia*

Correspondence should be addressed to Mebratu Markos; mebratumarkos@wsu.edu.et

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Magnesium (AZ31) is an excellent choice for a bionic implant. To enhance biocompatibility, the hardest graphene nanoparticles were reinforced with biocompatible materials. In this paper, biocompatibility composite material is produced by stir-casting nanoshell particles reinforced with various weight percentages (0, 1, 2, 3, and 4 wt. percent) of AZ31 magnesium alloy. To understand the mechanical properties of the composite material, results of which are compared to the base alloy (AZ31) are used. The study mentioned how AZ31 magnesium alloy, reinforced with reinforcing particles, may be used to create implant-related human bone materials. Magnesium alloy reinforced with reinforcing particles is described in the study.

1. Introduction

Magnesium has excellent biocompatibility and modulus of elasticity in line with the human bone. Inorganic-stage calcium-containing crystals are embedded in the bone, increasing the tissue's sensitivity to normal stresses. Due to pathology and desorption, bone tissue breaks. Metals utilized for clinical purposes are found in the manufacturing process of bone fixation devices [1]. Magnesium is in high demand in every sector involved in the design and manufacture of automobiles, aircraft, and diverse engineering to meet those industry's needs. However, further advancement will be necessary if this technological evolution is to continue. MMC is a possible solution. Fibres or particulate of a ceramic material, i.e., silicon carbide or graphite, are usually present in metal matrix composites to reinforce the low-density material, i.e., aluminium or magnesium. Specifically, higher stiffness, operating temperature, wear resistance, and customizable properties can be found in these materials. AZ31 magnesium alloys have the opportunity to explore as light alloys for replacing some conventional structural materials in cars and trucks, locomotives, and general aviation. Using particulate magnesium matrix composites to make isotropic materials with improved mechanical properties is a favourable fabrication process (MMCs). Each of these variables is beneficial in increasing the mechanical properties of MMCs. Mg alloy in the AZ series has properties of cost effectiveness, density friendliness, and good mechanical properties, as well as cast ability [2]. The resulting thermomechanical processed precipitates of Mg17Al12 improve the mechanical properties. In addition, AZ Mg alloy incorporates particle reinforcements (which causes a higher strengthening efficiency) and thus incorporates reinforcements [3, 4]. The AZ Mg alloy has a significant increase in the amount of aluminium in its semisolid region, making it appropriate for semisolid casting. Developing new lightweight materials from recycled materials will be critical to sustainable development [5–7]. When there are Ti and SS alloys limiting the supply, magnesium can be a suitable alternative. Magnesium is exceptional in having a high level of strength, load-bearing capacity, biocompatibility, toxicity, and wide abundance in the earth's crust, water, and the human body and a modulus of elasticity that matches the bone [8, 9]. This is why the bone is more elastic than normal; thus, it protects the implant and bone better.

Additionally, Mg-based materials reduce the trauma the host patient experiences while also benefiting the host [10–14]. This is significant because even though it is possible for Mg to be absorbed into the human body and excreted without triggering an inflammatory response, this does not occur if Mg is consumed or injected. To make magnesium an attractive temporary implant, it is necessary to use conventional materials with these two features [15–19]. There are various requirements for materials that use Mg; they must meet them all to function as an equivalent replacement for the materials they replace. The importance of having important properties such as biocompatibility and low toxicity and other undesirable side effects over the service life cannot be stressed enough [20]. To obtain novel Mg-based materials with enhanced mechanical and corrosion responses, biocompatible alloying elements/reinforcements are required [21, 22]. Magnesium, in its original form, has few disadvantages, such as flexibility and corrosion resistance, in aqueous environments [23, 24]. Ball milling is a mechanical method for grinding particles into small particulates. Conventionally, the particles are usually cracked apart by solvent molecules; however, the reactants are separated apart by mechanical stresses in ball milling.

Methods used in the past have included the use of Al_2O_3, Y_2O_3, SiC, and CNT nanoparticles in various Mg-based composites (also known as carbon nanotubes). Also, recent studies [25–29] show that increasing magnesium's strength and ductility at the nanoscale by using ceramic reinforcements is possible. Because AZ31 alloy is so widely used in engineering applications, it has been paid a lot of attention [30]. From a survey of the relevant literature, the researchers found that very little research has been conducted to study the mechanical behaviour of nanometer-sized particulate or fibre hybrid-reinforced metal matrix composites. Results obtained from experiments with AZ31 magnesium matrix composites reinforced with submicron-SiC particulates showed that the mechanical properties were improved significantly. Xiang et al. [4] proceeded with the stir casting of AZ31 and discussion of mechanical characterization of the SiC particles included. The studies found that increasing the reinforcing particle from titanium dioxide, also called titanium(III) oxide, increases ultimate tensile strength, yield strength, and elastic modulus, along with a decrease in grain size [31]. Eggshell is a low-cost, abundant source of calcium, one of the best reinforcement options, which can be derived from chicken aviculture. Bone flours and oyster shells contain toxic elements such as Cd, Al, and Hg, and these toxins cause diseases in people, making bone flours and oyster shells less useful for medical use. The role of calcium in promoting bone mineralization aids in bone remodelling [32]. Eggshell having a lower density and greater stability has been superior to calcium carbonate, industrially prepared. It has recently been discovered that eggshells enhance the refining and strengthening of grain size and strength in the Al and Mg matrix. Magnesium alloy AZ31 was synthesized by stirring in water, and this solution was applied to small eggshell-sized nanoeggshell particles [32–34]. Researchers are conducting a series of experiments in order to determine the effect of nanoeggshell particles on the mechanical properties of magnesium alloy AZ31 in which the particles are also incorporated.

2. Materials and Methods

Magnesium is an important metal used in numerous industries, including electronics, automobiles, and aerospace. The composition of magnesium alloy AZ31 is listed in Table 1. Ball milling was used to reduce the average size of the eggshell powder (15–35 nm) to a finer nanosize that is just above the sub-nanosize range. The particle size of the product dropped dramatically after ball milling. The powder was ball-milled for 15 hours and then refined for 20 hours, which refined the powder to an average particle size of less than 75 nm and a range of 15–35 nm. The overall size of the ball mill did not change as the 40-hour ball milling time remained constant. This is why the synthesis of the composite materials required a total of 20 hours of eggshell powder that had been ball-milled. Powdered eggshells did not have detectable peaks other than calcium carbonate after the milling process. After ball milling, no impurities or additional secondary phases were found. Magnesium's biocompatible feature is increased by utilizing nanoeggshell particles (15–35 nm size), which improve the material's mechanical properties. Magnesium alloy AZ31's distinct composition details are shown in Table 2.

The density data from the samples that were developed are documented in Table 3. To obtain theoretical density, the rule of mixtures method was used.

The experimental density of magnesium alloy AZ31 used in the experiment is 2.231 g/cc. In order to measure experimental densities, the nanoeggshell particles (wt. percentages of 1, 2, 3, and 4) were added. This increased the measured densities to 2.568, 2.765, 2.963, and 3.123 g/cc, respectively. A study following up on this led to a later discovery of rising porosity levels in the samples. Near-dense materials are acceptable under certain porosity limits, which is what makes this trend in porosities acceptable. The lower porosity levels primarily attributed to our control of extrusion parameters and avoidance of air entrapment in the molten slurry during the stirring process occur because of our advanced control techniques. Promotion of nanoeggshell particle reinforcement is made easier because the molten slurry in the steel mould is rendered incapable of

Table 1: Various chemical elements available in magnesium alloy AZ31.

Elements	Aluminium	Zinc	Manganese	Silicon	Ferrous	Calcium	Magnesium
Contribution (%)	3.3	0.83	0.31	0.03	0.002	0.0023	Ball

Table 2: Composition details of the composite specimens.

Specimen identification	Wt. % of magnesium alloy AZ31	Wt. % of nanoeggshell particles
MG0	100	0
MG1	99	1
MG2	98	2
MG3	97	3
MG4	96	4

Table 3: Density and porosity values of the samples.

Composition	Theoretical density (g/cc)	Measured density (g/cc)	Porosity
MG0	2.231	2.228	0.1346
MG1	2.568	2.561	0.2733
MG2	2.765	2.757	0.2902
MG3	2.963	2.951	0.4066
MG4	3.123	3.101	0.7094

supporting itself before the slurry is applied, so the particles are more uniformly distributed, and the occurrence of porosity is avoided.

3. Experimental Procedure

Stir casting (Figure 1) was used to make the AZ31 magnesium metal matrix composite. Once the furnace was hot enough, the ingot of magnesium was put in. Because magnesium is highly flammable, a gas that is both nonflammable and safe to breathe was continuously supplied to the furnace as an atmosphere. To prevent the egg white from becoming sticky, the nanoeggshell particles are preheated to 350°C before the addition of magnesium alloys. Magnesium must be heated to 750°C in the crucible before it is used to raise the temperature of the heating element to 450°C. The procedure involves mixing the eggshell particles with molten magnesium in the crucible furnace and then stirring the mixture for 15 minutes using an electric stirrer. The metal has reached a solidified state when it is naturally heated by convection and then poured into a fixed, large iron die, 150 mm × 150 mm × 25 mm in size. Figure 2 reveals the impact tester. The impact sample prepared by the ASTM standard is shown in Figure 3.

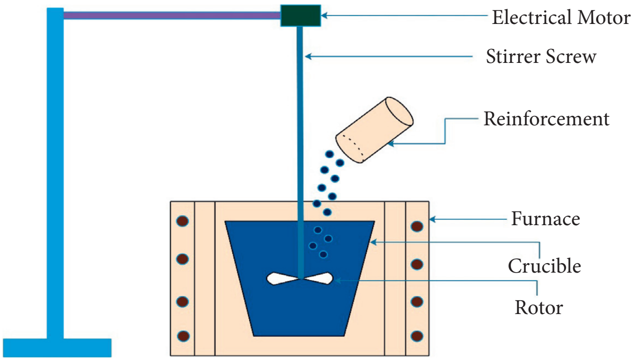

Figure 1: Experimental setup of the stir-casting technique.

4. Results and Discussion

4.1. Tensile Strength. In order to investigate the elasticity and ultimate strength of the material, the tensile test was performed according to ASTM-E32 standards. Every time the materials were reinforced, a specified amount was cut and machined at three different locations according to ASTM standards. The reinforced composite was built to an approximate 34% construction, and the calculated and graphed averages were compared to the testing on a UTM machine. As reinforcement was added, tensile strength increased gradually, as illustrated in Figure 4. Strength increases gradually with the increasing base magnesium alloy content to 80.73 percent. A pie chart displaying the percentage elongation of the composite is shown in Figure 5. The elongation increased at a much higher rate than the AZ31 alloy.

4.2. Young's Modulus. Figure 6 shows the variation in Young's modulus for all composite specimens. With nanoeggshell particles' content, Young's modulus of the MG0 composite sample is around 71 GPa, but it slightly increased to 83 GPa for MG4 composite specimens (4 wt. percent nanoeggshell particles).

Young's modulus depends on the orientation of nanoeggshell particles when being loaded. When nanoeggshell particles are positioned parallel to the loading direction, Young's modulus variation will be high. Conversely, when they are positioned perpendicular to the loading direction, the variation will be low. To get a medium value, roll a random number to find the orientation. As reported by this study, the milling and stir-casting techniques used in the current investigation could have caused nanoeggshell

Figure 2: Impact tester.

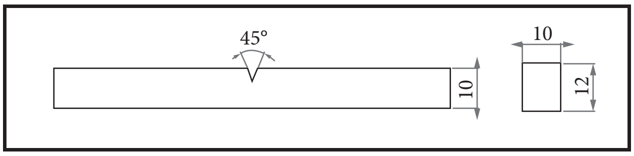

Figure 3: Schematic image of the impact sample.

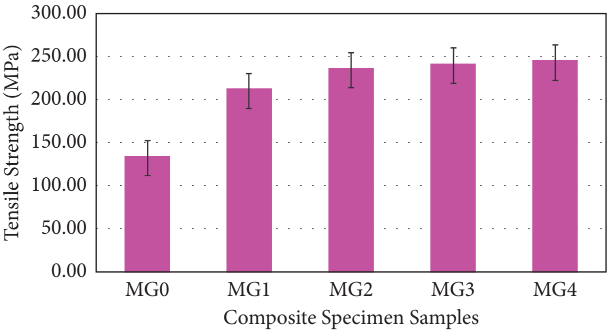

Figure 4: Tensile strength variation of composite specimens.

particles to align in a random orientation, which did not change in response to the applied tensile loads. Additional investigation is required to better understand the variation in Young's modulus in the peak loading condition with nanoeggshell particles' content. Since there is a greater amount of nanoeggshell particles in the composition, the ductility of the Mg alloy/nanoeggshell particle composite is drastically increased, and it still fits within the elongation limits for many applications. Ductility may have improved because there are more void nucleation sites due to the inclusion of nanoeggshell particles, resulting in a lower fracture strain.

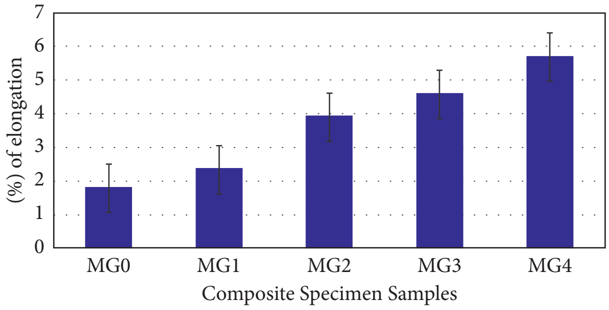

Figure 5: Variation on elongation percentage of composite specimens.

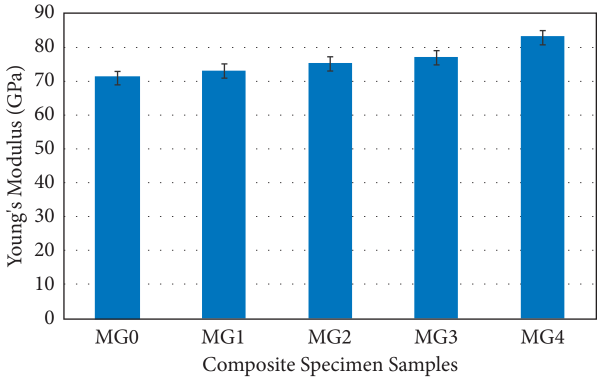

Figure 6: Variation on Young's modulus of composite specimens.

4.3. Yield Strength. Figure 7 shows how variations in yield tensile strengths are affected by Mg alloy and nanoeggshell particles' content. The MG1, MG2, MG3, and MG4 samples that contain nanoeggshell particle-reinforced composite specimens have the highest yield strength (MG0).

This boost from 93 MPa (with no nanoeggshell particles) to 131 MPa represents a boost in tensile strength (Mg alloy with 4 wt. percent of nanoeggshell particles). While improvements in yield strength (29% better) were due to the reinforcement effect of nanoeggshell particles, the strengthening of strengths (yield) was caused by the reinforcement effect of eggshell particles. Based on the findings of the present study, it can be inferred that the mechanical strength of Mg alloy, reinforced with nanoeggshell particles, gets stronger when compared to the studies conducted by other researchers. Concerning the yield strength of the magnesium alloy AZ31, the contributions of different reinforcements are considered, which include the addition of the nanoeggshell particle-reinforced composites.

4.4. Compressive Strength. A compression test was carried out using ASTM standards to understand the material's compressive properties. Every time the materials were reinforced, a specified amount was cut and machined at three different locations according to ASTM standards. Compression test results were recorded and plotted against the composite's reinforcement percentage. It can be concluded from Figure 8 that the compressive strength of the composite material increases with reinforcement and

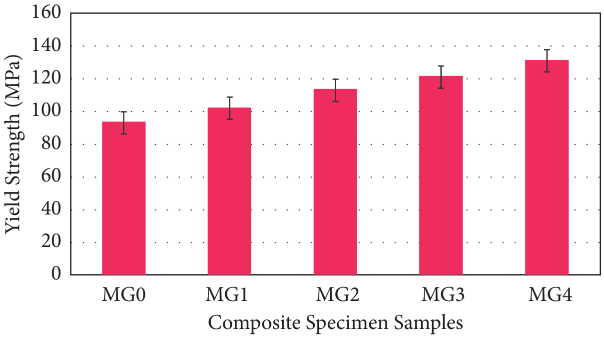

FIGURE 7: Variation on the yield strength of composite specimens.

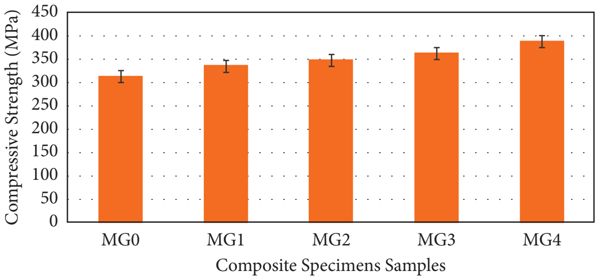

FIGURE 8: Variation on compressive strength of composite specimens.

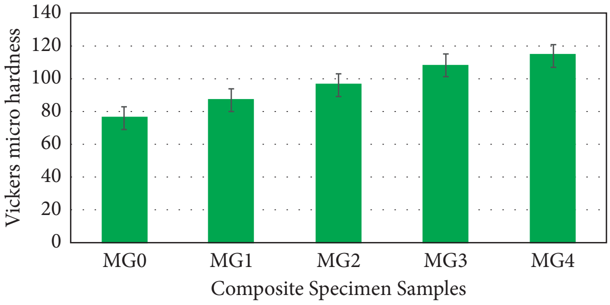

FIGURE 9: Variation on Vickers microhardness of composite specimens.

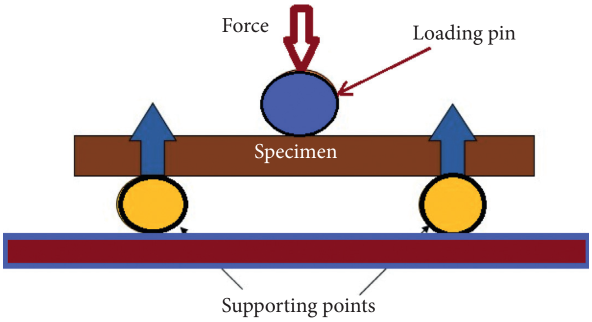

FIGURE 10: Schematic image of the flexural test setup.

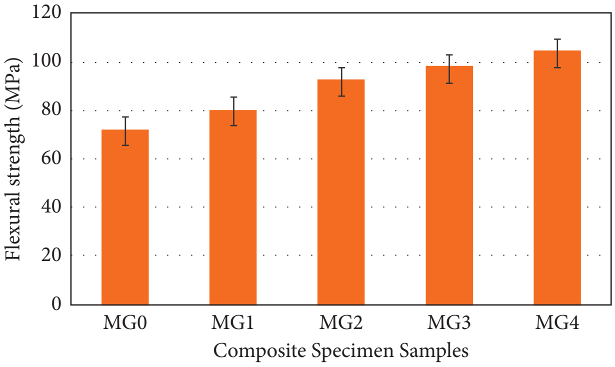

FIGURE 11: Variation on flexural strength of composite specimens.

increases quickly for a moderate amount of reinforcement. Using base magnesium alloy as a baseline, the strength of the composites gradually improves to 24.36%.

4.5. Microhardness. AZ31 magnesium alloy and composite materials were both tested in the hardness test, ASTM E384-99, to understand the effect of nanoeggshell particles in the magnesium matrix. Micro Vickers hardness test results show that the composite material was impacted by a 400 g load for 50 seconds with an 8 mm steel ball indenter. Five locations on the material were tested, and the results were plotted and represented as the composite's overall hardness. The hardness of the composite, which is shown in Figure 9, increases to 29.63 as opposed to the magnesium matrix.

The microhardness test results are shown in Figure 9. A pure AZ31 alloy composite specimen (MG0) was found to have a microhardness of 76 HV. Monolithic magnesium traditionally has microhardness in the range of 35–55 HV. Significant improvement in the properties of the magnesium alloy can be attributed to the solid solution strengthening of zinc in the melt in the presence of zinc as an alloying element. A monotonically increasing effect was observed after the addition of nanoeggshell particles. While all four composites show 88, 96, 108, and 114 HV in microhardness, MG1 has 1 wt.% nanoeggshell percentage, MG2 has 2 wt.% nanoeggshell percentage, MG3 has 3 wt.% nanoeggshell percentage, and MG4 has 4 wt.% nanoeggshell percentage. Using this enhancement, you can now see the difference between soft nanoeggshell particles and hard nanoeggshell particles, which results in improved grain size and resistance to localized deformation. Tribo measurements should not be confused with materials' hardness as an indicator of tribological response.

4.6. Flexural Strength. The three-point bend test was developed to study the material's bending behaviour according to ASTM standards. With each reinforcment, the prescribed amount was divided into three portions, which were then milled and machined at three separate locations according to ASTM standards. Flexural test arrangement is shown in Figure 10. After the value was plotted versus the percentage of reinforcement from the three-point flexural testing machine, the values were recorded. The composite's flexural strength will increase when the reinforcement intensity increases, as shown in Figure 11. Composites' strength was found to improve gradually to 30.89% when compared to the base magnesium alloy.

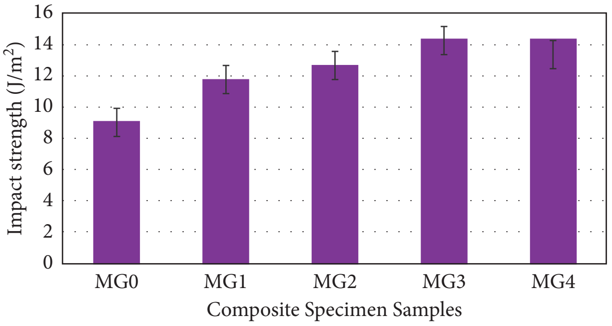

FIGURE 12: Variation on impact strength of composite specimens.

4.7. Impact Strength. To comply with ASTM standards, Charpy impact testing was required. The size we used for the test was 55 × 10 × 10 mm, with a 2 mm depth and the standard angle. The composites were divided into three groups, and the impact toughness of each was then investigated. In Figure 12, it was discovered that impact strength increases steadily with the percentage of nanoeggshell particles, then plateaus, and declines at levels of 1 to 3 percent of composite oxidation.

5. Conclusions

Based on the experimental studies, the following findings were drawn: the pure magnesium alloy AZ31 (0, 1, 2, 3, and 4 wt.% of nanoeggshell particle-reinforced composite specimens) was found to have the following properties: after developing an AZ31 magnesium alloy with nanoeggshell particle-reinforced composites, the particles were dispersed evenly throughout the alloy. When compared to AZ31 magnesium alloy, which was interesting, reinforced material had better results. A few early findings of the experimental phase indicated that the metal matrix composite did not include any intermetallic phase. AZ31 alloy was changed by the addition of nanoeggshell particles. The composite is typically stronger because of the more intricate texture. There is a positive correlation between the nanoeggshell particle hybrid ratio and overall strengthening (96 : 04). Hybrid ratios that are large produce the most robust hybrid composites. The new model agrees with the experimental data very well.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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