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IMPACT PERFORMANCE OF ENCAPSULATED SHEAR THICKENING FLUID INTEGRATED FOAM CORE SANDWICH COMPOSITES

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1. INTRODUCTION

Besides favorable properties of sandwich composites with high specific stiffness, good bending rigidity, thermal insulation, acoustic damping and ease of manufacturing, poor impact resistance is a major concern limiting their use in advanced technologies such as aerospace [1]. The impact loadings can be in a wide range from tool drops, runway debris to bird strikes and hailstorms implying the importance of crash absorbing property of these structures. These types of loadings can introduce damages on both face sheets and core materials which also can create debonding in between them. Using regular core materials such as honeycombs with lower surface area and poorer bonding to face sheet may decrease the properties of sandwich composites. Herein, a foam core material from polyurethane is used to provide an increased bonding within enhanced surface area between face sheet and core reducing debonding problems, and is a possible candidate having a closed cellular structure for impact resistivity. However, enhancing only the quality of bonding between face sheet and core is not enough since failure of sandwich composites initiates from its core under loading.

A local indentation or crack of foam core under impact load with a huge depth from collapsing vacancies between cells is not desired for the safety since crack initiation in core may grow and cause catastrophic failures during operation and its lifetime. Thus, latest researches have focused on a new approach based on rapid toughening and impact absorbing materials which are succeeded by embedding shear thickening fluids (STF) into composites [2, 3]. Particularly, STF impregnated Kevlar fabrics have been studied by many researchers for ballistic penetration performance [2, 4]. As stated, STF consist of nanoparticles in a carrier fluid forming a highly filled stabilized dispersion and nanoparticles stay in a randomly distributed position inside dispersion at rest and create clusters with an applied external stress increasing the viscosity substantially after a critical shear rate. In addition of their use in ballistic impact damper applications, STFs have also recently found a place to itself in porous structures as foams [3]. However, to the best of our knowledge, these studies are on the impact or dynamic compressive load damping performance of STF embedded open cell soft foams as a cushioning element for composite structures [3, 5].

In this work, rapid toughening effect of shear thickening fluids is used directly in closed cell rigid polyurethane (PU) foam cores to reduce the damage of sandwich composites under impact loads. Besides its expected benefits on impact performance of rigid foam core, embedding STF into foam also causes some problems as the difficulty of handling, integrating STF into structure and its stability during service life [6]. Thus, Zhang *et al.* studied the encapsulation of STF (e-STF) that is stiff enough to resist forces during synthesis process and behaves as a rubber like material under impact loads for an easy-to-apply impact resistant material [6]. This study aims to fulfill the need of literature studies on impact absorbing properties of sandwich composites by embedding STF microcapsules with a polyurethane compatible shell into closed cell rigid polyurethane foam core (e-STF/PU). Within this approach, by the encapsulation of STFs with polyurethane compatible shell, the impact resistivity of the sandwich composites will be studied.

2. EXPERIMENTAL

For shear thickening fluid, there are several studies explaining the STF structure as a concentrated colloidal suspension of silica particles and ethylene glycol [6, 9]. Thus, this study also repeated similar process to synthesize STF with a high weight fraction of silica particles in ethylene glycol. Materials for STF were commercially supplied from Sigma-Aldrich having a diameter of 12nm in the form of nano-powder and ethylene glycol. Silica particles are added to ethylene glycol gradually during mixing process by a mechanical stirrer at room temperatures. In order to have the most homogenous mixture, ultrasound sonication is also applied through the process when needed. Herein, two different weight fractions of silica particles are studied until now as 35% (STF-35) and 46% (STF-46). Further studies are going on to increase the silica loading capability inside ethylene glycol at least 50% by wt. Obtained STFs are tested by a rheometer of Anton Paar with 25mm parallel plate geometry at room temperatures performing a pre-shear loading first in order to eliminate bubbles and possible non-homogeneities. Shear thickening characteristic is clearly observed in Fig.1 for STF-46 while STF-35 does not show an obvious non-Newtonian behavior. This sharp increase in viscosity of STF-46, nearly threefold of initial value, resulted from the agglomeration or disordering of silica particles inside carrier fluid as shown in Fig.2(b). Wherein for STF-35, loaded amount of silica particles was not enough to show thickening behavior due to lack of effective hydrodynamic forces between particles creating clusters.

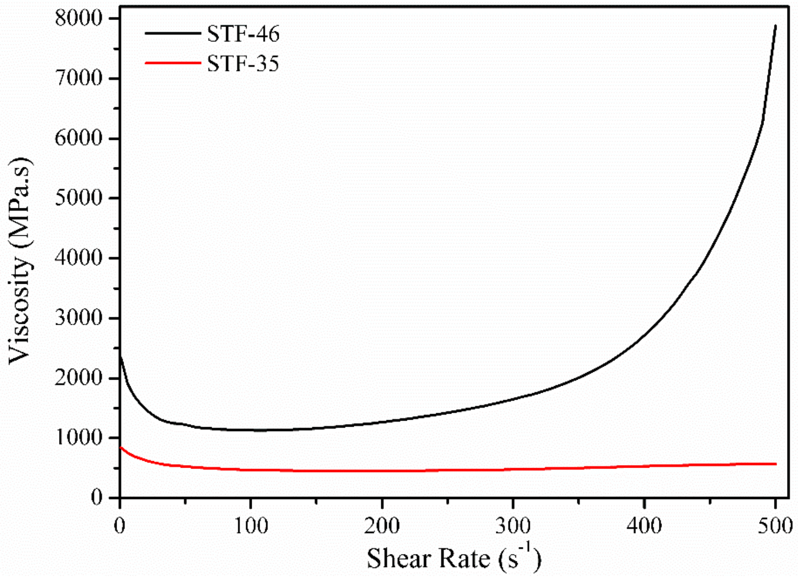

Fig. 1: The curves of viscosity vs shear strain rate for STF samples.

Following step of STF fabrication is identified as encapsulation where two major promising methods have been observed as solution polymerization and emulsion polymerization in literature. In a study, Chung *et.al.* synthesized microcapsules with a self-healing core by emulsion polymerization and successfully embedded into PU foam [7]. B.J.Blaiszik *et.al.* also studied polyureaformaldehyde (PUF) microcapsules prepared by in situ emulsion polymerization of urea and formaldehyde for shell and reactive solutions as self-healing materials for core [8]. Despite existing studies on microcapsules with self-healing material cores, there is still lack of studies on microcapsules containing shear thickening fluids, and particularly their integration into structure within existing processing techniques. Zhang *et.al.* successfully synthesized encapsulated STF to overcome the physical and chemical problems in handling of STF in polymers and found that e-STF does not lose its shear thickening effect to absorb impact energy [6]. In this study, both techniques stated above for microcapsule synthesis are performed since they both offer well-established capsules with liquid cores and a shell acting as a protective barrier from external environment. The optimized procedure and the best conditions are chosen to obtain the shear thickening fluid containing microcapsules embedded PU (e-STF/PU) cored sandwich composites. Morphology of the STF microcapsules are analyzed by scanning electron microscopy (SEM) and mechanical properties are examined.

Under impact, the protective shell of microcapsule behaves like a rubber like material and dampens the created impact energy. Silica particles increase the flow resistance and causes STF to behave like a solid after a critical shear rate. This behavior of STF in PU foam toughens the structure and eliminates the risk of a deep damage under impact in service preventing catastrophic failure of sandwich composite by modified foam.

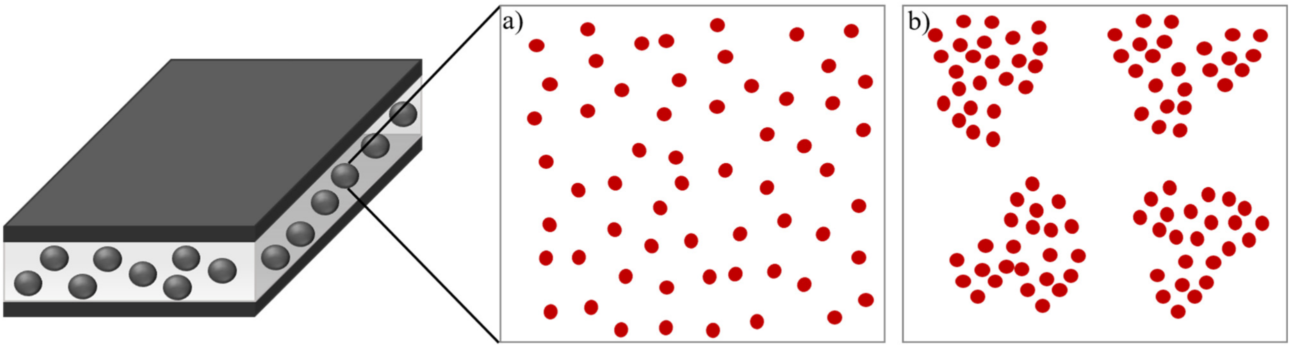

Fig. 2: Response of STF microcapsules after a critical stress (a) Particles at rest in STF, (b) Agglomerated particles under shear increasing the flow resistance, causing a shear-thickening behavior.

Prepared STF microcapsules are embedded in PU foam directly during foaming and STF microcapsules are mixed in polyol media by a mechanical stirrer at different stirring speeds. Then, remaining part of PU is added and mixed mechanically for foaming. STF microcapsules embedded rigid PU foams are placed in oven to perform polyurethane reaction. Two different core materials are used to fabricate sandwich composites as neat PU foam and e-STF/PU foam.

Foams are slimmed from top and bottom surfaces to get rid of non-homogeneities. Twill carbon fiber prepregs are used as face sheet for 4 plies each side. Sandwich composites are produced under pressure with a vacuum bag at 80°C for 4 h in oven for curing process of prepregs.

Response of e-STF/PU foams under quasi-static compression is studied according to ASTM C365-16 with 3 specimens for each case. Damage resistance properties of sandwich structures under impact are tested under impact to observe the rapid toughening effect of STF microcapsules in PU foam core.

3. CONCLUSION

Until now, microcapsules, shear thickening fluids and impact response of composites are studied by many researchers but none of these studies focused on integrating these three concepts to apply in sandwich composites. This study focuses on impact response of e-STF/PU cored sandwich in which impact load causes a huge increase in viscosity of STF, due to particle clusters after a critical shear rate, and toughens the polymer foam core. Fabricated STFs with a silica particle loading of 46% by wt. showed nearly threefold increase in viscosity and further studies are going on to achieve a better thickening mechanism by loading the carrier fluid with at least 50% by wt. fraction of particles. Stated mechanism is expected to prevent the catastrophic failure of sandwich structure by a modified core since damage starts from core first. Morphology and mechanical properties of e-STF/PU foam, neat PU foam and sandwich composites are studied through SEM, compression and impact tests.

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