

# Parametric Investigations of Melt Flow Index for Nylon6-Mica Composite Based Hybrid FDM Filament

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## Abstract

*The development of new hybrid filaments with improved mechanical and thermal properties has been driven by the increasing need for high-performance materials in additive manufacturing. This study explores the parametric investigations of the Melt Flow Index (MFI) for Nylon6-Mica composite-based hybrid Fused Deposition Modeling (FDM) filament. The investigation uses the Taguchi technique to examine how different extrusion temperatures, loads and the percentage of Mica filler affect the MFI, a critical factor that affects how easily materials flow throughout the FDM process. Results indicate that extrusion load contributes the most (69%) to MFI, followed by filler content (29%) and extrusion temperature (2%). The optimal parameters—250°C extrusion temperature, 5 kg load, and 20% Mica—resulted in an MFI of 2.411 g/10 min, comparable to commercial ABS. These experimental results highlight the crucial roles that both the extrusion load and the fraction of Mica play in optimising material performance for additive manufacturing, as they both considerably affect the MFI. The goal of this research is to help produce efficient and affordable feedstock materials for FDM applications by establishing a relationship between these parameters and the flow properties of the Nylon6-Mica composite. The results provide insightful information that may improve material formulas and processing methods, raising the calibre and dependability of components printed using FDM technology. This study establishes the foundation for future research on composite materials in FDM, encouraging advancements in the field of additive manufacturing by utilising hybrid materials that take use of both flow characteristics and mechanical capabilities.*

**Keywords:** Melt flow index, Nylon6-Mica composite, hybrid FDM filament, parametric analysis, additive manufacturing

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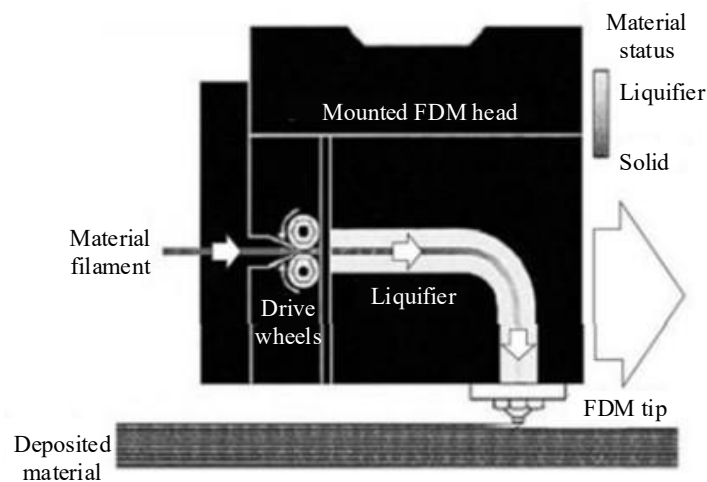
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## INTRODUCTION

Fused Deposition Modelling (FDM) technology was developed in the 1980s and has since become one of the most widely used additive manufacturing techniques, allowing a wide range of 3D objects to be created for a variety of sectors [1]. FDM is incredibly versatile since it works with a variety of thermoplastic materials, including elastomers, polycarbonate, and Acrylonitrile Butadiene Styrene (ABS). Figure 1 illustrates the fundamental operational principle of FDM, encompassing the transformation of material from solid to molten state via the liquefier. Molten material is deposited layer by layer through a nozzle in this method, with the use of a pre-programmed route derived from the STL file format [2]. Although ABS, one of the first materials used in FDM, has outstanding mechanical qualities, tougher polymers like polycarbonate and polysulfonic have been introduced as production demands have grown [3].



**Figure 1.** Fused deposition modelling [6].

The cost of patented FDM materials is still costly, despite its benefits. In an effort to address this, scientists have created new, reasonably priced feedstock materials and optimised the parameters of the FDM process to increase productivity and material utilisation [4].

The application of FDM technology in a variety of sectors has been further enhanced by efforts to optimise the mechanical qualities of the parts through internal support structures and finite element analysis, which have also yielded new insights into melt flow dynamics [5]. In the foreseeable future, FDM technology and materials should continue to progress, leading to more applications and reduced production costs. Lee et al. (2005) applied the Taguchi technique to optimize the parameters of the Fused Deposition Modeling (FDM) process, aiming to enhance the elastic performance and maximize the throwing distance of ABS prototypes [7]. Their analysis found air gap, raster angle, and layer thickness as the pivotal FDM factors that substantially affect the elastic characteristics of the produced components. A new composite material, consisting of 10% iron-filled ABS polymer, was developed and analyzed for its melt flow characteristics. The study focused on its behavior when extruded through a 90-degree bent tube liquefier head in an FDM machine, utilizing both 2D and 3D numerical simulations. Critical flow parameters such as temperature distribution, velocity profiles, and pressure drop were thoroughly investigated. The findings demonstrated a strong agreement in predicting the melt flow patterns, offering valuable insights into the material's processability and overall performance [2].

Despite advancements in composite materials for FDM, there is limited research on optimizing MFI for hybrid filaments. This study aims to bridge this gap by investigating how mica filler and processing parameters influence MFI.

## EXPERIMENTATION

According to the published literature, researchers have examined and analysed the material's flow via the FDM machine's nozzle, but there hasn't been much work done on the flow characteristics analysis that occurs before the printing. The MFI, which indicates the material's flowability, is one significant characteristic that may be examined and assessed [8]. Furthermore, it has been noted that there are no guidelines for MFI of composite materials. Currently, MFI of materials based on plastic is conducted according to ASTM-D-1238-95 standard. Investigating the flow properties of various composite materials is vital to establishing optimal material flow that meets the operational requirements of FDM machines. This study focuses on employing the Taguchi method to assess the Melt Flow Index (MFI) of Nylon 6 with varied amounts of mica powder. Additionally, extrusion weight and temperature are evaluated as controllable factors to understand their impact on the flow behavior and optimize the process parameters for enhanced material compatibility with FDM technology.

### Melt Flow Rate

Melt Flow Rate calculates how quickly thermoplastics extrude through a hole under specified load and temperature conditions. It offers a way to check the flow of molten material, which utilised to distinguish between grades, or assess how much the plastic has degraded due to moulding [9]. Melt flow indexers are used to measure MFI, and melted material is extruded through dies with defined lengths and diameters under load and temperature specifications. It serves as a gauge for the consistency of the polymer flow rate.

In order to prepare the composite, Nylon-6 was compounded with Mica, a filler chosen for its engineering qualities, using a Twin Screw Extruder (TSE). To ensure uniform distribution of mica in Nylon-6, the raw materials were pre-mixed in a high-shear mixer before being fed into the Twin Screw Extruder (TSE) for compounding. At CIPET: IPT, Kochi, compounding—the process of mixing polymers with additives—was carried out using a twin screw extruder featuring a 21 mm screw diameter and a 40:1 L/D ratio. The compounded materials were gathered into 2-3 mm pellets and put through MFI testing to examine how various filler ratios affect the flow properties necessary for FDM applications. To guarantee that the mixture is devoid of moisture, the composite is put in an electric oven and cooked to 160°C for 3 hours. The moisture content after drying was measured using a moisture analyzer, ensuring values remained below 0.1%. The molten material is extruded through a die by delivering a predetermined weight to a plunger, as determined by experimental conditions. The melt flow rate (MFR) is calculated by collecting the extrudate over a predefined time interval, weighing it, and stating the result in grams per 10 minutes. This measurement gives a quantitative assessment of the material's flow characteristics under the provided processing parameters.

### Experimental Procedure

The Melt Flow Index (MFI) testing process for the Nylon6 composite was performed at ICT, Mumbai, in accordance with ASTM Standard D1238. A precise quantity of polymer grains, generally ranging from 7 to 10 grammes, was weighed and prepared for analysis. The MFI testing apparatus was thereafter preheated to the designated temperature in compliance with ASTM requirements to guarantee accurate and uniform findings. Upon reaching the designated temperature, the die was meticulously inserted into the barrel, and the measured polymer material was introduced into the barrel using a scoop or funnel. A plunger was employed to thoroughly compress the material within the barrel to prevent void formation. Figure 2 illustrates the intricate construction and components of the melt flow indexer utilised in this experiment.



**Figure 2.** Melt flow indexer.

Upon the system's readiness, a standard weight, as delineated by ASTM D1238, was positioned on the piston within the barrel to exert the requisite pressure for extrusion. The time was recorded with a stopwatch as the material commenced flowing out the machine. The extruded polymer, accumulated over 10 minutes, was subsequently excised with a knife. The extrudate was then weighed on a computerised scale to acquire a precise mass measurement. The MFI was ultimately determined in grammes per 10 minutes, based on the measured weight of the extrudate, yielding a quantitative evaluation of the material's flow characteristics.

The Taguchi Design of Experiments (DOE) is a powerful statistical methodology, initially created by R.A. Fisher, that facilitates the analysis of the impact of input parameters on targeted responses [10]. Taguchi's method is a systematic strategy aimed at enhancing product and process robustness by reducing deviations from goal values. The process entails specifying key input parameters and their levels, choosing a suitable orthogonal array (O.A.), and executing trials according to the O.A. configuration. Subsequent to documenting response values, Signal-to-Noise (S/N) ratio plots are employed to identify ideal input combinations, succeeded by Analysis of Variance (ANOVA) to assess the relevance and contributions of different parameters [11].

This study established three control factors, each with three levels, as detailed in Table 1, and organised them according to the L9 orthogonal array. The control log for the final experiment is displayed in Table 2. Taguchi's L9 orthogonal array was utilised to assess the "lower the better" situation to develop a melt flow index (MFI) benchmark for the polymer composite suitable for fused deposition modelling (FDM), comparable to the MFI of commercial ABS. Minitab 21 was utilised to implement Taguchi's Design of Experiments.

**Table 1.** Input parameters.

→ Parameters ↓ Levels	Extrusion temperature (°C)	Extrusion load (kg)	Proportion of filler % (mica)
1	230	2.16	20
2	240	3.8	30
3	250	5	40

**Table 2.** Taguchi L9 O.A.

Experiment no.	Extrusion temperature (°C)	Extrusion load (kg)	Proportion of filler % (Mica)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	2	2
5	2	3	3
6	2	1	1
7	3	3	3
8	3	1	1
9	3	2	2

**Table 3.** Control log for final experimentation.

Experiment no.	Extrusion temperature (°C)	Extrusion load (kg)	Proportion of filler % (Mica)
1	230	2.16	20
2	230	3.8	30
3	230	5	40
4	240	3.8	30
5	240	5	40
6	240	2.16	20
7	250	5	40
8	250	2.16	20
9	250	3.8	30

## RESULTS AND DISCUSSION

The extruded material was measured using a scale with a minimum increment of 0.001 grammes. The melt flow index for the nine experiments are performed as formulated by Taguchi's L9 O.A. and three repetitions are also carried to reduce the experimental errors. Based on the control log for final experimentation from the Table 3, the nine sets with three repetitions are performed and MFI results are evaluated as shown in the Table 4.

This work uses the Taguchi L9 orthogonal array (O.A.) to examine "smaller-the-better" scenarios, seeking to define MFI criteria for composite materials compatible with FDM machines. The experimental design focused on optimizing key parameters to minimize MFI while retaining material compatibility and process stability. Table 5 presents the determined values of the signal-to-noise (S/N) ratio and the sum of squares for the nine experimental sets under the "smaller-the-better" criterion. Similarly, Table 5 displays the computed values of the sum of reciprocals and accompanying S/N ratios for the same optimization scenario. Figures 3–5 visually demonstrate the modification of major input parameters—extrusion load, filler content, and extrusion temperature—in relation to MFI and S/N ratios. These graphic representations highlight the influence of each parameter and provide insights into the parameter combinations that yield ideal MFI levels. This work enables the creation of standardized MFI benchmarks for composite materials suitable for FDM applications.

**Table 4.** Final experimentation.

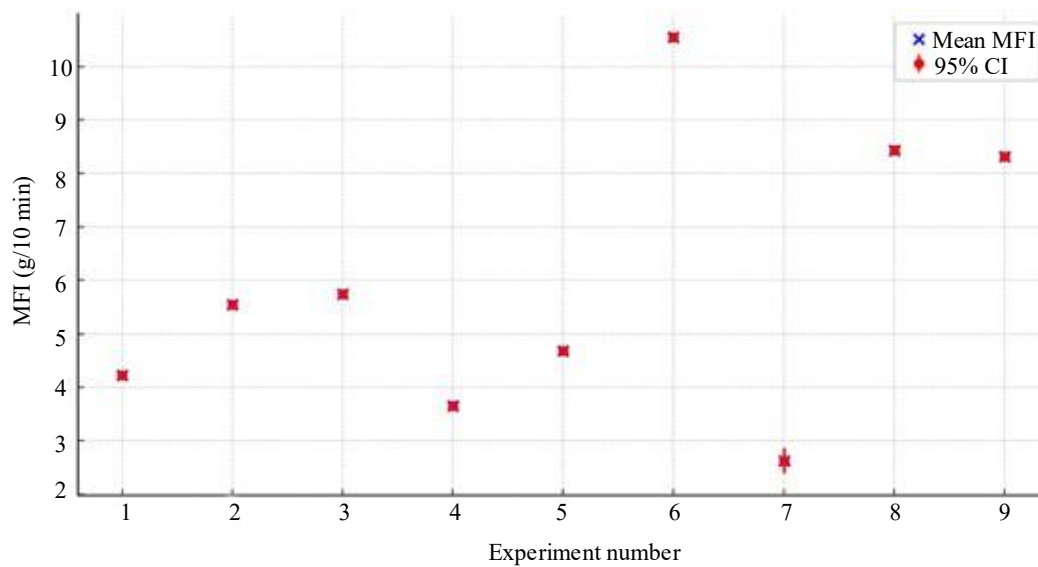
Experiment no.	MFI (gm/10minutes)		
	R1	R2	R3
1	4.210	4.237	4.225
2	5.521	5.568	5.547
3	5.735	5.751	5.755
4	3.647	3.659	3.641
5	4.682	4.687	4.669
6	10.530	10.543	10.551
7	2.721	2.625	2.531
8	8.436	8.443	8.430
9	8.311	8.316	8.321

**Table 5.** S/N ratios and means

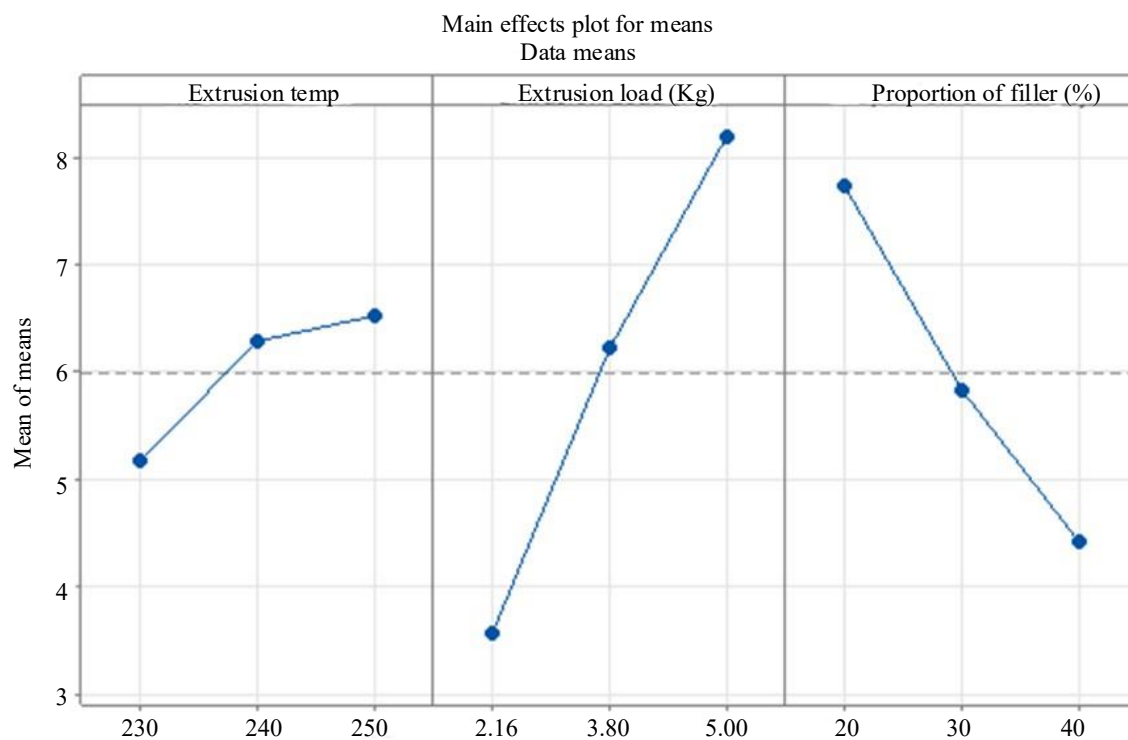
Experiment no. (runs)	S/N ratios (dB)	Means
1	-12.5145	4.2240
2	-14.8786	5.5453
3	-15.1888	5.7470
4	-11.2435	3.6490
5	-13.4037	4.6793
6	-20.4579	10.5413
7	-9.0224	2.8257
8	-18.5231	8.4363
9	-18.3983	8.3160

**Table 6.** Response Table for S/N Ratios For smaller is better

Level	Extrusion temp.	Extrusion load (Kg)	Proportion of filler (%)
1	-14.19	-10.93	-17.17
2	-15.04	-15.60	-14.84
3	-15.31	-18.02	-12.54
Delta	1.12	7.09	4.63
Rank	3	1	2



**Figure 3.** Melt flow index with 95% confidence interval.



**Figure 4.** Main effects plot for means.

The experimental results for MFI were analysed with 95% confidence intervals (CI) to assess the variability and statistical reliability of the measurements (Figure 3). As indicated in Figures 4–6, the best parameters for achieving the desired Melt Flow Index (MFI) are an extrusion temperature of 250°C, an extrusion load of 5 kg, and a filler percentage of 20%. These parameters coincide with the "smaller-is-better" optimization criterion. Table 6 shows the signal-to-noise (S/N) ratios for all values of the three input parameters. Statistical analysis of the data demonstrates that the extrusion load has the most significant influence on MFI, followed by the filler content and extrusion temperature. Furthermore, the error margin, discovered to be below 10%, gives considerable proof that the process is well-regulated and the experimental results are credible.

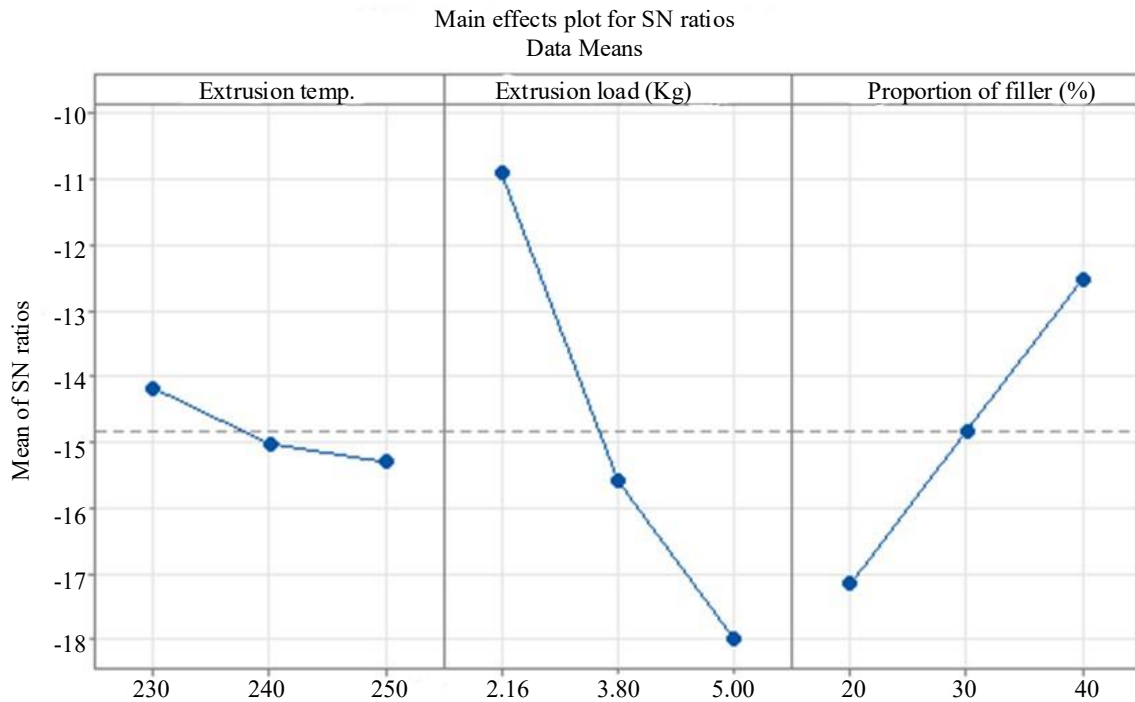


Figure 5. Main effects plot for SN ratios.

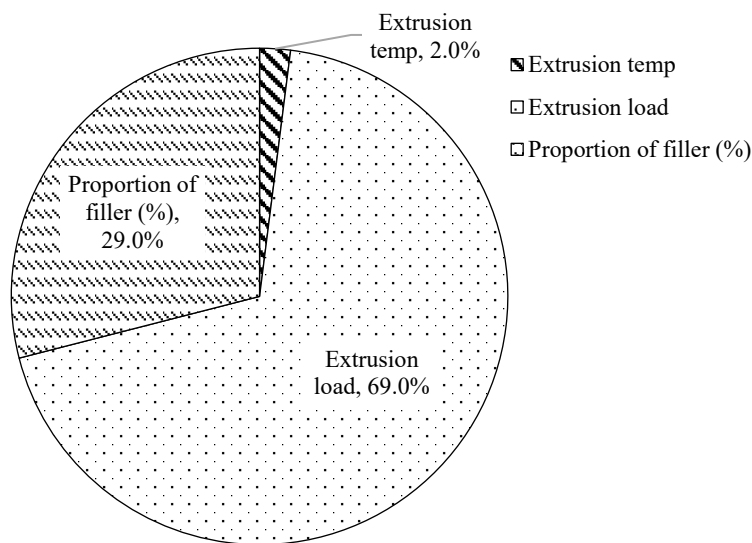


Figure 6. Factor's percentage contribution chart.

### CASE STUDY

Using the optimized Melt Flow Index (MFI) values, a composite filament with a diameter of 1.7 to 1.8 mm, made of Nylon 6 and mica, was successfully created using a single-screw extruder. The extrusion process was completed under optimal conditions to achieve constant filament quality. The freshly manufactured composite filament was then coiled onto a spool for ease of handling and later utilized in an FDM machine.

A test component with a diameter of 10 mm and a length of 30 mm was manufactured utilizing this composite filament in the FDM method. The dimensions of the fabricated part were measured for both circular and linear precision. The results indicated that the component corresponded to the dimensional

tolerance requirements stipulated by DIN 16901 standards. This demonstrates the feasibility of utilizing Nylon 6-Mica composite filaments in FDM applications while preserving accurate dimensional accuracy.

## CONCLUSIONS

The Melt Flow Index (MFI) is a significant parameter controlling filament flow behavior in the Fused Deposition Modeling (FDM) process. This study analyzes the effects of different filler-to-binder ratios, extrusion temperatures, and extrusion loads on MFI. The Taguchi L9 orthogonal array was applied to design the tests, and the findings are presented as follows:

The extrusion load is the most significant contributor, contributing around 69% to the MFI. A direct association is discovered between extrusion load and MFI: as the load increases, the MFI climbs proportionately.

The percentage of filler material (mica) is the second most influential component, contributing roughly 29%. The addition of mica to Nylon 6 optimizes material flow by enhancing binder melting and filler integration. However, at a specified threshold of filler content, the fluidity of the Nylon-Mica composite reduces, resulting in a lower MFI.

Extrusion temperature contributes for around 2% of the MFI variation. Higher temperatures allow quick melting of Nylon 6, reducing viscosity and better mixing with mica, which in turn enhances the MFI.

The optimal conditions for achieving an MFI comparable to that of virgin ABS plastic (2.411 g/10 min), commonly used in commercial FDM setups, are as follows: an extrusion temperature of 250°C, an extrusion load of 5 kg, and a mica filler content of 20%. These standards establish a benchmark for Nylon-6-Mica composites and open the road for producing materials with customizable compositions to fulfil specific FDM requirements.

Further research could explore the use of other filler materials, dual-filler systems, and changing filler-to-binder ratios to enhance the versatility and performance of composite materials in FDM applications.

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