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# Numerical and experimental evaluation of the mechanical behavior of Kevlar/glass fiber reinforced epoxy hybrid composites

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**Abstract** Flexural, tensile, and impact strength of hybrid Kevlar/glass reinforced epoxy composite is studied. Six different types of hybrid composite material were manufactured by hand layup process using different compositions of Kevlar and glass fiber. Tensile, flexural and impact strengths of manufactured samples were investigated using standard tests and compared. It is observed that tensile strength is greater for combinations with higher percentage (%) of Kevlar fabric and decreases with an increase in the glass fabric %age. Flexural strength is higher for combinations with greater %age of glass fabric and decreases with an increase in the Kevlar fabric %age. From drop weight test, it is found from visual inspection that damaged area is increased with an increase in the glass fabric percentage. Numerical simulation model incorporated with elastoplastic material data successfully predicts tensile and flexural experimental results.

## 1. Introduction

The composites materials are used due to superior mechanical properties of the fibers such as; higher strength to weight ratio, excellent tensile strength, higher stiffness and higher damage resistance [1, 2]. But standard composites have several limitations because fibers (glass, Kevlar and carbon) have superiority in some specific mechanical properties. To counter the problem, hybrid composite materials are used. Hybrid composites have better behavior and mechanical properties as compared to single fiber composites [3-8]. Due to this, it has gained importance in construction, aviation and automotive industries. Various researchers have investigated the characteristics of hybrid composites under tensile and compression loading. Vasudevan et al. [9] studied the influence of stacking sequences on mechanical properties of Kevlar/glass and carbon/glass hybrid composites. The authors noticed 7.5 % increase in absorption energy for these synthetic fiber reinforced hybrid composites.

Fan et al. [10] elaborated the thermal properties of different 14 layers of Kevlar and glass fiber reinforced hybrid composites. From the results, it was proved that hybridization-based composites with altered Kevlar/glass fibers has better thermal properties. Valença et al. [11] applied an innovative architecture to prepare the composite plates by using hand lay-up procedure and epoxy resin (DGEBA) reinforced with Kevlar/glass hybrid fabric and Kevlar fiber plain fabric. The samples were tested to evaluate its mechanical properties by bending, impact and tensile tests. These types of tests were conducted in the fill, parallel direction of wrap and perpendicular direction. FTIR was applied to prove the least curing time of resin to do the mechanical tests. SEM was used to evaluate the strengthening and matrix failure. The results depicted that composites manufactured with Kevlar/glass hybrid structure, reinforced with fabric, displayed good response in terms of mechanical strength, impact and bending energy. Rajesh et al. [12] studied the tensile properties of Kevlar composite manufactured by hand lay-up technique with four laminate layers. The micro details of composite fibers were evaluated by performing morphological analysis by using scanning electron microscope. The results depicted that Kevlar fibers are superior to others due to its good tensile strength and other mechanical properties. So, it can be applied as a substitute to other materials in numerous engineering industries. Srivathsan et al. [13] studied E-glass and synthetic woven fabric Kevlar reinforced composites manufactured by hand layup technique. These samples were cured by hydraulic compression moulding. The static mechanical change of these composites was determined by tensile, interlaminar shear and flexural tests. These composites were prepared under various stacking sequences, in-plane fibers orientations, and by considering its basic symmetric, asymmetric and accumulated layers. The volume fraction of these laminates was about 50 %. This study provided the characteristic behavior of hybrid composites. The morphology of the specimens was also evaluated using “scanning electron microscopy (SEM)”. Bandaru et al. [14] investigated the effect of hybrid composite under ballistic impact. The hybrid composites were manufactured by using different stacking sequences and different combinations. The results from FEA (finite element analysis) were equated with experimental results that showed the perfect agreement for the specific case (Kevlar fiber layer in glass fiber laminate) only. Moreover, the influence of stacking sequence on the ballistic velocity, energy absorbed and residual velocity was studied. The arrangement of Kevlar fiber at the rear side, glass fiber at the exterior and carbon fiber at the front side offered good impact resistance. Hence, the author concluded that the carbon fiber layer in Kevlar fiber laminate give the maximum impact resistance. Therefore, this sequence can be used for the design purposes as compared to other sequences. Sahu et al. [15] described the effect of hybridization on carbon, glass and Kevlar fibers-based hybrid composite through both experimentation and finite element analysis (FEA). Results from FEA had good correlation with experimental results. Sikarwar et al. [16] studied the effect of impact loading on the Kevlar/epoxy composites. The energy absorption capacity of the composites was also considered in this experiment. In this study, the Kevlar composites were manufactured using different fiber orientations and thickness value. The results showed that cross ply laminates have the maximum impact resistance as compared to the other orientations. Furthermore, energy absorption capacity is decreased with the rise in velocity for all Kevlar laminates. Bandaru et al. [17] investigated the thermoplastic hybrid composite reinforced with basalt and Kevlar fabrics through simulation and experiments. In this study, two types of hybrid composites were prepared with polypropylene matrix. One had a symmetric stacking sequence while other had asymmetric stacking sequence. Impact tests were performed on these two stacking sequences. The results showed that the impact limit was enhanced by 26 % when stacking sequence was asymmetric. Moreover, the damage of the front face was not affected by the sequence of stacking which gives the indication of the presence of 3D angle fabric. It was observed that all the stacking sequences affect the overall impact strength of the composites [18]. In another study the mechanical behavior of composites reinforced with hybrid fabrics of basalt/Kevlar and 2D plane woven was investigated [19]. During experimentation three hybrid and two homogeneous composites were prepared by using compression moulding machine. The mechanical properties were evaluated by doing tensile and in-plane compression testing. Both these testing showed that composites manufactured by using Kevlar and basalt yarns had improved tensile strength and in-plane compressive strength as compared to its base composites. Furthermore, development in mechanical properties such as strength, elastic modulus and strain (tension and in-plane compression) was observed in both of these tests due to hybridization. Numerical simulation was also performed in ABAQUS by using Chang-Chang criteria. The results showed the good relationship between the numerical and experimental solutions in terms of its damage pattern [18]. In different studies impact behavior of Kevlar epoxy matrix was observed with the addition of nanofillers were explained [20, 21]. Due to the addition of nanofillers the impact response of Kevlar epoxy composite was found increasing. The maximum impact load was found at 21 J impact energy. The increase of impact strength was good due to the addition of nanofillers but it resulted in the decrease of displacement. Wang et al. discussed that Kevlar fabric composite shows a linear behavior in a force displacement diagram as compared to glass fabric. This is because Kevlar fabric is more stiff and stronger than glass fabric and have higher elastic modulus and higher strength. This primarily depends on the nature of Kevlar fabric as it is weal in transverse direction due to highly anisotropic nature. In flexural test, opposite trend was observed. Glass fabric composites possess higher flexural strength than Kevlar fabric composite [22]. Thus, stacking sequence plays a vital role in strength and delamination of the hybrid composites. The literature review depicts that the existence of Kevlar/glass hybrid composites is less concentrated because of non-uniformity in results.

Current paper reports the flexural, tensile, and impact response of Kevlar/glass reinforced epoxy hybrid composite. The main intent of study is to gauge the flexural, tensile, and impact response of Kevlar/glass hybrid composite materials and also to verify the experimental results (tensile and flexural) with simulation results. The different weight %ages of Kevlar and glass fabric are utilized in construction of these hybrid composites. These hybrid composites were formulated by hand layup route. Flexural, tensile, and impact/drop weight tests were performed following ASTM D 3039, ASTM D7264 and ASTM D7136 standard, respectively.

Table 1. Stacking sequence and samples designation.

| Sr. No | Stacking sequence | Designations | Samples No.'s |
|---|---|---|---|
| 1 | Kevlar / Kevlar / Kevlar / Kevlar / Kevlar / Kevlar / Kevlar / Kevlar | K8 | K8-1 |
| | | | K8-2 |
| | | | K8-3 |
| 2 | Kevlar / Kevlar / Kevlar / Glass / Glass / Kevlar / Kevlar / Kevlar | K6G2 | K6G2-1 |
| | | | K6G2-2 |
| | | | K6G2-3 |
| 3 | Kevlar / Kevlar / Glass / Glass / Glass / Glass / Kevlar / Kevlar | K4G4 | K4G4-1 |
| | | | K4G4-2 |
| | | | K4G4-3 |

## 2. Experimental procedure

### 2.1 Materials

In this research, Plain woven E-glass (*2-Twill Weave glass fabric supplied by Interglass Technologies) and (1 *1-Plain Weave Kevlar 49 fabric supplied by DuPont Advanced Fibre systems) was used as a composite material.

In this study, adhesive media comprising epoxy Epotec YD 35 and Aradur 5052 (hardner) supplied by Huntsman Corporation (ratio) was used for the manufacturing of hybrid composites. Adhesive media has low viscosity, high resistance to temperature and excellent mechanical properties. These factors make this adhesive media highly suitable for Hand layup technique. The curing time of the hybrid composites was almost 48 hrs at room temperature. 4 mm thick laminated sheet, formulated with E glass fabric, is cured at ambient temperature for 24 hrs. Later, it was post cured for 4 hrs at 80 °C.

### 2.2 Preparation of hybrid composites

Six samples of hybrid composites, each with eight layers, were manufactured from two different types of fabric i.e. Kevlar and glass using hand layup. Different specimens were formulated by hand layup method as discussed in Table 1.

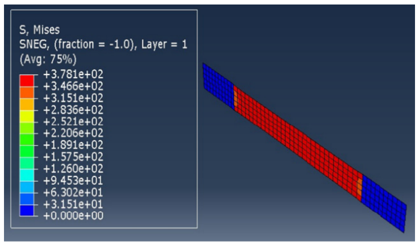
### 2.3 Mechanical study

Zwick/Roell Z100 machine was used to test the flexural and tensile strength of the corresponding standard samples. Tensile test was done following ASTM D3039 standard [23] by applying cross head speed 5 mm/min while the flexural test, at a strain rate of 1 mm/min, was performed referring ASTM D7264 standard [24]. The dimensions of the specimen were 250 mm × 25 mm.

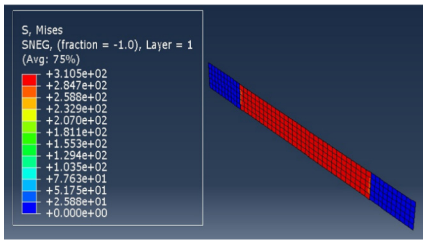
Impact/drop weight test was performed on Zwick Roell ZHIT 230F machine following ASTMs D7136 standard [25]. The specimen was installed inside the clamp during the tests. The dimensions of the specimen dimensions, for drop weight testing, was adjusted at 150 mm × 100 mm and a fixed 20J energy was applied to all the work pieces.

Table 2. Engineering constants used in simulation.

| Physical property | Glass/epoxy lamina | Kevlar/epoxy lamina | Source |
|---|---|---|---|
| $E_1 = E_2$ (MPa) | 7890 | 6330 | Experimentally |
| $E_3$ (MPa) | 4953 | 3507 | Analytically (ROM) |
| $G_{12}$ (MPa) | 2850 | 2361 | G/epoxy (literature) |
| | | | K/epoxy (analytically) |
| $G_{23} = G_{13}$(MPa) | 1795 | 1525 | Analytically (ROM) |
| $V_{12}$ | 0.03 | 0.34 | Experimentally |
| $V_{23} = V_{13}$ | 0.3 | 0.3215 | Analytically (ROM) |




(a)

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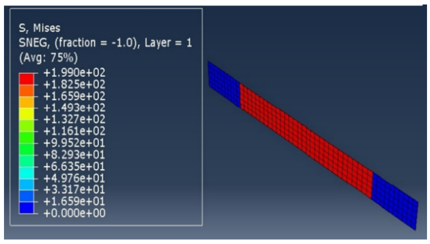



(c)

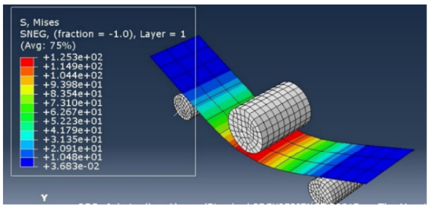
Fig. 1. Contour plots for von-Mises stress: (a) K8; (b) K6G2; (c) K4G4.

## 3. Numerical analysis

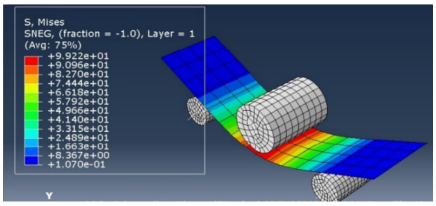
ABAQUS CAE 2017 [26], extensively used by researchers to solve the engineering problems, was selected as numeric tool to study the tensile and flexural performance of specimens.

### 3.1 Tensile simulation

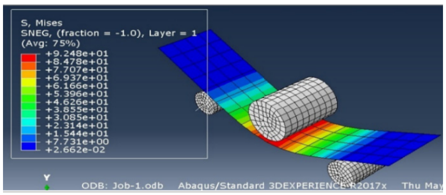
In step-1 part is modeled by taking 3D mesh element. Glass ply and Kevlar ply are described in material definition by assigning them orthotropic properties. In step 2, the composite layup is defined. Assembly is formed, mesh type and analysis parameters are defined in the subsequent steps. In the interaction module, the reference point in upper grip is coupled with all




(a)




(b)




(c)

Fig. 2. Contour plots for von-Mises stress: (a) K8; (b) K6G2; (c) K4G4.

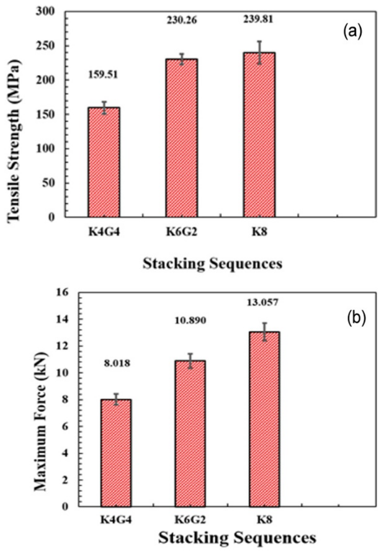



Fig. 3. (a) Bar chart for maximum tensile strength of different sequences; (b) maximum force of different sequences.

the nodal points in tensile test model. In the boundary conditions module, lower grip is fixed while upper grip is displaced by applying displacement load on reference point. Later, the meshing of model is done, and results are viewed after running the simulation to get force-displacement diagram. Contour plots for von-Mises stress for different sequences are explain in Fig. 1. Engineering constants used in these simulations are discussed in Table 2.

### 3.2 Flexural simulation

In a three-point bending simulation, the 3 mm-radius cylindrical supporting rollers and 5 mm-radius loading rollers were modeled as discrete shells. The specimen was discretized with shell elements and followed an orthotropic linear elastic model. The orientation of the specimen is taken from Table 1. Hard contact condition and coefficient of friction of 0.15 were assumed for normal and tangential contact direction. The supporting rollers were fixed, and the loading roller was x-mm displaced downwards. The simulations were run to view the results and get force-displacement diagram. Contour plots for von-Mises stress for different sequences are exhibited in Fig. 2.

## 4. Results and discussions

### 4.1 Tensile testing

As discussed earlier tensile tests were conducted following ASTM D3039 standard. Three different hybrid composite sequences containing different percentages of Kevlar and glass were tested. It is observed that K8 combination possess higher tensile strength and bear maximum prior to failure force then the K6G2 and K4G4 hybrid composites. Similar type of trend in results were reported by previous researchers [22, 27].

The trend observed in composites having different stacking sequences were as followed: K8 > K6G2 > K4G4. So, it is evident that, the Kevlar fiber reinforced composites have more tensile strength than its hybrid composites with glass fiber. This is because the glass fibers are more brittle and stiffer than Kevlar fibers. When the hybrid composite specimens K6G2 and K4G4 are compared, the specimen K6G2 has the highest tensile strength, which is 30.72 % more than the specimen K4G4.

This is because the Kevlar fibers has less stiffness and more tensile strength when hybridized with the brittle and stiffer glass fibers, so, the hybrid composite total tensile strength increased [28]. It is clear from the obtained results that mechanical properties of the hybrid composites are totally depend on layers of Kevlar fibers.

The same phenomenon also observed in bearing force prior to failure. The K8 samples bear maximum prior to failure force then its hybrid composites. From each composition, three (3) specimen were tested and their maximum tensile strength and force in the form of bar charts are presented in Figs. 3(a) and (b), respectively. In tensile simulation the linear elastic model was studied. The numerical force vs displacement behavior of K8, K6G2 and K4G4 sequences are explain in Figs. 4(a)-(c), respectively. The force-displacement arcs of hybrid composites from the experiment and FEA are in good agreement. However, the force-displacement curves of K6G2 and K4G4 specimens are lower than the FEA prediction. In tensile simulation, a minimum error of 2 % is found for K8 sequence while maximum error 17 % is found for K6G2 sequence. This variation in results is due to waviness of fiber and hand layup techniques

Table 3. Young's modulus of failure strain.

| Stacking sequence | Young's modulus E (MPa) | Failure strain (%) |
|---|---|---|
| Tensile test results | | |
| K8 | 6330 | 5.5 |
| K4G4 | 8605 | 3.1 |
| K6G2 | 7943 | 4.6 |
| Flexural test results | | |
| K8 | 2768 | 3.1 |
| K4G4 | 4589 | 3.2 |
| K6G2 | 4302 | 4.1 |

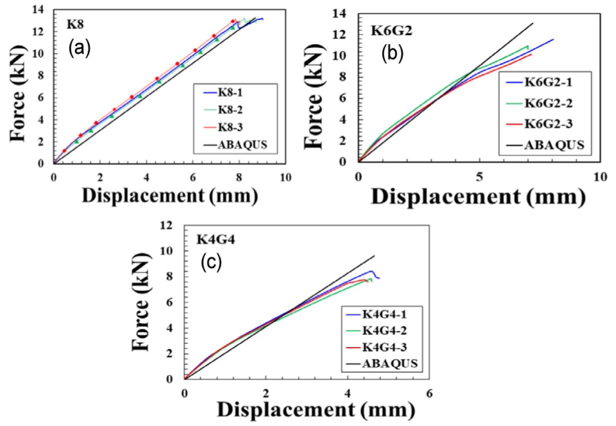



Fig. 4. (a) Force vs displacement behaviour of K8 sequence; (b) K6G2 sequence; (c) K4G4 sequence.

references. The error for K6G2 is maximum in both tensile and flexural simulation it is due to poor adhesion between single glass ply and Kevlar ply [29].

In case of force-displacement curves, the hybrid composites showed similar trend as compared with K8 specimens, beginning from non-linearity, and evolving into a linear slope. The nonlinearity is fundamentally attributed to the deformed matrix resin [30]. After the initial nonlinearity, the curve slopes become more linear indicating the glass fiber deformation. The young's modulus and failure strain for these sample in tensile lading are discussed in Table 3.

## 4.2 Flexural testing

Flexural or three-points bending tests were conducted following ASTM D7264 standard [24]. Three samples of each composition were tested, and their mean tensile strength and force are analyzed. The flexural strength of K8, K6G2 and K4G4 hybrid composites were 126.773, 131.657 and 218.197 MPa, respectively. It is revealed that K4G4 stacking combination possess higher flexural strength and maximum force prior to failure. The flexural strength of K4G4 specimens rose up to 41.980 % compared to K8 composite materials may be due to improved interfacial linkage between fabric and resin [30]. The hybrid composites findings suggest the capacity of hybridization to soak up more energy and deliver higher molecular flexibility by opposing the crack propagation. Figs. 5(a) and (b) show the bar chart for max. flexural strength and flexural force prior to failure, respectively.

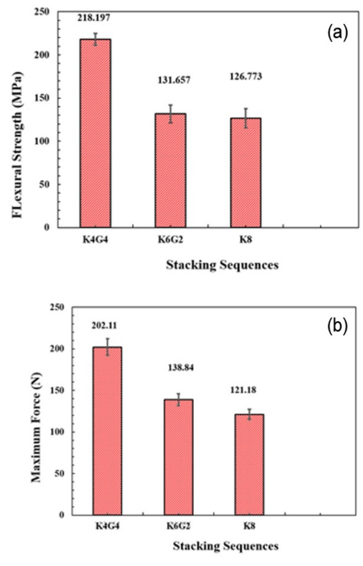



Fig. 5. (a) Maximum flexural strength of different sequences; (b) maximum flexural force of different sequences.

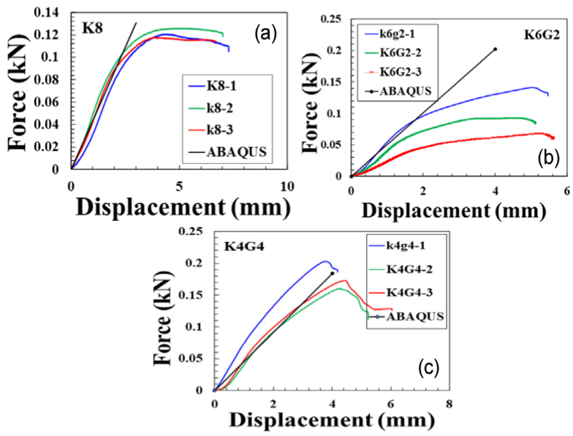



Fig. 6. (a) Flexural force vs displacement graph of K8 sequences; (b) K6G2 sequences; (c) K4G4 sequences.

The K4G4 hybrid composites bear max. force prior to collapse as compared to K6G2 and K8 composites. The max. force prior to failure of K4G4 hybrid composites rose up to 40.04 % as compared to K8 composites. Same as in tensile simulation the linear elastic model in flexural simulations was studied. The flexural force vs displacement curve for K8, K6G2 and K4G4 stacking sequences and the related numerical behavior are explained in Figs. 6(a)-(c), respectively. The experimental force vs displacement curves of K8, K6G2 and K4G4 composites are lower than the FEA prediction which is may be due to the presence of the shear damage. The FEA prediction also suggests that the maximum force prior to failure of the K4G4 composites is higher than the K8 composites. It can be

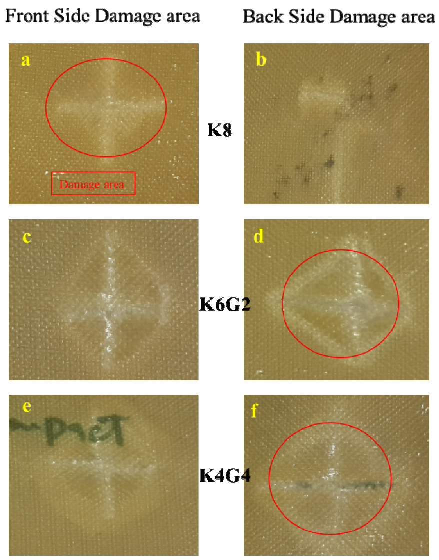



Fig. 7. Front and back side damaged area of (a)-(b) K8 samples; (c)-(d) K6G2 samples; (e)-(f) K4G4 samples.

concluded from both the experimental and FEA results that positive hybrid effect exist by substituting Kevlar fibers with glass fibers. In flexural simulation the minimum error of 8 % is found for K8 sequence and maximum for K6G2 i.e. 31 %. This variation in results is due to waviness of fiber and hand layup techniques. The young's modulus and failure strain for these sample in flexural loading are discussed in Table 3.

### *4.3 Drop weight testing*

Drop weight test was completed by applying 20J energy for all specimens. The damage area for front and back sides of K8, K6G2 and K4G4 sequences are discussed in Fig. 7. From the observation, all three composites showed different damage pattern at the front and back face with delamination profile clearly seen in these composites. The delamination is strongly guided by the mismatch of bending stiffness of each ply. In the case of K8, bending stiffness mismatch was minimum since the plies were uniform (all plies were made of Kevlar), while in hybrid composite, the bending stiffness mismatch was more pronounced since it was composed of different ply materials.

## 5. Conclusion

In this study, flexural, tensile, and impact response of hybrid Kevlar/glass reinforced epoxy composite were systematically investigated. K8 sequence possess higher tensile strength. Tensile properties decline with a rise in the glass fiber percentage in hybrid composite materials. It is due to higher stiffness of Kevlar fabric in comparison to the glass fabric.

Flexural properties are improved with an increase in the glass fiber percentage in hybrid composites because Kevlar fabric is weaker than glass fabric in the transverse direction.

In the drop weight testing, damaged area is improved with an increase in the glass fiber percentage in hybrid composites. Numerical simulation has good potential to successfully predict experimental results. Simulation results have good scope in aerospace and automotive industries, specifically, to predict the tensile and flexural properties.

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