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Experimental investigation on Crash Worthiness of GFRP-Al Multi Material Structures under Edge and Flatwise Compression Test

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ABSTRACT: Through this study, we propose a novel approach that combines the lightweight and non-corrosive nature of Aluminum as an outer cover and the high compressive strength and deformation-resistant properties of GFRP as an inner cover forming a multicell structure cylinder. The crashworthiness of composite materials and their energy absorption capabilities have been investigated, showcasing the potential of glass fiber-reinforced polymer composites. To exploit the benefits of both aluminum and glass fiber-reinforced polymer composites. This design combines the lightweight and non-corrosive nature of aluminum with the high compressive strength and low deformability of glass fiber-reinforced polymer composites. The resulting Aluminum-covered GFRP composites can serve as effective crash boxes in vehicles, offering protection against sudden impacts on components. This innovative concept not only promises cost-effectiveness and high load-bearing capacity but also opens up new avenues for research in crashworthiness among researchers, academicians, and industrial professionals. This research seeks to bridge the gap between material usage, sustainability, and innovation, with potential applications in various sectors, including automotive, aviation, and defense vehicle manufacturing. By promoting the adoption of Aluminum-covered GFRP composites, we aim to enhance safety standards and drive further advancements in the field of crashworthy materials.

KEYWORDS: Multicell cylinder, GFRP, Aluminium, crashworthiness, High-load bearing capacity

I. INTRODUCTION

Increasing the technological and scientific development on light weight components like Aluminum, Magnesium, Titanium in various field such as automobile, aviation, industrial areas has created an innovative thing around the world. Among these aluminum Al is widely used because of their material properties such as light weight, low density, high corrosion resistance, high thermal conductivity, easy machinability when compared to steel [1]. Last few decades, the over usage of metallic element has created a huge demand on metals among the nation around the world. To effectively use these limited resources in a sustainable and environmentally friendly manner the circular economy model of production approach is used. This will reduce the impact on waste material usage in the environment [2]. Among those metallic components, Aluminum is considered as an environmentally friendly material because of its recyclability of waste from beverages in food processing industries, medicinal field and construction areas. Recent development over the fiber reinforcement polymer material on various field such as automotive, wind energy, aviation, recreational activities, aerospace, transport vehicle as boosting the industrial sector to further creating new things. It has also gained popularity because of its high strength, stiffness, high corrosive resistance, and less dense nature. Further, Fiber reinforcement polymer material has two distinct components namely fiber and resin. Of this component, fiber plays an important role in determining the physical properties of the composites. And the most used fibers are carbon fiber, glass fiber and aramid fiber. Then, another important element in composite material is resin which can be classified as thermosetting and thermoplastic forms. Above all, the thermosetting resin like epoxy and polyester have some distinct quality such as well bonded three-dimensional molecular structure after curing. Moreover, the mechanical behavior of reinforced composites depends on the fiber strength, stability and matrix strength [3]. Among those fibers, the glass fiber is characterized as having specific properties like very high tensile and compressive strength, elasticity, good thermal performance, good water resistance, good electrical insulation, thermal insulation and excellent durability [4].

Further, despite several advantages in aluminum over the other metallic elements, it has less compressive strength when it comes to acting on compressive force. To improve its performance, the glass fiber reinforced polymer composite is used. This paperwork is to Analyse the crashworthiness of the vehicle components like bumper case and

crash box during the sudden brake or else in an accident like situation. Earlier, the bumper case was to be made on steel framed which carried huge weight. To avoid this situation, there were many studies taken on them. Raj kumar et al [5] has investigated that glass fiber reinforced polymer composites are used to make the bumper case instead of using steel frame. There brings the result that the composite material used bumper is lesser in weight along with high load withstanding capability compared to the steel frame. Further, Hussain et al [6] investigated the crashworthiness of composite material and they provide detailed insights on how the drop in weight of the component has produce less impact on the material and further studied on energy absorption in automobile crash boxes. Based on the above paper reviews show that the glass fiber reinforced polymer material has having high load withstanding capacity and cost effective. Moreover, this paperwork is modified in nature on material usage in which it studies the crashworthiness of Aluminum covered glass fiber reinforced polymer composites. Because of its less weight, non-corrosive nature the aluminum is used as outer cover and high compressive strength and less deformative nature of glass fiber reinforced polymer material is used as inner cover to withstand maximum load on material. So, this could be used as crash box in vehicles to protect from sudden impact on components. Furthermore, this will create a path on creating innovation and to take more such research on crashworthiness among the research scientist, academicians, industrial professionals. Thus, this could also be applied in various fields such as automotive, aviation, defense guard vehicle manufacturing, etc.

II. EXPERIMENTAL PROCEDURES

2.1 MATERIALS

The aluminium cylinders are participated in this research study because of its light weight offering a high strength-to-weight ratio making them suitable for structural applications that requires strength with minimum weight [7]. Aluminium of 606T6 is acquired due to its high strength performance. Density ranges from 2.6 g/cm³ to 2.8 g/cm³, which is significantly lower than the other metals. Two aluminium cylinders of different diameter of 81mm and 33mm having same thickness of 3mm are employed, ensured to have a consistent height of 90mm (as shown in fig no1) and purchased from India Aluminium Trading Co. Glass reinforced fibers(GFRP) unidirectional are utilized having thickness of 0.5mm, 300gsm. The polymer resin involved is epoxy resin of LY566 grade with density 1.4 g/cm³ and the curing agent is hardener of HY951 with density 0.98 g/cm³ and purchased from Metro Composites, Chennai, India.

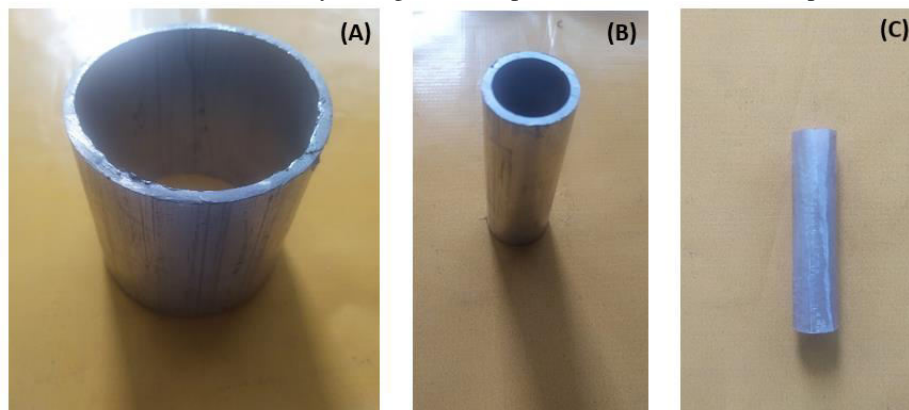


Figure 1: (A) Outer case aluminium cylinder, (B) Mid case aluminium cylinder, (C) Composite glass cylinder

2.2 SAMPLE PREPARATION

2.2.1 FABRICATION OF GLASS FIBERS CYLINDERS

A long straight tube of diameter 18mm are involved as mold for fabricating the glass fiber cylinders. Totally eight number of glass fiber cylinders are required to fill in the gap between the two aluminium cylinders. The dimensions for the fabrication of glass fiber cylinders are 90mm width and 30mm length are marked and separated from the unidirectional glass fiber sheet. make sure of the mold tube without any dent, curve bending etc. fabrication of fiber glass cylinders are prepared by following steps. Initially the mold is fully waxed and covered with release film to prevent sticking or adhesion during curing. The ratio of resin and hardener is 100:10 i.e., 50ml of epoxy and 5ml of hardener are blended together in ambient temperature. The removed fibers sheet is rolled on mold slowly while applying resin at the same time. Uniform spreading of resin necessary for better finishing. Let the resin applied structure cure in the ambient temperature. It takes around 3 to 4 hours by the fabricated fiber glass cylinder to cure and separated from the mold. The same procedure is followed for rest seven fiber glass cylinder fabrication. The Figure1 shows the fully finished fiber glass cylinder.

2.2.2 ASSEMBLING OF MULTI-CELL CYLINDERS

A multicell cylinder is a composite structure composed of multiple cylindrical layers arranged in a concentric configuration. Each layer is made of different materials, such as metals, polymers, or composites, with distinct properties. The purpose of using multiple cells is to enhance the structural integrity and strength of the cylinder. This design allows for improved load-bearing capacity and efficiency compared to a single cylindrical structure. Multicell cylinders find applications in various industries, including aerospace, automotive, and marine, where lightweight design and high strength are essential [8] [9]. Multicell cylinder is assembled with two aluminium cylinders and eight fiber glass cylinders. The aluminium cylinder having smaller diameter (33mm) is placed at the center of large diameter (82mm) aluminium cylinder. The space between two aluminium cylinders is packed with eight fiber glass cylinders as shown in the Figure 2.



Figure 2: Assembled multicell cylinder

III. CHARACTERIZATIONS

The assembled multicell structure are inspected for visual defects and allowed to participate in further compression tests. Both flatwise and edgewise compressions test conducting in the multicell structure to evaluate the valuable information about mechanical properties, structural integrity and performance of the materials under compressive loads. The multicell cylinder is positioned center in the UTM machine fixture (as shown the Figure 3) for both flatwise and edgewise compression

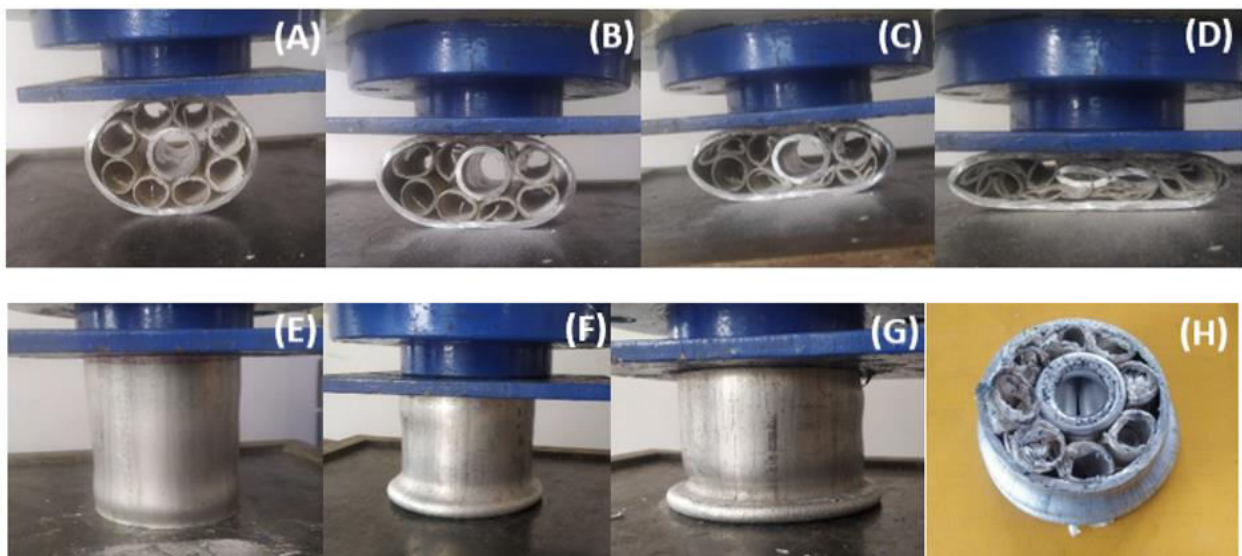


Figure 3: (A-D) illustrate the slow deformation in flatwise compression, (E-F) illustrate the slow deformation in edge wise compression



IV. RESULT AND DISCUSSION

4.1 MECHANICAL BEHAVIOUR

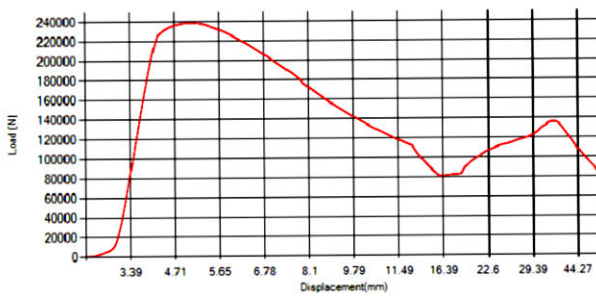
The Compressive strength refers to the ability of a material or structure to withstand compressive forces without undergoing deformation or failure. It is a critical mechanical property that determines the maximum compressive load a material can withstand before it collapses or experiences significant deformation. Table 1 and Graph analysis illustrates the mechanical behavior (compressive strength) of multicell cylinder of edgewise and flatwise compression.

Table 1: Ultimate stress of edgewise compression (EW) and flatwise compression (FW)

Sample Description	Compressive strength (n/mm2)
EW-A	46.36
EW-B	45.37
FW-A	10.52
FW-B	09.49

GRAPH A

Graph Type : Load Vs. Displacement



GRAPH B

Graph Type : Load Vs. Displacement

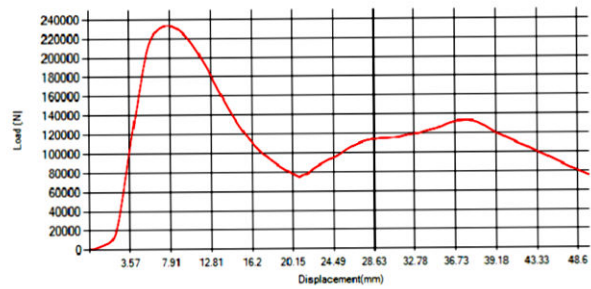
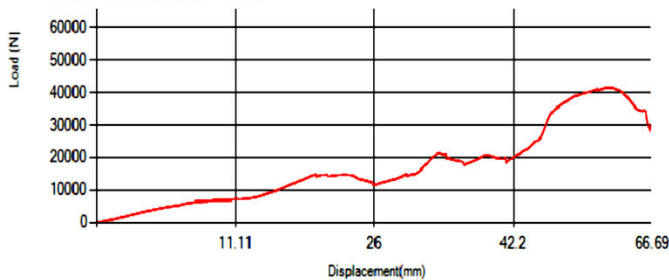


Figure 4 Graphical analysis of edgewise compression

The above two graphs illustrate the edgewise compressive load applied on the multicell structure. Two similar samples are tested to acquire exact strength value by comparing each results. Before first stage of deformation begin, the structure attaining the maximum load as shown in the graphs and the structure resist the load applied for some duration with increasing in load constantly. Load started to drop due to deformation. Deformation occurs steadily with resisting the load. GFRP materials reduces the deformation speed by controlling the deformation of center aluminium cylinder (as shown in Figure no 6). Slight rise in load occurs with continuous deforming in second stage in the above graphs. Due to inner structural damage and GFRP breakage load rises slightly with increases in deformation. At last stage the overall structure breakdown which results in total deformation of multicell cylindrical structure.

Graph A

LOAD VS DISPLACEMENT



Graph B

LOAD VS DISPLACEMENT

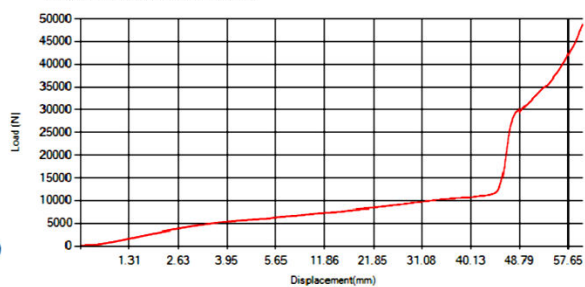


Figure 5: Graphical analysis of flatwise compression

The above two graphs represent flatwise compression. The max load attained in flatwise is 50 KN. In this type of compression deformation begins from starting of the test as shown in above graphs. Load rises due to hallow space are occupied by the broken GFRP materials. Load rises with reducing in length of the structure.

4.3 EFFECTS OF COMPRESSIVE FORCE ON MULTICELL CYLINDER STRUCTURE

The overall structure of multicell cylinder act as a single structure while in compression and resisting the load applied equally by all cylinders. edgewise compressive strength attaining 46.36 n/mm² at max load near 240KN which is better performance than flatwise compression. Upto 50mm reduced from the total length of the structure. It takes long duration for deforming and also there is duration gap between each deforming stage of multicell cylinder structure (as shown in Figure 3 & 6). Multicell cylinders often possess high edgewise compression strength due to several factors inherent to their design and construction. Here are some reasons why multicell cylinders exhibit high edgewise compression strength [10]. Multicell cylinders consist of multiple cells or compartments arranged in a cylindrical configuration. Each cell acts as a separate load-bearing unit, distributing the applied compressive forces across multiple load paths. This distribution of load helps to effectively resist deformation and increases the overall compressive strength of the cylinder in the edgewise direction. Multicell cylinders can incorporate structural reinforcement elements, such as ribs or stiffeners, within each cell or between adjacent cells. These reinforcements enhance the rigidity and strength of the cylinder, particularly in the edgewise direction [11]. The presence of reinforcement elements (GFRP) helps to prevent buckling or localized deformations, contributing to the higher edgewise compression strength. The cross-sectional shape of multicell cylinders is often optimized for increased edgewise compression strength. The structure design, which provide inherent resistance against deformation and maintain structural integrity under compressive loads. The structure distributes the applied forces more evenly across the walls of the cylinders and inner cylinders resulting in higher edgewise compression strength. GFRP materials possess high stiffness and strength characteristics, allowing them to withstand higher compressive loads in the edgewise direction [12]. The controlled and consistent construction enhances the edgewise compression strength of the cylinder. multicell cylinders structures are designed to maximize their edgewise compression strength. The incorporation of multiple load paths, structural reinforcements, optimized cross-sectional shapes, collectively contribute to their superior performance under edgewise compressive loads. The edgewise compressive strength is typically better than the flatwise compressive strength due to several reasons. Firstly, the fiber orientation in GFRP material plays a significant role. The fibers are aligned along the length or width of the panel, allowing them to effectively resist compressive forces in the edgewise direction. However, in the flatwise direction, where the fibers are parallel to the loading direction, their resistance to compression is reduced. Secondly, the presence of edges provides better lateral support in edgewise compression. The edges of a panel can resist lateral deflection and instability, thereby enhancing the load-carrying capacity and overall strength. On the other hand, flatwise compression lacks substantial lateral support, making the panel more prone to buckling, wrinkling, or delamination, which ultimately reduces its compressive strength. The geometry and slenderness of the panel also contribute to the difference in compressive strength. Edgewise compression benefits from a favorable aspect ratio, where the width or thickness of the panel is relatively smaller compared to its length. This aspect ratio helps resist buckling and local instabilities, resulting in a higher compressive strength. In contrast, the larger span of the panel in flatwise compression increases its susceptibility to buckling and localized deformations, leading to a lower compressive strength. Understanding these differences is essential for making informed decisions regarding material selection and structural design to ensure the desired strength and stability of components under different loading conditions.

Figure 6 shows how load acting on the multicell cylinder structure. In ANSYS, compressive analysis and deformation analysis are performed to study the behavior of structures under different loading conditions. Compressive analysis focuses on studying the structural response of a component or system when subjected to compressive forces or loads. It helps assess the structural integrity, stability, and buckling behavior of the object under compression. Deformation analysis, also known as structural analysis, focuses on understanding how a structure responds to external forces and loads by analyzing its deformation behavior. It helps evaluate factors such as stress distribution, strain, displacement, and overall structural stability. Both compressive analysis and deformation analysis in ANSYS are powerful tools for studying the behavior of structures under different loading conditions [13] [14]. It enable to assess the structural integrity, stability, and performance of various designs and make informed decisions based on the analysis results.

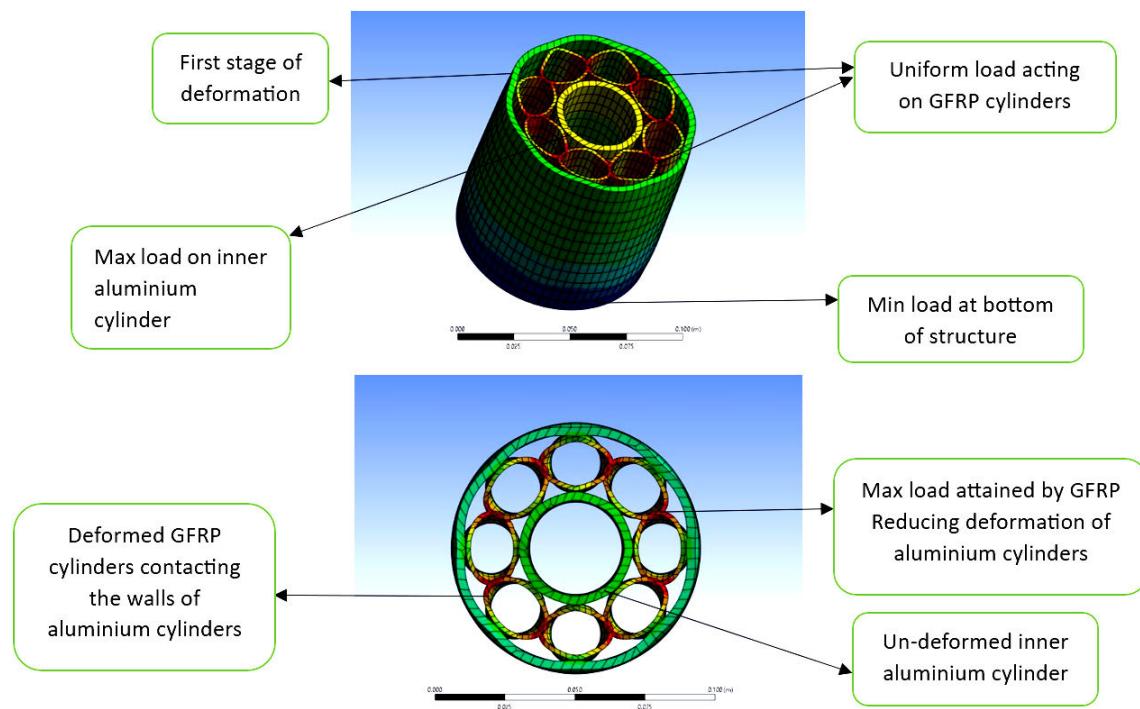


Figure 6: Compressive Analysis of Multicell Cylinder Structure on Ansys

The compressive strength of flatwise compression is typically lower than that of edgewise compression due to the differences in the structural response and failure modes in these two loading configurations. Flatwise compression is more prone to buckling compared to edgewise compression. When a flat panel is loaded in the flatwise direction, the compressive forces tend to induce buckling modes that result in sudden lateral deflection or instability. Buckling can reduce the effective load-carrying capacity of the structure and lead to premature failure. Flatwise compression can cause delamination between the layers. The compressive loads induce shear stresses between the layers of GFRP, leading to the separation or debonding of the layers within the composite structure. Delamination significantly weakens the structure and reduces its compressive strength. Flat panels subjected to compression in the flatwise direction can experience wrinkling or dimpling. Wrinkling occurs due to localized buckling of the panel, resulting in deformation and reduction of load-carrying capacity. This phenomenon is more prevalent in thin and flexible panels. The strength and stiffness properties of aluminium and GFRP materials are often different in the flatwise and edgewise directions. Due to the inherent anisotropy, the material having lower strength and stiffness in the flatwise direction, resulting in a lower compressive strength. Compressive strength of flatwise compression is influenced by the core configuration where the structure having hollow space loses the resisting the load uniformly through the structure. Some of GFRP cylinders experience the load after deformation happened to a certain length. Graph analysis shows the maximum load attained in flatwise compression.

V. CONCLUSION

From results and analysis, it clearly illustrates that the structure with glass fiber reinforced polymer improving the structural strength in both compression test (flatwise and edgewise). GFRP increases the structural load resisting capacity and reduces the deformation duration. Focusing on compression results multicell cylindrical with GFRP cylinders in free space reduces the impact both edgewise and flatwise but better performance in edgewise attaining ultimate stress of 46.36 N/mm² whereas flatwise attaining ultimate stress of 10.52 N/mm². The FEA analysis shows how load is resisted by the structure as shown in Figure 6 and also it gives clear view how GFRP reducing the impact by creating contact with walls of aluminium cylinders, filling the space between the two aluminium cylinders delaying the deformation of the structure. The variation in strength is due to the structural support and contacting area of the structure. Even aluminium executing high strength features, GFRP cylinders provides extra supportive strength to overall structure forming a multicell cylinder structure. The design of structure looks similar to the old gun revolver cylinder. Because the structure possessing low deformation receiving 240 kN of load (as shown in Figure 4) the multicell structure can be utilized or can be replace the crash box of automobiles and inner bumpers of automobiles

reducing the impact created during accidents. Edgewise structure performing better than flatwise from the test results it be concluded. Also, multicell cylinder structure in edgewise resisting high load and even more improved by involving more GFRP cylinders in the structure

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