

Figure 1: Pictorial Representation of Emulsion Under Study With Shear Thickening Fluid as Discrete Phase

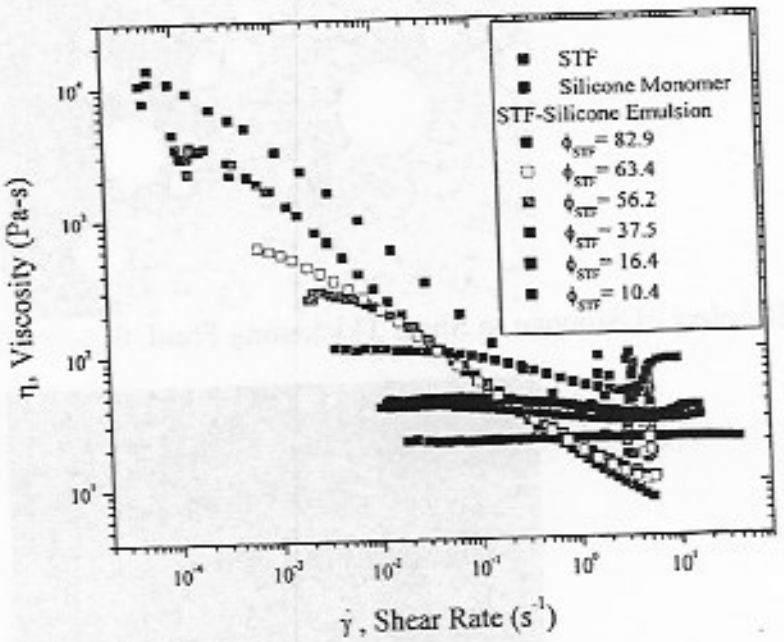


Figure 3: Viscosity-Shear Rate Relationship for STF Suspoemulsions, STF and Suspending Fluid.

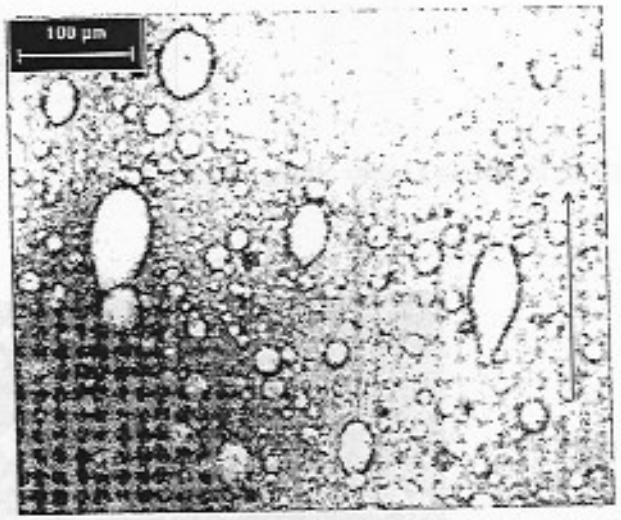


Figure 4c: Silicone in Discrete Phase Under Shear, Φ_{SR}=63.4, Displaying Droplet Deformation

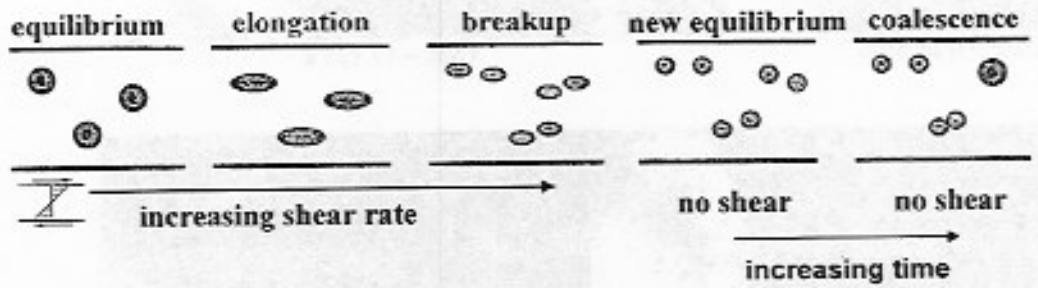


Figure 6: Stress-time Droplet Evolution

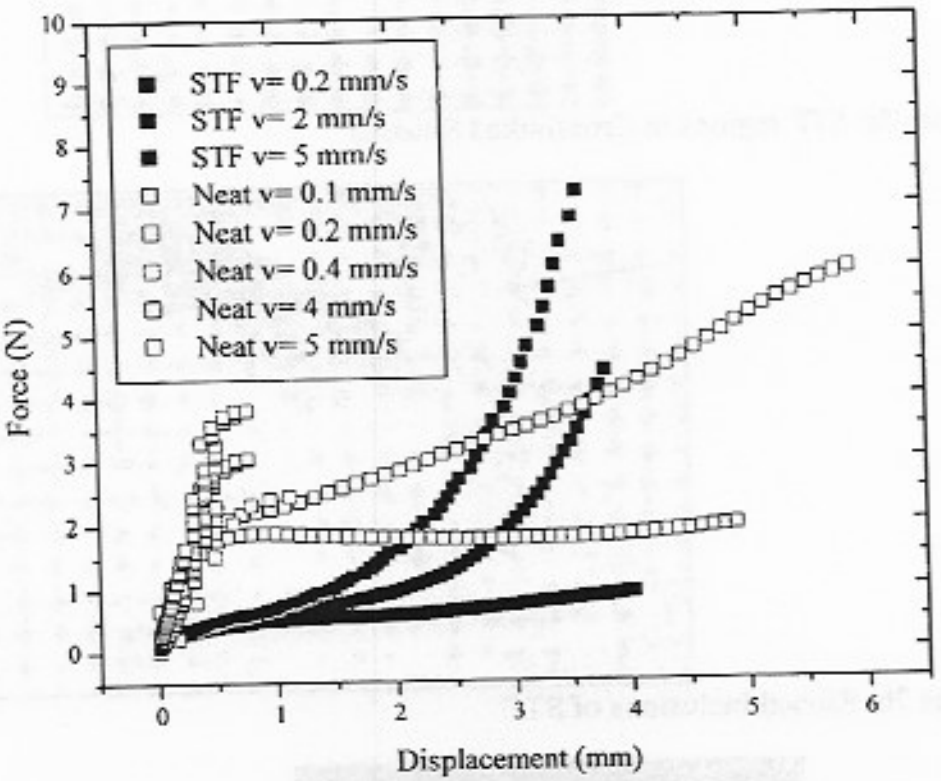


Figure 8: Compiled Force Displacement Curves

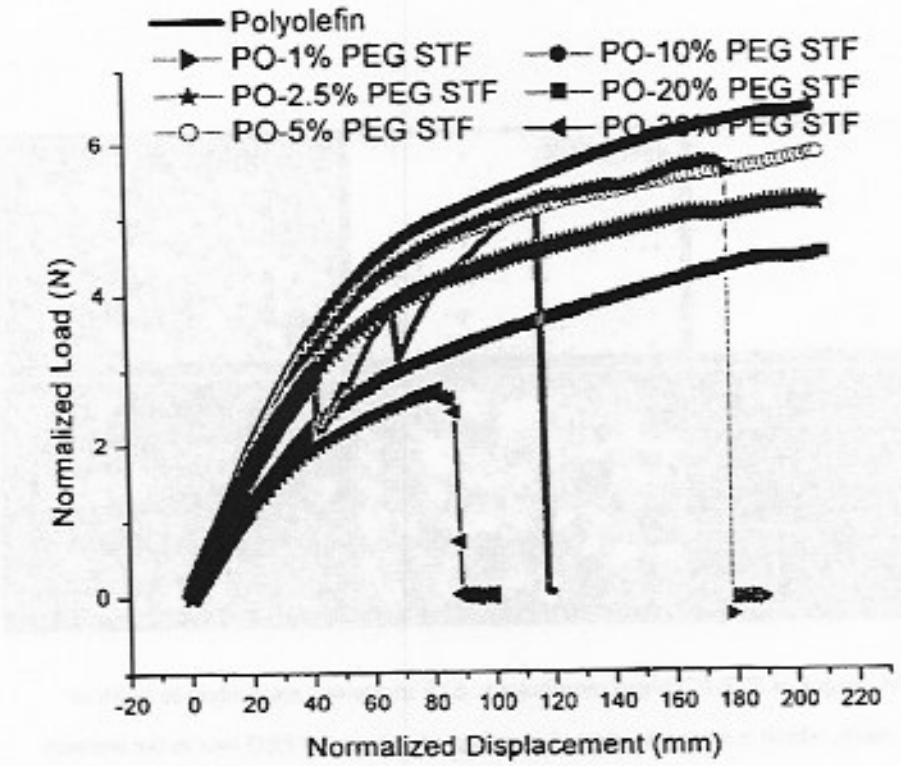


Figure 10: Trouser Tear Test results for samples, as labeled.

[0008] The general realization of an emulsion, such as the ones under study, is treatment of one phase as continuous and the second as discrete droplets, either ellipsoidal or spherical in shape, or as both phases in a continuous form (known as co-continuous). The discrete phase droplets can deform, break up, aggregate, and coalesce under flow. Flow induced deformation is quite complex (Edwards, B. J., Dressler, M., "A rheological model with constant approximate volume for immiscible blends of ellipsoidal droplets," Rheol. Acta 42, 326-337 (2003)), (Wetzel, E. D., Tucker, C. L., "Droplet deformation in dispersions with unequal viscosities and zero interfacial tension," J. Fluid Mech. 426, 199-228 (2001)). A more in-depth discussion of droplet deformation can be found in Cavallo, Dagreou, S., Allal, A., Marin, G., Mendiboure, B., "Linear viscoelastic properties of emulsions and suspensions with thermodynamic and hydrodynamic interactions," Rheo Acta 41, 500-513 (2003). Edwards, or Wetzel (Wetzel, E. D., Tucker, C. L., "Droplet deformation in dispersions with unequal viscosities and zero interfacial tension," J. Fluid Mech. 426, 199-228 (2001). Wetzel, E. D., Tucker, C. L., "Microstructural evolution during complex laminar flow of liquid-liquid dispersions," J. Non-Newtonian Fluid Mech. 101, 21-41 (2001)). Even more important to the current work are the results of Kernick and Wagner (Kernick, W., Wagner, N. J., "The role of liquid-crystalline polymer rheology on the evolving morphology of immiscible blends containing liquid-crystalline polymers," J. Rheol. 43(3), 521-549 (1999)) showing that non-Newtonian fluids in emulsion can lead to dramatic changes in morphology under flow due to shear rate dependence of morphology.

[0009] The analysis of the emulsion under study is performed with the premise that the state of the discrete phase droplets can be understood through consideration of droplet breakup and coalescence (Doi, M., Ohta, T., "Dynamics and rheology of complex interfaces. I," J. Chem. Phys. 95, 1242-1248 (1991)), (Taylor, G. I., "The viscosity of a fluid containing small drops of another fluid," Proc. R. Soc. London Ser. A 138, 41-48 (1932)), (Taylor, G. I., "The formation of emulsions in definable fields of flow," Proc. R. Soc. London Ser. A 146, 501-523 (1934)). Work by Rusu (Rusu, D., Peuvrel-Disdier, E., "In situ characterization by small angle light scattering of the shear-induced coalescence mechanisms in immiscible polymer blends," J. Rheol. 43(6), 1391-1409 (1999)) highlights in detail the complexities of the dynamic equilibrium between droplet coalescence and dispersion mechanisms. The droplet coalescence is broken down into four stages (i) the collision between the two drops; (ii) the drainage of the matrix film separating the colliding drops; (iii) the rupture of the matrix film; and (iv) the drop coalescence. The work on the shear-induced coalescence of droplets is considered to be consistent with previously understood mechanisms. However, the prediction of final morphology (particle size distribution and state of dispersion), in connection with the magnitude of deformation and stresses, is very difficult (Iza, M., Bousmina, M., "Nonlinear rheology of immiscible polymer blends: Step strain experiments," J. Rheol. 44(6), 1363-1384 (2000)).

[0010] Adding more of the dispersed phase can lead to the formation of a co-continuous morphology or phase inversion. Ageropoulos, G. N., Weissert, F. C., Biddison, P. H., Bohm, G. A., "Heterogeneous blends of polymers. Rheology and Morphology," Rubber Chem. Technol. 49, 93-104 (1976) concluded that the point of phase inversion is reached when the torque ratio of the components is equal to the component volume fraction ratio. Work by Utracki (Utracki, L. A., "On the viscosity-concentration dependence of immiscible polymer blends," J. Rheol 35(8), 1615-1637 (1991)) suggests the phase inversion point can be predicted based on the dependence of the viscosity on the volume fraction of monodispersed hard spheres in the matrix, as proposed by Krieger and Dougherty (Krieger, I. M., Dougherty, T. J., "A mechanism for non-Newtonian flow in suspensions of rigid spheres," Trans. Soc. Theol. 3, 137-152 (1959)). A more in depth analysis of the previous work in the area of phase inversion can be found in work by Astruc, M., Navard, P., "A flow-induced phase inversion in immiscible polymer blends containing a liquid-crystalline polymer studied by in situ optical microscopy," J. Rheol. 44(4) 693-712 (2000).

[0011] The blend or emulsion under study is a mixture of a shear thickening fluid comprised of particles in a suspending media, dispersed in an immiscible liquid (FIG. 1). The solid particles are suspended in the suspending media at a sufficient loading to produce a shear thickening fluid. The particles are not added to the silicone phase and the emulsion can be reduced to two phases. Such realizations are known as suspoemulsions, which refer to the dispersion of a suspension in an immiscible liquid. Phase inversion, either by concentration or processing, can lead to the dispersion of the immiscible liquid into the shear thickening fluid, or the existence of co-continuous microstructure.

[0012] Previous literature is limited to a few investigations dealing with a shear thickening phase in an emulsion (Pal, R., "Non-idealities in the rheological behavior of emulsions," Chem. Eng. Comm. 121, 81-97 (1993)), (Tan, H., Tam, K. C., Jenkins, R. D., "Rheological Properties of Semidilute hydrophobically Modified Alkali-Soluble Emulsion Polymers in Sodium Dodecyl Sulfate and Salt Solutions." Langmuir 16, 5600-5606 (2000). Pal (Pal, R., "Non-idealities in the rheological behavior of emulsions," Chem. Eng. Comm. 121, 81-97 (1993)) studied the rheological behavior of pure component EDM oil, a non-discontinuously shear thickening fluid, and emulsions containing EDM. Results showed that with the addition of an emulsifying agent the oil could be emulsified in deionized water (Newtonian fluid) resulting in an emulsion with Newtonian viscosity behavior.

[0013] Studying the rheology of immiscible dispersions of a non-Newtonian liquid-crystalline polymer Kernick and Wagner found dramatic changes in morphology under flow due to shear rate dependence of morphology. It is therefore expected that a suspoemulsion containing the highly non-Newtonian shear thickening fluid will have a change in morphology under different flow conditions.

[0014] Such suspoemulsions can have useful applications in and of themselves due to their complex rheological properties. In addition, such suspoemulsions can be precursors to forming STF composite materials that can have useful applications. An example of the latter is a polymer blend containing STF inclusions, which is processed when the polymer is above or near to its melting transition such that it can be processed, but is used below this temperature where the polymer is more rigid. Another example is the formation of a suspoemulsion in a crosslinkable or polymerizable matrix fluid such that the STF composite is formed upon crosslinking or polymerization of the matrix fluid.

SUMMARY OF THE INVENTION

[0015] One aspect of the invention is drawn to a composite which comprises a shear thickening fluid (STF) combined

(TPE). Melt processable polymers include but are not limited to polyolefins such as polyethylene and polypropylene, nylon, polymethylmethacrylate, polyvinylchloride, polyethylene terephthalate (PET), polycarbonate and the like. Thermoplastic elastomers would include such as materials as those sold under the trade names Santoprene™ (Exxon Mobil Chemical), Hytrel® (DuPont Company), and Engage™ from DuPont-Dow Elastomers. In this instance, increased temperature is used to liquefy a polymeric material. At the processing conditions required to achieve the desired melt flow properties of the polymer second material, the shear thickening fluid would be compounded with the polymer melt to achieve the desired level of mixing and microstructure. The temperature would subsequently be reduced to generate the solid polymer-shear thickening fluid composite.

[0037] End use articles can be generated from the aforementioned novel materials through injection molding, thermoforming, extrusion, and conceivably any method used to fabricate articles from the second polymeric material alone as known to those skilled in the art.

[0038] Alternatively these materials could be incorporated as discrete laminar regions between layers of the second material, such as between layers of polymeric materials and composites (such as polycarbonate and fiberglass reinforced epoxy) glass, ceramic, or metal films or sheet. Such laminar composites could exhibit dramatically improved ballistic or impact related energy dissipation, as the compression associated with impact would initiate improved energy dissipation between the second material layers within the construction. The particles in the shear thickening fluid of the invention are preferably colloidal particles having a particle size less than 10 microns and more preferably less than one micron. The laminates formed are different than the laminates disclosed in WO 2004/012934 (WO '934). The laminates disclosed in WO '934 require a specific shape (corrugated egg crate shape). The invention can be practiced not using the specific shape required by WO '934.

[0039] The shear thickening composite materials are different than those disclosed by Plant (US 2004/0171321) as they describe a dilatant material impregnated into a resilient carrier. The dilatant material are dilatant compounds and putty and are distinct from the shear thickening fluids described in this work.

[0040] Liquid-shear thickening fluid composites: One embodiment of the invention relates to a composite liquid-liquid mixture, or blend, where the two liquids are immiscible or only partially miscible such that they develop a heterogeneous morphology, and where at least one component in the mixture is a fluid that exhibits a shear thickening transition, (increase in viscosity resulting from increased shear stress or shear rate). We have shown that blends of shear thickening fluids incorporated into a second fluid medium exhibit rheological behavior indicating their ability to impart improved energy dissipative capabilities to composites made there from.

[0041] Such a fluid may have utility in control and damping applications. One such application may be a mechanical limiting fluid that resists deformation beyond a certain applied stress or deformation rate. Such a fluid may have utility when incorporated as a coating, impregnated into or dispersed within a solid material. Such a fluid could serve as a layer between two materials such as glass, metals, or plastics to provide energy dissipative characteristics. One application for such a fluid would be to impregnate or imbibe it into a porous solid scaffold material. Such solid material structures would include, but are not limited to fiber yarns, woven fabric, spunlaced or spunbonded nonwoven fabric, an open cell foam (to form a co-continuous network with the solid open cell foam network/scaffold), or to exist as discrete droplets within a solid. The composition of the yarns or fabrics would include synthetic materials, such as polymers, elastomers, as well as inorganic fibrous materials. Polymeric fibers include high modulus polymeric fibers such as polyaramids poly(phenylene diamine terephthalate) sold by Dupont under the registered trademark KEVLAR®, nylon, polyester, Dacron etc. Elastomeric fibers include polyisoprene, other fibers included within the scope of this invention include high modulus inorganic fibers and/or fiber yarns and/or fabrics, or natural occurring fibers such as cotton, wool, hemp. etc. High modulus inorganic fibers and fiber yarns and fabrics include, but are not limited to graphite, E-glass, S-glass, ceramics fibers etc.

[0042] The novel blend could be incorporated as discrete droplets or co-continuous phases within a solid material by methods described earlier for fabricating solid-shear thickening fluid composites.

[0043] Distinction Between Our Invention and Dilatant Energy Absorbing Materials

[0044] Palmer et al. [US 2005/0037189 A1, WO 03/055229 A2, WO 2005/000966 A1] describe an invention whereby a "polymer-based dilatant" is distributed into a solid, foamed synthetic polymer matrix to form a "self-supporting energy absorbing composite". Plant (US 2004/0171321) describes a dilatant material impregnated into a resilient carrier. These applications use a known, commercially available polymer (i.e., "silly putty") that dilates under strong deformation as a component in a composite material. These applications are limited in scope and are fundamentally different than what is proposed here, in that: A) dilatant materials expand in volume when subject to stress, while shear thickening materials are essentially incompressible and have a viscosity that increases with shear stress; B) the shear thickening materials consist of colloidal and nanoparticle dispersions, as opposed to "a material in which the dilatancy is provided by polymer alone or by a combination of polymer together with one or more other components, e.g. finely divided particulate material, viscous fluid, plasticizer, extender or mixtures thereof, and wherein the polymer is the principle component" [Palmer and Green, US 2005/0037189 A1. Thus, the invention described herein is distinguished from the work of Palmer et al. and Plant by both principle and materials, and is not derivative thereof.

[0045] Applications

[0046] Applications for shear thickening fluids incorporated into pads for sports equipment. Bicycle, motorcycle helmet, construction hardhat and the like which incorporates padded regions between the outer shell and the wearers head containing shear thickening fluids either in suspoemulsions, impregnated in foams, existing as discrete droplets or stripes or layers within an elastomer, or as part of a co-continuous or interpenetrating network of shear thickening fluid network within a solid plastic or elastomeric material.

[0047] A mouth guard fabricated from a conformable polymer or elastomer containing discrete or co-continuous regions of shear thickening fluids would likely exhibit improved energy dissipation. Such an article could reduce the likelihood of concussion, dental damage, etc.

[0048] Conformable Pads incorporating discrete regions, dispersed droplets, co-continuous networks of shear thickening fluids within a solid polymeric or elastomeric second

samples will be referenced by the volume fraction of shear thickening fluid contained, Φ_{STF}.

TABLE 2

Emulsion Compositions

Mass of Shear Thickening Fluid (gm)	Mass of Silicone (gm)	Weight % STF	Φ_{STF}
3.042	0.379	88.9	82.9
2.2796	0.7922	74.2	63.4
1.721	0.809	68.0	56.2
3.904	3.915	49.9	37.5
1.938	5.946	24.6	16.4
0.7048	3.6701	16.1	10.4

[0058] STF-Suspoemulsion Structure: The two components were mixed by hand and a sample of this emulsion plated onto a glass slide for inspection under an optical microscope; representative images are shown in FIGS. 2*a* and *b*. It was suspected that the absence of a mechanical mixer would create a very polydisperse droplet size due to the non-uniform power input (Kitade, S., Ichikawa, A., Imura, N., Takahashi, Y., Noda, I., "Rheological properties and domain structures of immiscible polymer blends under steady and oscillatory shear flows," J. Rheol. 41(5), 1039-1060 (1997)). Visual confirmation of the formation of two distinct phases enabled sizing of the disperse phase. The droplet size of the disperse phase as prepared was found to range between ~1 and 100 μm.

[0059] STF-Suspoemulsion Rheology: A 25 mm cone and plate geometry (gap=0.0509 mm, angle=0.099 radians) was utilized on a strain-controlled rheometer (Rheometrics SR-5000) to determine the rheological properties of each emulsion and the pure components. Testing was performed at a constant 25° C. with a peltier and constant temperature water bath used for temperature control. The samples were subjected to a uniform force gap testing followed by a creep test at 5 Pa until the viscosity of the sample reached a steady state, approximately two minutes. This was done to insure homogeneity of the sample and to set a fixed shear history for each test. This constant preshear should result in an emulsion morphology at steady state as a balance between droplet breakup and coalescence. Stress sweeps were run on the rheometer with a maximum time of 30 seconds per data point and frequency sweeps were run without a time limitation for each data point. After completion of the rheological tests a portion of the used sample was then plated for observation under the optical microscope. The quick relaxation time of the sample made quantitative analysis of samples plated after testing in the rheometer inaccurate, as the system relaxed before the phase microstructure could be analyzed. The measurements, however, helped in qualitative understanding of the effects of shear flow on the sample morphology.

[0060] A simple shear cell was constructed by inserting sample between two glass microscope slides. The slides could then be sheared with respect to each other and the resulting fluid behavior observed under an optical microscope with image capturing software.

[0061] A more complete analysis of the shear thickening phenomenon for systems very similar to the one studied is given by Lee and Wagner (Lee, Y. S., Wagner, N. J., "Dynamic properties of shear thickening colloidal suspensions," Rheol Acta 42, 199-208 (2003)) and the interested reader is referred to that manuscript for a thorough explanation of STF rheological behavior. Barnes (Barnes, H., J. Rheol. Vol. 33, 329 (1989)) provides an extensive, but not exhaustive, list of possible shear thickening fluids.

[0062] The viscosity as a function of both strain rate and stress for the neat materials and suspoemulsions are shown in FIG. 3.

[0063] As can be seen the viscosity of the emulsion is highly dependent on the volume fraction of shear thickening fluid in the mixture and the shear stress imparted. The viscosity of each emulsion is a nontrivial combination of the pure component curves. At low shear thickening fluid volume fractions, the samples display Newtonian like fluid behavior at low stresses and a very small shear thinning region. At higher STF loadings the low shear viscosity more closely tracks that of the STF. The emulsions with the highest volume fractions of shear thickening fluid (Φ_{STF}=82.9, 63.4, 56.2) also exhibit discontinuous shear thickening at increasingly higher stress levels while the lower volume samples exhibit shear thickening followed by a plateau and then a second shear thinning region.

[0064] The critical stress for shear thickening is defined as the stress at the minimum in the viscosity vs. shear stress curve at the onset of shear thickening, and is shown in Table 3.

TABLE 3

Critical Stress Values for Shear Thickening as a Function of STF Phase Volume

Φ_{STF}	Critical Rate (s^{-1})	Critical Stress (Pa)	Critical Viscosity (Pa-s)
100	3.583	43	12.1
82.9	1.737	40	22.5
63.4	4.647	49	10.4
56.2	5.095	56	11.0
37.5	2.576	126	49.1
37.5	3.554	158	44.5
16.4	7.633	251	32.8
10.4	6.297	186	29.5

[0065] This is clear evidence that the STF phase in the novel STF suspoemulsions is able to exhibit shear thickening. The stress required for shear thickening is highest at low STF loadings.

[0066] Thixotropy in the form of hysteresis in the flow curves was observed at intermediate and low STF phase volumes. This is described in greater detail in U.S. application Ser. No. 11/260,742 filed Oct. 27, 2005 which again is incorporated by reference in its entirety including all the figures. Such hysteresis is a sign of shear sensitivity of the microstructure.

[0067] The viscosity-concentration relationship of the mixtures was determined by taking the viscosity of each component at constant stress values. This relationship is shown in Table 4

TABLE 4

Viscosity of Suspoemulsions as a Function of Stress and STF Phase Volume

	Stress vs. STF Phase Volume%					
	0%	15.87%	36.55%	55.14%	82.86%	100%
1 Pa	21.097	44.316	113.510	265.730	10821.000	2055.100
2 Pa	21.188	45.661	109.920	220.300	5624.800	656.860

ing is more apparent for the low volume (Φ_{STF}=16.4, 10.4) shear thickening fluid samples than in the dynamic testing where the low volume fraction samples more closely resemble the pure silicone oil sample. This suggests the shearing of the sample affects the microstructure of the sample. A more in depth discussion of the dynamic properties of the shear thickening fluid response can be found in work done by Lee and Wagner (Lee, Y. S., Wagner, N. J., "Dynamic properties of shear thickening colloidal suspensions," Rheol Acta 42, 199-208 (2003)).

[0077] For emulsions with a low volume fraction of shear thickening fluid, Φ_{STF}=10, the silicone is the continuous phase and the shear thickening fluid is dispersed in discrete droplets. An important concept for understanding the flow field would be a characterization of the droplet break up and coalescence, FIG. 6.

[0078] It is hypothesized that the emulsion droplets follow typical behavior under the applied shear stresses such that a dynamic equilibrium will be reached for a given steady flow between droplet breakup and coalescence. That leads to a droplet size distribution proportional to the power input, or applied stress, on the fluid. The higher the stress, the smaller the average droplet becomes, whereas when the applied stress is decreased the droplets coalesce under flow and the average size increases (Wagner et al. Doi-Ohta model for blends AICHE J. 45 (1999)). This becomes complicated by the presence of a shear thickening fluid in the droplet phase, as beyond a certain critical droplet stress the behavior of the STF will transfer from a liquid to solid-like phase. At this critical droplet stress the stress of the bulk phase is hypothesized to be the measured critical stress shown in Table 3.

[0079] At first consideration it is expected that the critical droplet stress required to initiate the shear thickening response is equivalent for emulsions of various volume fractions of shear thickening fluid. This would be expected as the shear thickening response is stress controlled. For emulsions with Φ_{STF} of around 65% and higher the critical stress value are equivalent to that of pure component shear thickening fluid. This supports the observation that the shear thickening fluid is the continuous phase at high concentrations of STF. It is not known, however, if silicone is also co-continuous at any of the volume fractions. It is remarkable that emulsions with lower STF loadings still show a clear signature of shear thickening. At the lowest loadings, the STF phase cannot be co-continuous and yet, a clear transition is evident even if it does not lead to the discontinuous behavior observed for the higher STF loadings. It is very significant that shear thickening is induced in the droplets, as this has never been previously reported.

[0080] Evidence for the possibility of microstructure formation within the emulsion under shear flow at high stress levels, such as a phase inversion from discrete to continuous, is found in Table 4. The viscosity for a constant stress value changes drastically with increasing composition. In the region of lower volume fraction the viscosity-concentration relationship is relatively independent of stress. In the region of high shear thickening fluid volume the relationship is more dependent on the stress. This is due to the shear thinning behavior of these samples. The flip from a simple relationship to a highly stress dependent one occurs when the volume fraction of shear thickening fluid is approximately one half. This suggests a phase inversion point occurring in this regime, presumably shifting from a continuous phase of silicone to one of shear thickening fluid.

[0081] The dynamic frequency sweeps for each material can be used to further support our observations about phase inversion. The crossover frequency, G'=G" (G'_c), for each sample was determined by finding the intersection of the two curves. For samples not showing crossover within the range of the testing limits the crossover frequency was determined by extrapolating the moduli curves to an approximate intersection. Where there is a continuous phase of silicone oil the dominant relaxation time of the system is close to the value of that of the pure component. Conversely, the relaxation time of the system is close to the value of pure shear thickening fluid when the volume fraction is higher than 50%, which supports phase inversion.

Example 2

Colloidal Shear Thickening Fluid in Foams and Cured Rubbers Composites

[0082] Sample Preparation: The shear thickening fluid (STF) was prepared using amorphous silica powder (Nippon Shokubai KE-P50) dispersed in 200 MW Polyethylene Glycol (Clariant PEG-200). The average diameter of the silica particle was 450 nm and the density was determined to be 2.055 g/cm^3 at 25° C. using a density meter (Anton-Paar DMA 48). The silica particles were first added to PEG at a weight fraction of 30% with the diluteness of the system aiding in particle dispersion. This mixture was then centrifuged for 2 hours and the supernatant removed, leaving a cake of close packed silica particles (Φ_{STF}~64%). Very small amounts of PEG were added to the silica particles until the mixture reached the desired flow properties, higher additions of PEG at this stage would decrease the viscosity of the solution. Thermogravimetric analysis was conducted on the sample to determine the weight fraction of particles in this final solution, 59.52%, which was then used to determine the volume fraction of silica in PEG, 49 vol %.

[0083] Four sizes of polyurethane open cell foam were used, with an average pore size of 60, 70, 80, and 90 pores per inch (ppi). They were each received from Foamex International and have a density of ~0.1 gm/cm^3.

[0084] A negative poisson ratio Teflon foam was acquired from W. L. Gore for testing purposes. The material construction does not allow the shear thickening fluid to wet the foam due to the surface tension. We anticipate improved performance using a STF that wets the foam.

[0085] Neat samples of various silicones were cured as were samples with encapsulated regions of shear thickening fluid. To encapsulate the shear thickening fluid the components were massed and mixed together by hand until an emulsion of the silicone and shear thickening fluid was generated. This emulsion was set into a mold and put in the oven at seventy degrees Celsius until cured. The oven was used to speed the kinetics of the polymerization.

[0086] A two-part polymerizable silicone oil, acquired from GE Silicones (SLE5700-D1), has been rheologically characterized in Part I of this paper. The silicone can be polymerized with the addition of the catalyzing agent, Part B, in a 50/50 weight ratio with Part A.

[0087] Two elastic silicones were tested, Silastic T2 and Silastic S with green curing agent (Dow Corning). Silastic T2 is a translucent high strength mold making silicone and is created using a 10:1 ratio. Silastic S is also a high strength silicone with the same mixing ratio. Both cure at room temperature and are immiscible with shear thickening fluid.

should also be noted that the shear thickening fluid was observed to thicken visually at these high stress levels.

[0099] Both neat silicone and STF-Silicone composites were tested at various levels of initial force load. The same problems were encountered for the silicone as in the open cell foams. There was a tremendous amount of slip present suggesting another testing method may be more appropriate.

[0100] Compression Testing: The force required to compress open cell foams impregnated with shear thickening fluid is compared to the compression of the same neat open cell foam. The results for the neat foam and STF-Foam are shown for the different velocities in FIG. **8**.

[0101] Interestingly the STF modifies the foam response in a somewhat unexpected manner, allowing the foam to be more "flexible" at low rates while resisting deformation at higher rates. These results suggested interesting application and as a consequence, drop impact testing was performed.

[0102] Impact Testing: The response of both neat and impregnated open cell foams was tested against the impact of a stainless steel ball bearing. The impact of the bearing on the two different STF-Foam composites was recorded by digital camera as shown in U.S. application Ser. No. 11/260,742 filed Oct. 27, 2005, which again is incorporated by reference in its entirety including all the figures. The rebound height of the bearing is noticeably subdued for the STF foam and almost all of the impact energy is absorbed, a response expected from an inelastic solid.

[0103] Discussion of Results—The mixing and curing of these rubbers (GE Silicone, Silastic T2, Silastic S) worked well. When mixed with the shear thickening fluid discrete inclusions of STF could be formed. This work has shown that containment of shear thickening fluid within a polymer composite is possible and that the STF remains active.

[0104] Compression measurements and drop testing is conclusive that there is an exploitable response of the STF-Foam system. There is an obvious visual difference in the impact of an open cell foam impregnated with shear thickening fluid. This energy absorption is noticeable and possibly exploitable for practical application. There is an apparent "hardening" of the foam during the impact as the shear thickening fluid transitions from its fluid to solid-like state.

[0105] The results of the dynamic rheological tests showed a shear thickening of the viscous modulus in the open cell foam-STF composite but no clear result of the STF rubber composites. It is not clear what the actual strain on the sample was because of the large amount of slip present between the parallel plates and the sample. Further study would include the use of disposable plates so that the sample could be attached, removing any possibility of slip.

Example 3

Shear Thickening

Polymer Blends

[0106] Blend Preparation: Suspoemulsions of STFs in polymer melts also show useful and novel properties. The same PEG-based STF was prepared as stated in the previous two examples and blended with an ethylene-octene copolymer (Engage® 8200, DuPont-Dow Elastomers). Blending was performed at 80° C. using a Haake Rheocord with a small counterrotating mixing chamber at 200 rpm for 2 minutes. The resultant STF-polyolefin was cooled and observed to be an elastic solid. Samples for tear testing and SEM characterization were prepared using a Carver press with a custom made die. The compression molding was performed at 80° C. for 15 minutes melt time and 15000 lbs. compression with 10 minutes annealing.

[0107] The blends were characterized by pressing bars of 45×12×3 mm of solid material for torsional rheological testing and films of 2 mm thickness for Trouser Tear Method for Tear-Propagation Resistance of Plastic Film according to ASTM D 1938. A minilnstron was employed at a separation rate of 250 mm/min. Scanning Electron Microscopy (SEM) was performed to characterize the blend morphology by cutting the bars with a razor blade to expose surface.

[0108] FIG. **10** shows micrographs of the phase morphology obtained by scanning electron microscopy. Clearly the blend morphology has the STF phase dispersed in the matrix polymer, showing that the blending procedure is successful in producing morphology with micron-sized features. The STF inclusions are polydisperse with a size that increases with STF loading. As the STF loading reaches 30% by volume, significant coalesoence of the STF inclusions is observed.

[0109] Mechanical Testing: Torsional rheological testing performed at room temperature using an ARES rheometer equipped with the torsional testing tooling. All samples showed a higher elastic modulus than shear modulus, and the modulus is observed to increase with loading of the STF, with a maximum at 1 vol % of the STF phase. Table 7 shows the elastic modulus at 0.5% strain amplitude and 1 hz oscillation frequency, showing that the modulus increases with the addition of STF and then, decreases.

TABLE 7

Elastic Modulus of Polyolefin STF blends at room temperature measured in torsional testing at 0.5% strain amplitude as a function of STF phase volume in the blend.

ϕ	G' at 1 rad/s
0	3.994E6
0.010	4.094E6
0.025	3.473E6
0.050	3.502E6
0.100	3.147E6
0.300	2.964E6

[0110] Tear Testing: Representative tear test (ASTM D 1938 standard) results are shown in FIG. **10**, where it is seen that neat polyolefin and 1 vol % STF blends tear through, whereas 2.5, 5, 10 and 20 vol % do not fail during the course of the experiment.

[0111] Higher STF loadings lead to failure. Clearly, the presence of STF inclusions in the PO leads to substantial enhancement in tear resistance.

[0112] Table 8 shows the energy dissipated during the tear testing, which is defined as the area under the force versus displacement curves shown in FIG. **12**.

TABLE 8

Energy dissipation during Tear Tests.

Volume Fraction of STF Phase	Energy Dissipated During Tear Test (J)
0.01	0.64
0.025	0.83
0.05	0.97
0.1	0.89
0.2	0.67

21. (canceled)

22. (canceled)

23. (canceled)

24. A composite which comprises a shear thickening fluid (STF) combined with a scaffold material wherein the STF comprises a suspending fluid and particles suspended in said suspending fluid and the particles are colloidal particles having a particle size less than about 10 microns.

25. The composite as claimed in claim 24, wherein the scaffold material is an open cell or closed cell foam.

26. The composite as claimed in claim 24, wherein the scaffold material is a porous scaffold material.

27. The composite as claimed in claim 24, wherein the scaffold material is expanded polytetrafluoroethylene (ePTFE), or microporous or expanded polyethylene, an engineered porous plastic or rubber, where inclusions are available to be filled partly or completely with STF.

28. The composite as claimed in claim 24, wherein the scaffold material is an expanded porous natural material.

29. The composite as claimed in claim 28, wherein the scaffold material is wood, porous stone or skeletons of marine organisms.

30. The composite as claimed in claim 1, where the immiscible matrix material is a crosslinkable resin that forms a solid upon crosslinking.

31. The composite as claimed in claim 1, where the immiscible matrix is a resin and foaming agent such that it can be cured to form a foam.

32. The composite as claimed in claim 1, wherein the immiscible or partially miscible matrix material is a molten polymer, or resin that can be foamed or crosslinked.

33. The composite as claimed in claim 1, wherein the immiscible or partially miscible matrix material is a polyurethane, an epoxy or UV curable resin.

34. The composite as claimed in claim 1, wherein the immiscible or partially miscible matrix material is an elastomeric or elastomeric gel material or silicone gel.

35. The composite as claimed in claim 1, wherein the immiscible or partially miscible matrix material is a polyolefin.

36. The composite as claimed in claim 1, wherein the immiscible or partially miscible matrix material is a polyethylene, polypropylene, nylon, polymethylmethacrylate, polyvinylchloride, polyethylene terephthalate (PET) or polycarbonate.

37. A conformable padding which comprises the composite as claimed in claim 1.

38. A cast material which comprises the composite as claimed in claim 1.

39. A seat cushioning or neck support which comprises the composite as claimed in claim 1.

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