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# Effect of Indenter loading Rate on Hybridized composite Laminates Subjected to Quasi-static indentation

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## Abstract

*The fiber-matrix interface plays a major role in the mechanical properties of composite materials which mainly depends on the ability of transferring load from matrix to fiber during loading condition. Many researchers has concluded that the strain energy transfer process influence properties when composites subjected to quasi-static indentation. This research work deal with effect of rate of indentation in different E glass / epoxy composite laminates hybridized with E glass powder of various proportions, it is also studied that how the fiber orientation will influence the E glass powder percentages during loading It is observed that as the powder percentage is increased the strength of the laminate is reduced but in some cases as illustrated in the figures, powder addition will have different effect in laminates with different fiber orientation*

**Keywords:** Epoxy resin, E-glass fiber, Filament winding, laminate, Indentation, E-glass powder.

## Introduction

It has been increasing enormously at present; the usage of composite materials in the areas of automotive, aerospace, defense and in sports industries and in many more applications. Composite materials have many advantages over conventional materials because of their superior properties like strength to weight ratio, stiffness to weight ratio, non-corrosive properties, resistance to climatic conditions, high fatigue life, product cost etc., the fiber-matrix interface plays a major role in the mechanical properties of composite materials which mainly depends on the ability of transferring load from matrix to fiber during loading condition. Many researchers has concluded that the strain energy transfer process influence properties when composites subjected to quasi-static indentation. The composite structures may get damage during manufacturing, maintenance works and during their service. They may be subjected to low velocity impact by the tools also. This local impact is likely to cause damage locally and induce degradation in their strength. The type and size of damage will depends on different parameters i.e., geometry of the specimen support, impactor diameter, size, shape and angle of impact. Extensive studies are taking place concerning the foreign object damage response of composite materials structures. It also observed that low energy impacts are very significant for the composite structural members. In such composite materials, impactor causes an internal damage that cannot be found out by physical inspection system but can induce an appreciable reduction in strength. Damage mechanism in composites due to quasi-static indentation is same as the low velocity impacting; hence it supports quasi-static indentation experimentations to analyze the impact damages. Earlier experimental studies have taken place to characterize the damage due to indentation. Damage mechanisms are local phenomenon below the indenter as the tri-dimensional fiber impregnation prevents delamination. The aim of this research work is to investigate the influence of fiber angle in the damage of composite laminate, subjected to quasi-static indentation. Damage in the composite laminates results from the interaction between different failure mechanism like matrix cracking, fiber-matrix debonding, delamination between the successive layers and fiber breakage. However in quasi-static indentation mostly the damage may result due to delamination between the layers. For this purpose, static tests were conducted on the composite laminate loaded at the centre by a spherical stainless steel indenter. All the experimental tests were stopped at fixed displacement of the indenter. Composite laminates with different fiber angles were supported on a square frame. Low energy impacting is very much needed for polymer matrix composites in which impacting causes an internal damage mechanism which cannot be observed by a visual inspection method, but many cause a appreciable reduction in strength. The experimental results show that damage mechanism in polymer matrix composite in quasi-static indentation process is same as that of low velocity impacting[1]. Delamination was modeled by reduced stresses using two interface damage mechanism parameters relating to interfacial tension and shear failure mechanism, whereas fracture mechanical concepts are introduced by relating the complete energy absorbed in the damaging process to the interfacial fracture energy[2].

Simulated the different damage phenomena of composite structures subjected to low velocity impacts[3]. A simple power law equation was assessed, correlating the dent depth with impact energy[4]. the penetration energy is substantially unaffected by the loading speed and it is also effective in static tests[5]. Metals show visible damage caused by impact mainly on the surface of the structures, but for composites the damage is hidden inside the member when subjected to low velocity impact[6]. While zhou and Greaves studied damage resistance and tolerance of glass fiber reinforced plates with different thickness[7]. Liu et al. obtained the perforation threshold of composite laminates with different thickness and bending stiffness and thickness is more efficient than bending stiffness on the perforation threshold[8]. N. Rajesh et al woven glass epoxy laminates were subjected to low velocity impact loading at different energy levels shown the results that dynamic response of these systems depends on the elastic properties of the fiber materials[9]. E-glass powder with different % by weight is added during the preparation of the laminate. The prepared laminates with different fiber orientation are subjected to quasi-static indentation at an indenter travel speed of 0.5mm/min and 1.5mm/min with a maximum travel of 3mm from the top surface of the laminate. For each fiber orientation the laminates are hybridized with 0.5%, 1.0% and 1.5% of E-glass powder by weight. The aim of the experimental work is study the combined effect of fiber orientation, E-glass powder % and the rate of indenter travel.

## Material preparation

E-glass/epoxy composite laminates were prepared by passing the E-glass fibers of 1200 TEX, through the resin bath of epoxy and hardener mixed with E-glass powder maintaining a constant temperature of about $45^0$C. The fibers are then wound on a rotating drum with 15 rpm. After complete winding on the drum then it is cut opened and lay on a flat table in the atmospheric condition for about 48 hours to get the tackiness. It is then cut in to required sizes and placed one over the other to obtain the desired thickness of the laminate. All the overlapped layers then compacted between the two parallel flat steel plates with stainless steel spacers of required laminate thickness. The plates are clamped with nuts and bolts with washers; the clamped setup is then placed in the oven. Maintain the oven temperature of $80^0$ C for 4 hours and $120^0$ C for next 4 hours so that any entrapped air or volatile gases will be escaped for the first four hours and chemical reaction between the epoxy and hardener will takes place for the next four hours and will lead to permanent set and finally result into a single solid composite laminate. After total curing of 8 hours oven is then switched off so the temperature in the oven may come down to normal temperature. Take out the composite laminate and trim the edges so that the laminate is ready for testing purpose.

**Experimentation:** Indentation tests were conducted on universal testing machine. The composite laminate is placed on a supporting steel frame. A square opening flat plate is placed on top side of the composite laminate is clamped rigidly with nuts and bolts. The clamped laminate set up is placed on the loading frame under the indenter of the testing machine. A spherical stainless steel ball indenters of diameter 8.17mm, is used for indentation. The tests were conducted with the controlled displacement of the indenter (1.0 mm/min). A 10 Kilo Newton load cell evaluated the load carrying capacity on each composite laminate. The load and displacement data were obtained for 5 minute duration. The composite laminates with different fiber orientation and with different proportions of E-glass powder is indented for a fixed displacement of 5 mm, so that the damage in the different laminates is observed as shown in the figure-3.

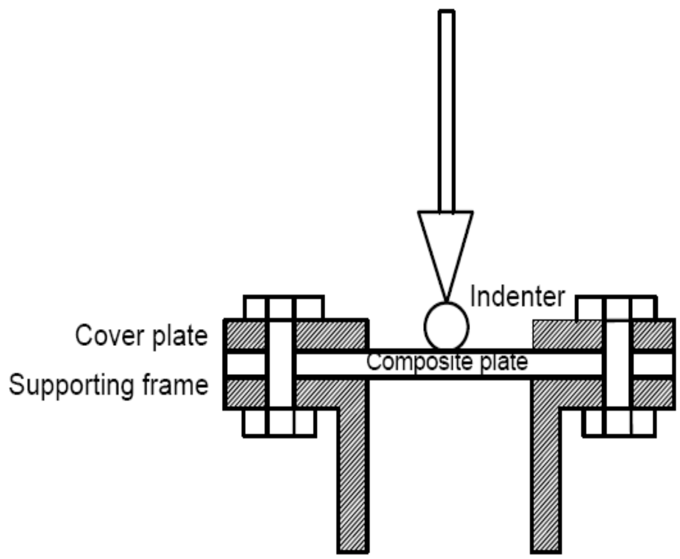



**Figure-1**
**Schematic diagram of indentation process**

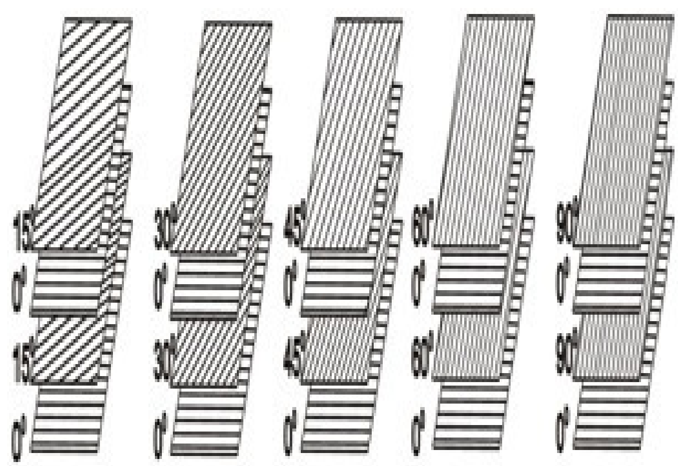


**Figure-2**
**Sequence of angle plies**

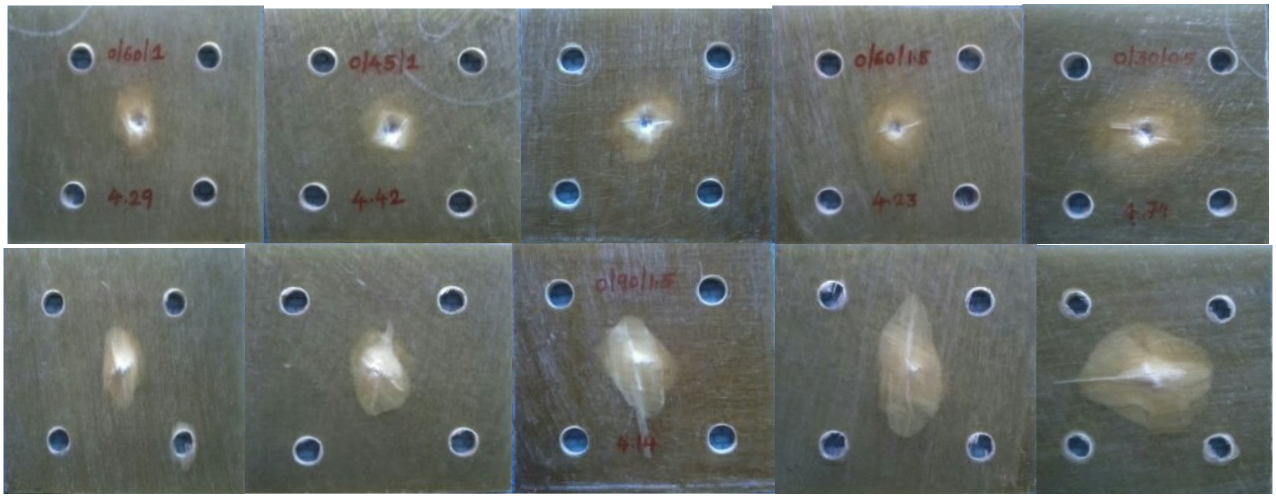
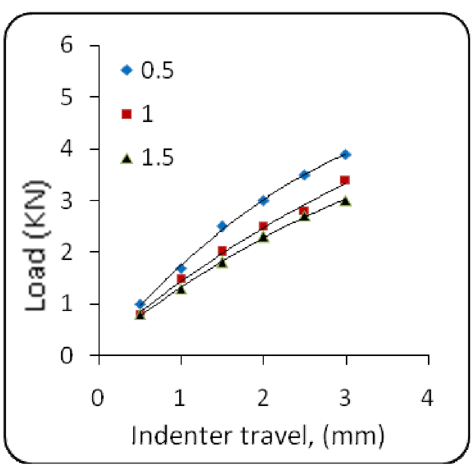


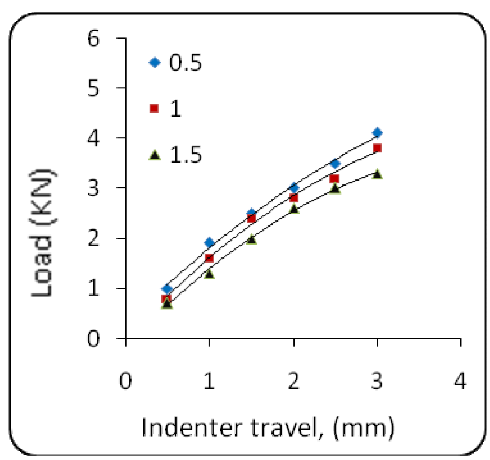
**Figure-3**
**Laminates after indentation**
Top Side of Laminates after Indentation. Bottom Side of Laminates after Indentation

**Table-1**
**Experimental Data**

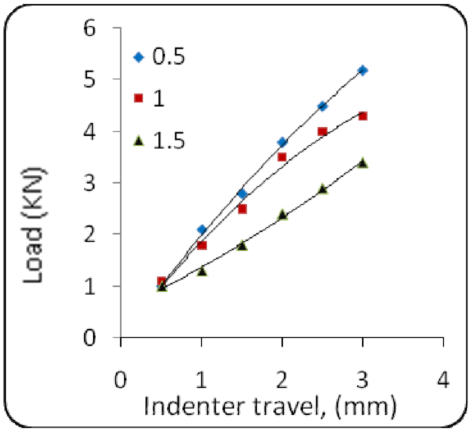
| | **E-GLASS POWDER=0.5%** | | **E-GLASS POWDER=1.0%** | | **E-GLASS POWDER=1.5%** | |
|---|---|---|---|---|---|---|
| **θ / Indenter travel rate** | **0.5 mm/min** | **1.0/mm/min** | **0.5mm/min** | **1.0mm/min** | **0.5mm/min** | **1.0mm/min** |
| $(0^0/15^0)$ | 3.9kN | 4.1 kN | 3.4kN | 3.8kN | 3.0kN | 3.3kN |
| $(0^0/30^0)$ | 5.2 | 5.6 | 4.3 | 4.0 | 3.4 | 3.7 |
| $(0^0/45^0)$ | 5.0 | 5.5 | 4.0 | 4.5 | 4.0 | 4.0 |
| $(0^0/60^0)$ | 4.6 | 5.0 | 4.0 | 4.5 | 3.1 | 4.2 |
| $(0^0/90^0)$ | 4.4 | 5.0 | 4.0 | 4.2 | 3.5 | 3.7 |




Rate of indenter loading=0.5mm/min
**Figure-4**
**load vs. Indenter travel. Fiber Orientation $(0/15^0)$**



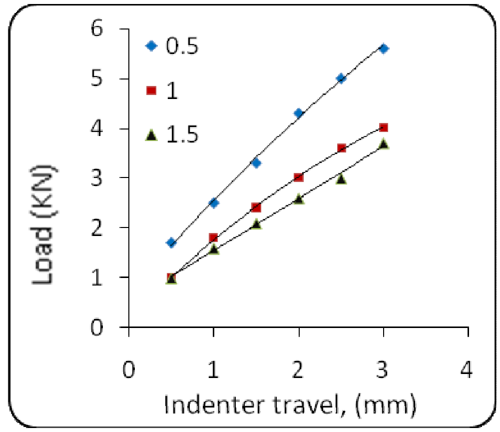

Rate of indenter loading =1.5mm/min
**Figure-5**
**load vs. Indenter travel. Fiber Orientation $(0/15^0)$**




Rate of indenter loading=0.5mm/min

**Figure-6**

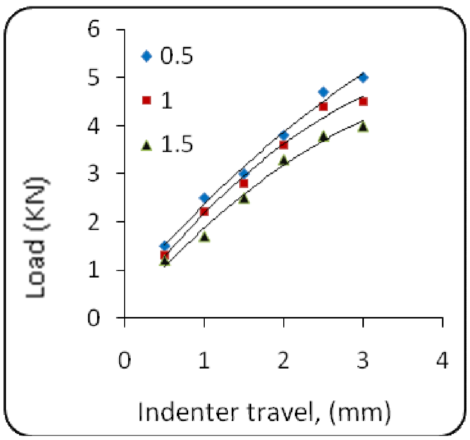
**load vs. Indenter travel. Fiber Orientation (0/30$^0$)**




Rate of indenter loading =1.5mm/min

**Figure-7**

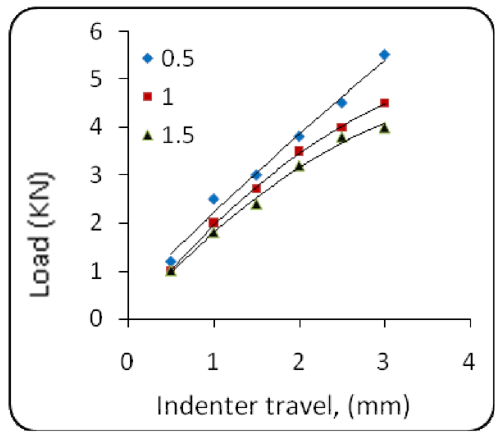
**load vs. Indenter travel. Fiber Orientation (0/30$^0$)**




Rate of indenter loading=0.5mm/min

**Figure-8**

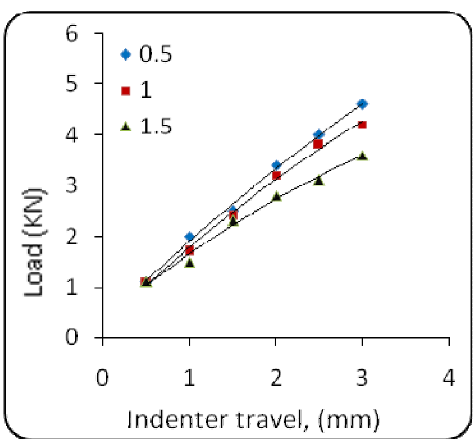
**load vs. Indenter travel. Fiber Orientation (0/45$^0$)**




Rate of indenter loading =1.5mm/min

**Figure-9**

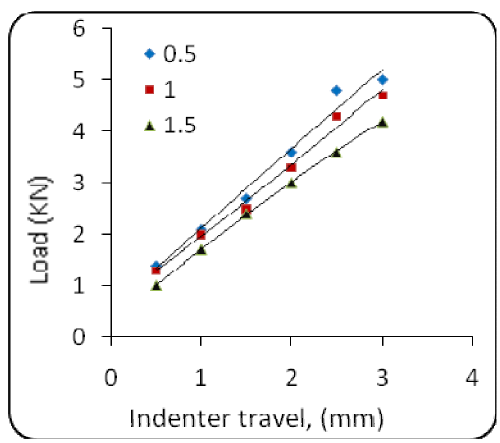
**load vs. Indenter travel. Fiber Orientation (0/45$^0$)**




Rate of indenter loading=0.5mm/min

**Figure-10**

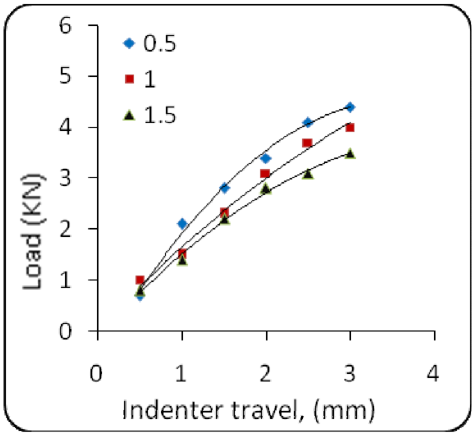
**load vs. Indenter travel. Fiber Orientation (0/60$^0$)**



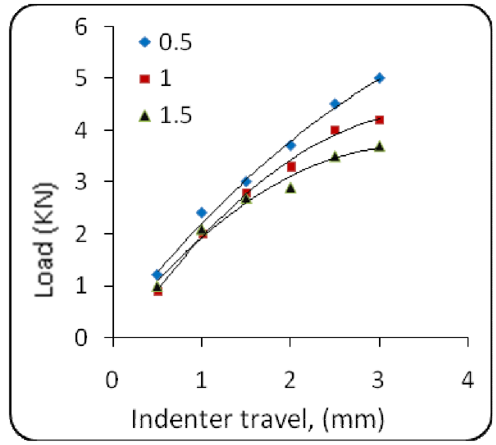

Rate of indenter loading =1.5mm/min

**Figure-11**

**load vs. Indenter travel. Fiber Orientation (0/60$^0$)**




Rate of indenter loading=0.5mm/min
**Figure-12**
**load vs. Indenter travel. Fiber Orientation ($0/90^0$)**




Rate of indenter loading =1.5mm/min
**Figure-13**
**load vs. Indenter travel. Fiber Orientation ($0/90^0$)**

## Results and Discussion

The laminate with ($0^0/15^0$) fiber orientation has a least load bearing capacity, compared to other fiber orientation. The maximum load bearing capacity is 3.4 KN. When indenter rate of loading is 0.5 mm/min., it is observed that up to 1.5 mm indenter travel the load is proportionally increasing with the indenter travel and after it increased gradually and then increased suddenly. This is because there is a fiber break when the indenter displacement is increased from 1.5 mm to 2.0 mm. At 0.5mm indenter displacement the laminate with ($0^0/45^0$) shown maximum load and whereas minimum load for the laminate with fiber orientation ($0^0/15^0$). At 1mm indenter displacement ($0^0/ 90^0$) laminate shown maximum load carrying capacity. At 1.5m indenter displacement, laminate with ($0^0/30^0$, $0^0/45^0$, $0^0/90^0$) shown maximum load. At 2mm indenter displacement maximum load recorded for ($0^0/30^0$) and ($0^0/90^0$) laminates. At 2.5mm indenter displacement, laminate with ($0^0/30^0$) and ($0^0/90^0$) noted maximum load. At 3mm indenter displacement, maximum load is for the laminate with ($0^0/30^0$) fiber orientation.

At 1.5mm/min rate of indenter loading for all the indenter displacement values, laminate with ($0^0/30^0$) recorded with maximum load, and laminate with ($0^0/15^0$) is shown minimum load carrying capacity. Irrespective of rate of loading the laminate with ($0^0/60^0$) fiber orientation laminate shown average load as in the case of 0.5mm/min rate of loading. For all the indenter displacements values ($0^0/30^0$) laminate is shown maximum loading carrying capacity and ($0^0/15^0$) laminate with minimum load carrying capacity. For 0.5% of E-glass powder, the change in the rate of loading is influenced only for the laminate with ($0^0/45^0$) fiber orientation. The maximum load carrying capacity increased from 5.1KN to 5.6KN with the rate of loading is 0.5mm/min and 1.5mm/min for the laminate ($0^0/30^0$). Also increased minimum load carrying capacity from 3.4 KN to 4.1 KN for the laminate with ($0^0/15^0$) fiber orientation.

When E-glass powder in the laminates increased to 1%, then the following observations made from the experiments i.e., higher the rate of loading, higher is the load carrying capacity. This is because all the fibers at different layers will not take part in load carrying then no fibers breakage and hence load carrying capacity will be more, in other words higher is the speed of strain wave propagation. When the rate of loading is 1.5mm/min, there is a steep increase in the load carrying capacity for the laminate with ($0^0/45^0$) with a value of 4.9KN as 4.5KN with a rate of loading 0.5 mm/min. However for both rate of loading ($0^0/45^0$) and ($0^0/60^0$) reached maximum load with minimum load. Hence with 1% E-glass powder in ($0^0/45^0$) shown to be the best.

For all the indenter displacements from 0.5mm to 3mm for both rate of loading. The laminate with ($0^0/45^0$) carried more load and ($0^0/15^0$) laminate with minimum load. When the E-glass percentage is increased to 1.5% still the laminate with ($0^0/45^0$) fiber orientation shown to be the best with small loading fluctuation during loading when the rate of loading is 0.5 mm/min, but in the case of 1.5 mm/min the laminate with ($0^0/45^0$) is absolutely free from loading fluctuations with a steep increase in the load carrying capacity. However ($0^0/30^0$) laminate is shown to be the minimum load carrying capacity and as usual ($0^0/60^0$) laminate appear to be average load carrying capacity without any load fluctuations. The load capacity of the laminate is decreasing due to settlement of powder in between the laminae or inter laminar space, this led to degrade the laminate strength or reduced inter laminar shear strength of the laminate. However as the rate of indenter travel speed are 0.5mm/min. and 1.5mm/min and observed that there is an improvement in strength for all the laminates with different fiber orientations. This is because higher the rate of indenter travel into the laminate, faster is the strain energy propagation lower is the inter-laminar shear strength of the laminate; thereby higher is the strength of the laminate.

## Conclusion

The laminate with fiber orientation ($0^0/30^0$) is shown better in strength for both indenter travel velocity 0.5mm/min and 1.5mm/min with a maximum of 5.6 KN and 5.2 KN respectively at 0.5% of E-glass powder. Whereas the laminate with fiber orientation ($0^0/15^0$) is shown low strength of 3.0 KN at 1.5% of E-glass powder. Therefore strength of the laminate is depending on fiber orientation, percentage of the E-glass powder added to the laminate preparation and rate of indenter travel in to the laminate.

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