Effect of carbon nanotubes on the tensile strength of aluminum in the automobile industry

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Abstract

The Fatality Analysis Reporting System (FARS) has reported that a third of fatalities are due to rollovers in car accidents. Interest in carbon nanotubes (CNTs) reinforcing aluminum has gained attention over the years. Previous research has concluded that the tensile strength of metals gradually increase with the increase of CNT concentration. By implementing CNT-reinforced aluminum in automobiles, there can be a decrease in rollover fatalities as the tensile strength increases. Data was collected from other articles to test the effect of CNTs on the tensile strength of aluminum. Different CNT concentrations were tested: 0.5, 1, 2, and 5. High energy ball milling was used to disperse the CNTs throughout the aluminum. It was concluded that the tensile strength increased with the addition of CNTs. The 2 wt.% CNT produced the highest tensile strength value to its higher dispersion value, increasing by ~50%. Further work is still required to fully disperse CNTs to reach the peak performance of CNT-reinforced aluminum.

Introduction

Rollovers

About 3% of car accidents involve a rollover in which a car flips over on its side or roof. Rollover crashes account for approximately 30% of car fatalities due to their violent nature (Deutermann, 2004). From 1991 to 2004, the United States registered a total of ~250,000 rollovers (Strashny, 2007). Rollovers occur due to the loss of control of the vehicle or impact against external objects. Most rollovers are single-car crashes where vehicles usually strike against a curb or ditch. This means that rollovers typically occur without the fault being on the driver however, the majority of rollover fatalities during 2010 (69%) were due to the lack of seatbelt protection (NHTSA, 2013). Rollovers have maintained a constant rate, continuing to account for a third of car fatalities over the past decades (Strashny, 2007). Over several decades, truck and van rollover fatalities seem to have kept a constant rate but SUV rollover fatalities have been steadily increasing (Figure 1). Data table is limited to passenger vehicles which are split into three categories: vans, pickup trucks, and SUVs. SUVs carry more passengers than pickup trucks explaining the higher amount of deaths. In 2004, there were approximately 32,000 vehicle occupants who were fatally injured in all types of car accidents, and roughly 10,500 were included in a rollover (Strashny, 2007). It was seen that rollovers contributed to a third of total deaths caused through car accidents. In 2010, it was estimated that about 191,000 passengers were involved in a car rollover, causing more than 7,600 people to die (NHTSA, 2013). The year of 2010 is the earliest year of which data is available and by examining the trends over the past two decades, it is predicted that they have kept steady rates up to date.

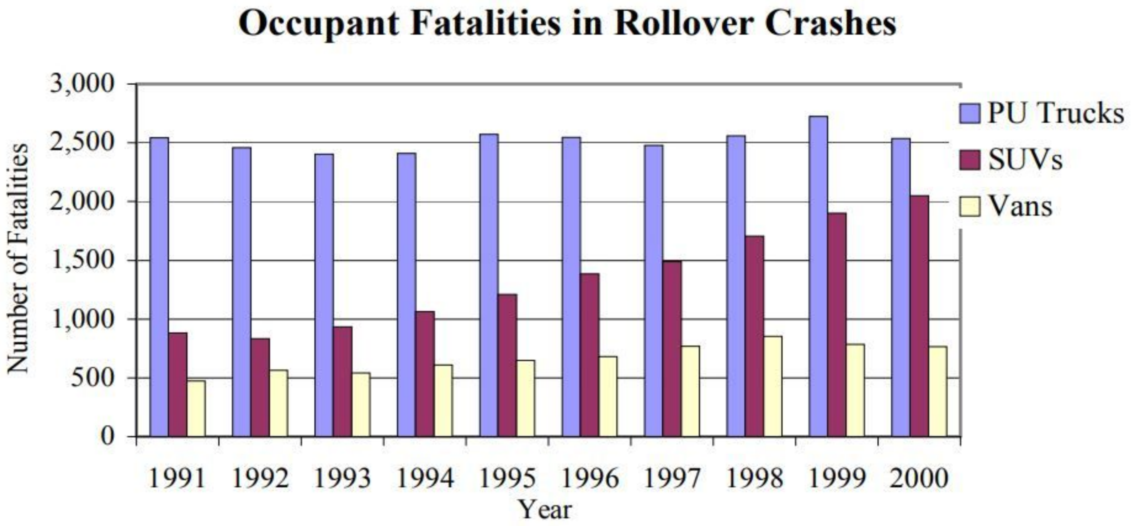

Fig. 1- Shows the trend of fatalities in rollovers of pickup trucks, SUVs, and vans. between the years 1991-200. Statistics received from the National Center for Statistics and Analysis, NHTSA, and FARS. (Deutermann, 2002).

Rollovers are one of the main contributors of fatalities in car crashes and remain relevant in the automobile industry in concern of automobile safety. Although the amount of rollover fatalities have decreased from 2004 to 2010, there were still less fatalities during the late 1990's which is absurd as technology has enhanced over the decades (Deutermann, 2004). There have been several actions which attempted to decrease the amount of car fatalities from rollovers such as the implementation of technology. Plenty of factors contribute to fatalities including the speed of the car, under-influenced drivers, highways, multi-car crash, etc. Technology can't account for all factors as it is incapable of adapting in every given environment. As one cannot control the actions of a driver or technology, the framework of an automobile can be altered to reduce fatalities. Rollovers have kept a steady rate until recently which is why the recognition of this issue is not immense, seeming irrelevant. Implementing CNTs into the composition of aluminum is one way to prevent a car's roof-work from collapsing upon itself. Nanotechnology could be introduced to the automobile industry to manipulate with the car's atoms and molecules to improve their strength.

Introduction to Carbon Nanotubes

In the June of 1991, Sumio Iijima discovered the carbon nanotube when examining carbon materials under an electron microscope (Yu et al, 2007). Carbon nanotubes (CNTs) are tube-shaped materials made up of carbon atoms with beneficial mechanical properties due to their complex, cage-like structure as shown in Figure 2 (Costanzo Research Group, 2014). Despite their size varying from 0.7-2 nanometers, CNTs are known for their unique mechanical properties: immense strength, lightweight, cheap, and electric and thermal conductivity (Zou & Li, 2016). The tensile strength of CNTs exceeds that of high strength steels by hundreds of percent (Ritter et al, 2010). Tensile strength is a material's resistance before it breaks under tension. CNTs can be classified into two families: single-wall nanotubes (SWNT) and multi-wall nanotubes (MWNT). Both families have similar properties and high tensile strength as SWNTs are composed of rectilinear tubular unity, and MWNTs are simply series of SWNTs inside of each other (Bellucci et al, 2007). Both families have similar mechanical properties, but MWNTs have been reported to have less superior properties in comparison of SWNTs, which is why SWNTs are studied in this paper (Yu et al, 2007). Over the past decade, interest in carbon nanotube composites have grown exponentially with potential applications varying from aerospace to sports industries. In aerospace engineering, CNTs are being used to cover electric circuits from electromagnetic interference (Bellucci et al, 2007). CNT- reinforced plastics have also made their way into protective gear used in sports (Attanasio et al, 2017). Previous research has shown how the implementation of CNTs can strengthen the polymers in polypropylene materials (Ritter et al, 2010). Ritter and his team further described why polypropylene strength properties were increasing, further explaining how the microstructure of the nanocomposites changed with the addition of carbon nanotubes, therefore increasing its strength. The carbon atoms in CNTs are strongly bonded by Van der Waals forces which require stronger forces to break (Ritter et al, 2010). It is similar to how a diamond is built; the carbon-carbon bonds require high amounts of energy to be broken (Fei et al, 2018). As CNTs alone have distinctive properties, CNTs and many (poly) materials or metals have been melted together to create a CNT-reinforced composite, improving their mechanical properties (Cui et al, 2009). CNTs have the ability to improve the electrical, thermal, and mechanical properties when combined with polypropylene substances. The crystalline morphology of polypropylene substances can be influenced by CNTs, increasing the rate of the crystallization process (Seo, Lee, & Park, 2005). This leads to the increase of thermal and electrical conductivity, and mechanical properties, which are due to the sharper crystallization, influenced by CNTs. It was also concluded in another study conducted by Kaganj et. al; the presence of CNTs in polypropylene influenced its crystalline structure, affecting the mechanical

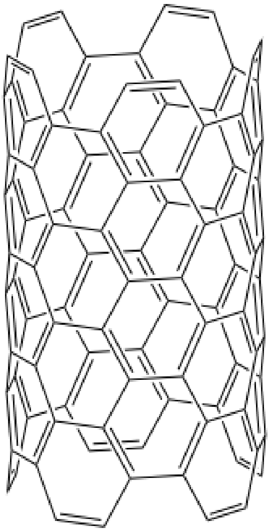

Fig. 2- Structure of a single wall CNT (Costanzo Research Group, 2014)

properties of the overall product (2008). Most papers examined the nanocomposites' mechanical properties, microstructure, strength, and distribution by using Scanning Transmission Microscopes and Electron Transmission Microscopes (Khandoker et al, 2011). The polypropylene materials reached their peak performance allowing the revamped material to be widely used in packaging materials. However, CNTs have not been implemented into everyday objects despite the advantages they possess due to some inconsistency.

Dispersion Methods

A major key in effectively creating a nanocomposite depends on the dispersion of the nanotubes, to control the bonding between the nanotubes and the matrix, the material where the bonding develops (Bellucci et al, 2007). This highlights the significance of examining former research papers to provide their established dispersion method and CNT concentration. The main source of error in most of the articles was the equal dispersion of CNTs. CNT dispersion methods were found to damage CNT properties, therefore an effective method was needed (Jagannatham, Sankaran, & Haridoss, 2015). CNTs are difficult to disperse due to their small size and bonding. As CNTs are attracted through Van der Waal forces, they form clusters, making the control of their dispersibility a tedious process (Moore et al, 2003). Effective dispersion methods are necessary as clusters of CNTs reduce the strength and stiffness of aluminum as clusters don't allow CNTs to bond throughout the matrix (Esawi et al, 2010). Scientists have varied their dispersion methods as many conclude in undesired results. These methods

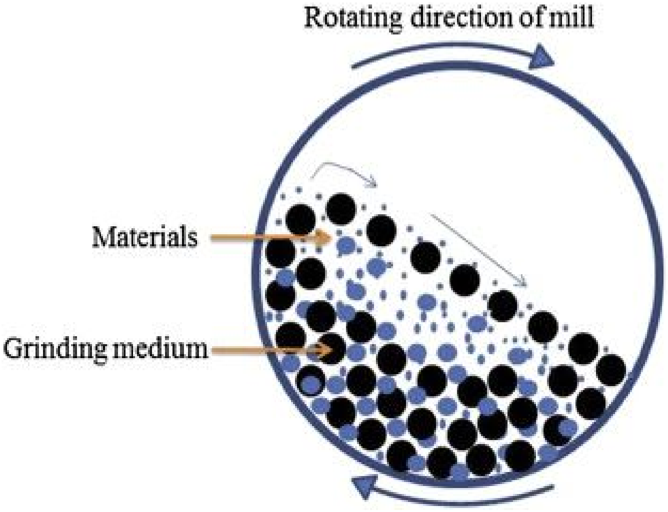

Fig. 3- Schematic diagram of ball milling technique (Khadka, 2014).

included high energy ball milling, sonication, and melt mixing. Sonication is the use of pressure waves to create the formation of bubbles that allow high intensity turbulence (Ali, Shahabuddin, & Asif, 2015). The turbulence allows the mixing between the nanotubes, thus being most effective at a longer time limit. Sonication however is efficient when using aqueous solutions. Melt mixing processes include the molding of CNTs and the matrix in a Brabender PL-19 single screw extruder (Pötschke et al, 2005). The melted nanocomposite is then cooled and molded into the preferred shape. The most commonly used dispersion method when working with metals is the ball milling technique (Figure 3). A ball mill is a device that is able to blend nanomaterials through proper orientation and energy (Suh & Bae, 2013). The high energy ball milling process was a common dispersion method in which a powder mixture is mixed in a cylinder, hit with high energy collisions from the balls (Chen et al, 2016). Aluminum powder and CNTs are put into a metal cylinder which rotates, mixing both powders. The milling speeds and times however lead to difficulties in using future metallurgy techniques to use the CNT-reinforced aluminum (Esawi et al, 2010). After ball milling, vacuum sintering and hot extrusion was utilized to finalize the CNT-reinforced aluminum. Vacuum sintering is the formation of solid mass through heat and pressure, without liquefying the product, and hot extrusion forms the shape of the solid aluminum (Nouri, 2010). Both processes affect the nanocomposites' mechanical properties as immense temperatures shorten CNTs, lessening their attraction forces and strength (Liang & Li, 2016). The best dispersion method is critical as the tensile strength values heavily depend on the dispersibility of the CNTs.

Implementing CNTs

Ever since carbon nanotubes were discovered in 1991 by Sumio Iijima, research has mainly focused on using carbon nanotubes in polymers such as plastics, or to reinforce polypropylene (PP) matrices. There has been even fewer cases testing them on metallic matrices due to the complications of complete dispersion. CNTs have proven to strengthen other metals and have proposed to be a viable alternatives since they are lightweight and cheap, compared to other metal nanocomposites. Previous scientists have proven that CNTs reinforced polypropylene materials, iron, and other metals (Zou & Li, 2016). Zou synthesized magnesium/carbon nanotube composites with a powder metallurgical method. The experiment concluded that the compounds yield strength improved with the microstructure, which gradually increased with the addition of CNTs. By researching experimental results in which CNTs were implemented into metals, the idea that nanotubes can reinforce aluminum can be brought upon. Recently, a group of scientists have blended CNTs with aluminum metal to create a revamped aluminum nanocomposite (Esawi et al, 2010). CNT-reinforced aluminum foams have already proven to be better replacements of existing foams in trains and automobiles (Aldoshan & Khanna, 2017). Aluminum is currently utilized in the automobile industry, typically used in the car’s body panels, as it is lightweight yet sturdy. Since aluminum has already been combined with CNTs, aluminum nanocomposites can be implemented into the framework of automobiles (Figure 4). The microstructure and mechanical properties of CNT-reinforced aluminum are unique and relatively cheaper compared to other metal composites (Su et al, 2014). The addition of CNT-reinforced aluminum allows automobile industries to provide additional safety at a lower cost compared to other proposed techniques such as the addition of technology, inputting monitors to assist drivers.

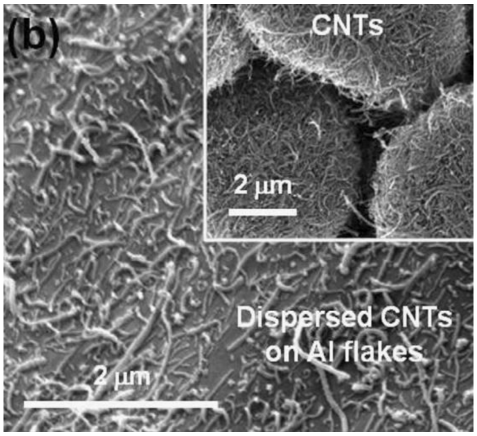

Fig. 4- CNTs dispersing throughout aluminum imaged on a transmission electron microscope. (Su, 2014)

The increase of CNT concentration should strengthen mechanical properties in aluminum as it does in other metals (Zou & Li, 2016). Computer, phones, and cars are made up of aluminum, so by strengthening the aluminum, these items will withstand additional pressure and stay intact after an accident. The main focus of the paper is strictly aluminum materials used in the automobile industry for several reasons. The car's roof will be made of aluminum nanocomposites because in rollover accidents, the roof of a car has the highest intake of damage. Carbon nanotubes have the potential of strengthening the roof due to their mechanical properties. CNTs are strictly implemented in the roof due to financial reasons. Although carbon nanotubes are relatively cheaper when compared to other nanocomposites, it would still take large amounts of CNTs to strengthen all of the car, which would cost more money than companies would be willing to pay for. By having a CNT reinforced roof, there's a possibility that the roof will withstand additional damage, refraining from enclosing towards the passengers. Given that the addition of CNTs improves mechanical properties of aluminum with the correct dispersion method, the tensile strength of aluminum nanocomposites in cars is experimented in the study. Due to previous success, the purpose of this study is to investigate whether aluminum nanocomposites are favorable alternatives in the automobile industry by testing the effects CNTs have on aluminum products. This paper is a systematic literature review where previous articles will be studied for the research's purpose. If the tensile strength of the nanocomposite roof increases significantly, then automobile safety will be one step closer to its ideal state.

Purpose

The goal of this study is to research the effect carbon nanotubes have on the tensile strength of aluminum used in the automobile industry. The design of the paper will be outlined by other scientists' research. The experiment will mainly focus on the implementation of CNTs on the roof of a car. By strengthening the roof's molecular properties, rollovers may be less dangerous towards the passengers. By having a CNT reinforced roof, the possibility of the roof withstanding more damage increases. All aluminum products can also benefit from this as durability increases. The main variable in this study is the tensile strength of the aluminum. Tensile strength is a material's resistance before it breaks under tension. Implementing CNTs into aluminum may allow cars to withstand more damage in accidents.

Research Question

Would CNT-reinforced aluminum withstand additional damage in a rollover than the typical aluminum used in the automobile industry?

Hypotheses

Alternate Hypothesis: Aluminum's tensile strength will increase as CNT concentrations increase.

Null Hypothesis: CNTs have little to no effect on the tensile strength of aluminum.

Methods

The design of the paper was conducted as a systematic literature review. The outline and data was influenced by other scientist's peer-reviewed research articles.

Data Sources

Data regarding information from previous experiments with carbon nanotubes, effects of CNTs on the tensile strength of aluminum, and dispersion methods were found in Ebscohost, CSUCI's library database, ScienceDirect, PLOS One or Google Scholar. Statistics regarding the amount of rollovers and fatalities due to rollovers came from the National Center for Statistics and Analysis (NCSA), National Highway Traffic Safety Administration (NHTSA), and Fatality Analysis Reporting System (FARS). Data retrieved regarding amount of rollovers came from government organizations that retrieved data from official reports. The most recent study was from the year of 2010 as earlier years have not been released to the public up to the date of this paper. The amount of rollovers came from larger vehicles, disregarding compact cars. Dispersion values were concluded by using high energy ball milling for varying hours. Dispersion was examined through Scanning Transmission Microscopes and Electron Transmission Microscopes to study the microstructure. Vacuum sintering and hot extrusion were followed in order to test the tensile and yield strength values. Tensile testing was done on an INSTRON 50 KN tensile testing machine. Articles had intensity ratios of D and G band were 0.86, 0.96, and 0.97 respectively, concluding that ball milling and hot extrusion caused little damage to CNT structure (Carvalho et al, 2016). D band is the bonds of disordered graphite and G band is the bonds of carbon atoms. Many articles measured intensity values to determine whether or not the tensile and yield strength values were viable. For the papers concluding in the predicted results, reflection on the dispersion method was held into consideration as many failed to equally disperse CNTs. The lack of dispersibility later played a role on the tensile and yield strength values. The formation of clusters left certain spots vulnerable, decreasing the overall strength values. On top of dispersibility, dispersion methods affected CNT properties as sintering and hot extrusion required high amounts of heat, decreasing the bonding forces. Despite setbacks in dispersibility and methods, articles concluded positive results.

Selection Criteria

1. The references' publication date vary from 2003 to modern day.
2. Articles must have included carbon nanotubes effect on electrical conductivity, thermal conductivity, equal dispersion of CNTs, or tensile strength of materials or metals.
3. All articles post 2001 concerning the amount of rollovers and fatalities were held into consideration throughout the paper. Data all came from government organizations.

4. Data represented in this paper were collected from these validated references that either conducted experiments or collected data from other peer-reviewed papers.

Results

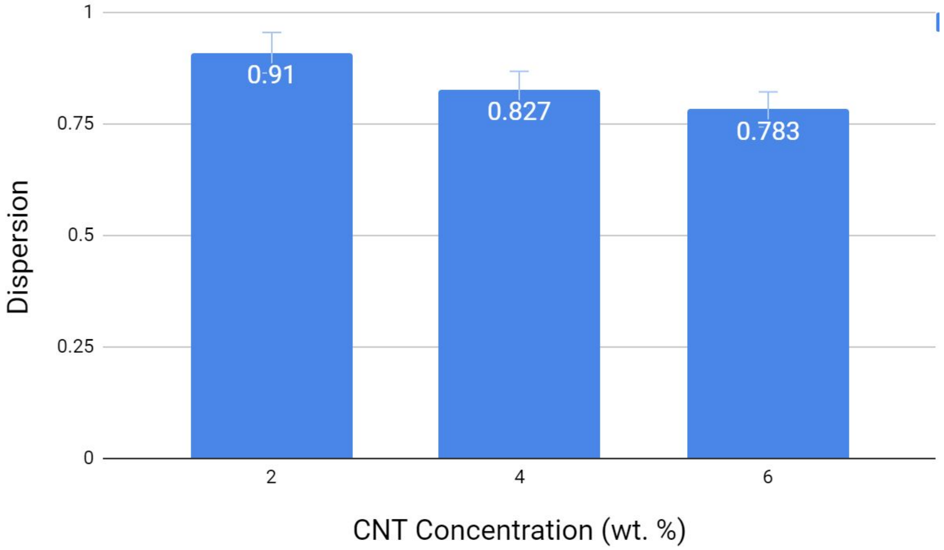

Figure 5: The Effect of CNT Concentration on the Equal Dispersion of the CNTs. The values of fully uniform and non-uniform states of dispersion are 1 and 0 respectively. Retrieved from Carvalho, O, Miranda, G et. al (2016), Yazdanbakhsh et. al (2010), Bakshi et. al (2009), and Luo and Koot (2007).

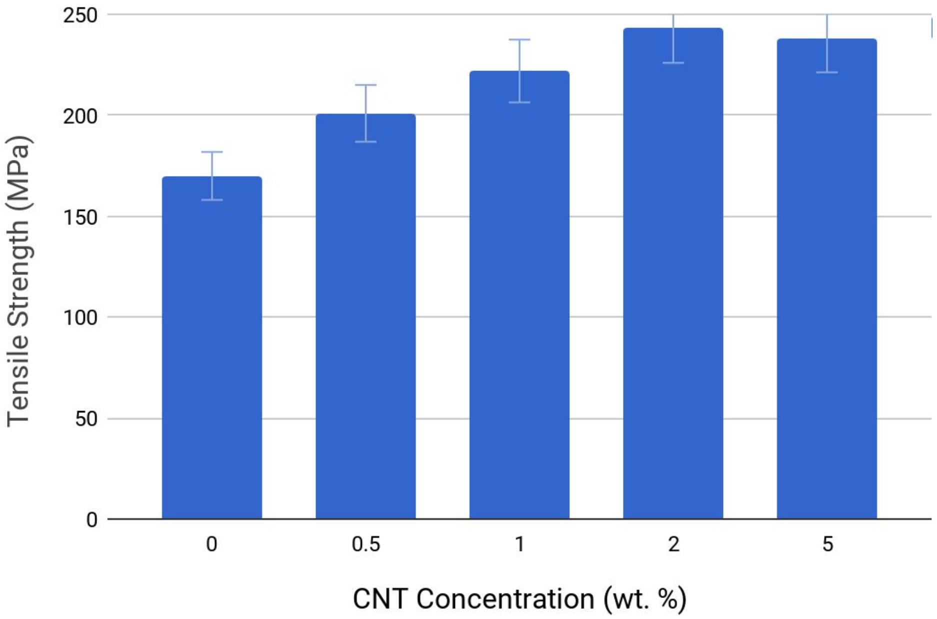

Figure 6: Effect of Carbon Nanotubes on the Tensile Strength of Aluminum. Shows the predicted tensile strength (MPa) with increasing CNT concentration. Concentration is measured in wt. % which is weight of solute per weight of solvent. Controlled has no CNT concentration. Retrieved from Esawi et al. 2010, Jagannatham et al. 2015, and Carvalho, O., Buciumeanu, M., et al. 2016.

Table 1: Shows the tensile and yield strength of CNTs in aluminum by using ball milling. Each experiment was conducted using a 2 wt. % CNT. Jagannatham et. al had the controlled variable which was a common tensile and yield strength.

wt. % CNT	Dispersion Method	Tensile Strength (MPa)	Yield Strength (MPa)	Experiment Conducted by
0	N/A Pure aluminum	162	73	Jagannatham et. al
2	High energy milled for 1h, vacuum sintered, and hot extrusion	231	203	Jagannatham et. al
2	High energy milled for 1.5h, sintered, and hot extrusion	334	276	Yang et. al
2	High energy milled for 6h, compacted and hot extrusion	348	-	Esawi et al (2009).
2	High energy milled for 5h, vacuum sintering, and hot extrusion	252	180	Perez-Bustamante et. al
2	High energy milled for .5h, compacted, and hot extrusion	254	-	Esawi et al. (2010)
2	Low energy milled for 6 days, vacuum sintered, and hot extrusion	244	-	Carvalho et. al

Values of tensile strength and yield strength were all averages of article's results in which several studies were conducted. P values for tensile strength were 0.0093 and .0097 for the yield strength.

Discussion

Dispersion of CNTs

The improvement of mechanical properties depends on the distribution of CNTs throughout its matrix. CNTs tend to form clusters when dispersed in materials. CNTs have a large surface energy and attract each other due to their Van der Waal forces, therefore creating clusters (Jarolim et al, 2016). The clusters affect the overall strength as they leave certain spots of the aluminum nanocomposite vulnerable, thus an efficient dispersion method is needed in order to perfectly execute the experiment (Li, Chen, & Ma, 2016). Figure 5 shows the decrease of dispersion as the CNT concentrations increase. High energy ball milling is the preferred dispersion method between CNTs and a metal matrix, therefore being the dispersion method in this study. The 6 wt. % CNT solution has too many CNTs for the ball milling device to disperse, which later affects it tensile strength. The presence of clusters in CNT contents larger than 1 wt. % CNT have led to the decline of strength, stiffness, and ductility of the nanocomposite (Esawi et al, 2010). It can be seen that the 2 wt.% CNT composite had a higher dispersion value than the other two solutions (Figure 5). According to Esawi et. al, the tensile and yield strength of the 2 wt.% CNT should be higher than those of 4 and 6 wt.% due to the higher dispersion value (2009).

Data collected in Table 1 used high energy ball milling which lasted from 35-50 minutes and once source used low energy ball milling which took 6 days. Table 1 shows the effect of the variation in ball milling times on tensile strength. Esawi et. al had the highest MPa value by ball milling for 6 hours, yet Perez-Bustamante et. al ball milled for 5 hours and had a MPa value of 252. Yang et. al concluded a 334 MPa by ball milling for 1.5 hours (2013). It is noted that the heat extrusion times could have played a role but many articles deem any dispersion method as inconsistent. It is why many papers did not achieve the predicted results as they could not display appropriate dispersion guidelines (Shangguan & Huang, 2017). On top of poor dispersion, CNT pull-out affects the strengthening of the nanocomposite. The pull-out force is also known as the debonding force which weakens the Van der Waal forces between the

CNTs, decreasing their mechanical properties (Jia, Chen, & Yan, 2015). To improve pullout strength, there must be an increase in the surface roughness of the matrix for the formation of chemical bonds between the matrices and carbon (Liu, Zhang, & Lua 2012). It should be noted that every dispersion method is inconsistent which is why the dispersion of CNTs is critical.

Yield Strength

Yield strength of the CNT-reinforced aluminum follows the same trend of tensile strength in which 2 wt.% CNT was concluded to be more effective. The MPa value of yield strength is less than the tensile strength value as it is the amount of stress a material can take before change in shape of a solid body without fracture (Yang et al, 2013). The addition of CNTs in mixtures above 2 wt.% CNT reduces the yield strength due to the formation of clusters once again (Jagannathan et al, 2015). Table 1 shows the values of 2 wt.% CNT yield strength after being high energy milled. Yield strength increases by approximately 300% in the three studies that included the improvement of yield strength in an aluminum nanocomposite. The increase of yield strength is significantly larger than that of the tensile strength, which is due to the change in microstructure and crystallization. Tensile strength deals with the amount of stress before a material completely breaks under pressure. Overall, the yield strength values tripled with the addition of 2 wt.% CNTs, but updated dispersion methods can still increase MPa values. With a P value of 0.0097, the change in yield strength is statistically significant.

Tensile Strength

Tensile strength increased as CNT concentration increased in aluminum (Figure 6). Data was collected from several papers to conclude the values of the tensile strength. It can be observed that the 2 wt.% CNT composition has the highest MPa value. The tensile strength increased by 50% from the original strength of the pure aluminum. In order to have achieved its peak performance, a small amount of

CNTs must have been added to improve the mechanical strength of the nanocomposite (Li, 2017). It is agreed that the 5 wt.% CNT had a smaller tensile strength as it had a lower dispersion value, creating clusters, providing no additional support as the 2 wt.% CNT had a higher MPa value (Ham, Choi, & Chung, 2005). Clusters are due to the attraction of the CNTs Van der Waal forces, which affected their overall impact on the aluminum. However, the 5 wt.% CNT has the potential of having a higher MPa value depending on the ball milling and hot extrusion times. In fact, other experiments had opposite results when testing both 2 and 5 wt.% CNTs. George et al. reported a MPa value of 138 for 2 wt.% CNT as they only ball milled for 5 minutes and a 500+ MPa value for 5% wt (2005). As previously stated, the dispersion method of the CNTs is vital in concluding higher tensile strength values. With a P value of 0.0093, the increase in tensile strength is significantly higher.

Although there is an inconsistency of tensile strengths, MPa values increased no matter the dispersion method. Table 1 concludes the positive effect on the tensile strength of aluminum by CNTs, but future work is required to conclude the additional support the CNTs provide including: the difference 50 MPa makes in a car accident, effects on an automobile's paint, effects of environment on CNTs, etc. The microstructure of the reinforced aluminum determines its wear resistance and can be improved 4 times than it's original (Bakshi et al, 2010). Although the CNTs wear properties have been tested, it cannot be assumed that they will have similar results when exposed out into the environment. It is important to test the nanocomposites resistance abilities in order to convince the public that CNT-reinforced aluminum are favorable alternatives in comparison to regular aluminum.

Conclusion

In this study, CNTs were effectively dispersed within an aluminum sample to improve the tensile strength of aluminum. Data gathered by peer reviewed papers regarding the increase of tensile strength and the dispersion of CNTs supported the hypothesis to an extent.

High energy ball milling was analyzed to determine if it was an effective dispersion method between the CNTs and aluminum. It was concluded that the 2 wt.% CNT had the best dispersion, thus having better mechanical properties than 4 and 6 wt.% CNT (Esawi et al, 2010). Vacuum sintering and hot extrusion affected CNT properties in several papers which is why some articles concluded with different results. The ball milling time can be increased to attempt to improve dispersion results but mechanical properties of a nanocomposite weaken as ball milling time increases. Many articles reported data that contradicted other papers due to the dispersion method and the controlled variables (Carvalho et al, 2016). For example, the 2 wt.% CNT had a higher tensile strength value than other CNT concentrations in certain papers, while in other articles, it had a very low tensile strength (George et al, 2005). The interest in CNT-reinforced aluminum will decrease if consumers believe they are gambling their chances of having a well supported product.

The primary focus was to strengthen the aluminum roofing of cars to prevent rollovers that may result in death. Although dispersion values were difficult to perfect, tensile and yield strengths still increased. 2 wt.% CNT was the ideal CNT to aluminum ratio as it outperformed other concentrations due to its higher dispersion value. The mechanical properties of aluminum noticeably increased as tensile strength increased by ~50% and yield strength tripled with the addition of CNTs. All aluminum products will benefit from this study as they would become more durable. More importantly, aluminum used by the automobile industry will be able to withstand additional pressure, hopefully reducing the amount of rollover fatalities each year.

Further Work

There is still more testing to be done in order to conclude whether or not CNT-reinforced aluminum is a favorable alternative in the automobile industry. Dispersion methods were noted to be very inconsistent which resulted in the inconsistency of tensile strength values. To improve the dispersion methods, the correct ball milling and hot extrusion times need to be further tested to conclude which set of times consistently yield similar results. Additional studies on the effects of vacuum sintering and hot extrusion on mechanical properties should be conducted to allow mechanical properties of CNTs to perform at their peak performance. CNT-reinforced aluminum is also to be tested in outdoor environments and how the CNT structures are going to hold. Heat affects the CNT structure, therefore the effect the sun has on the CNTs over time needs to be tested. The effect of CNT-reinforced aluminum on the paintjob of a car over long and short terms is to be tested. Consistency of dispersibility and tensile strength values should be obtained before heading into actual implementation into vehicles. The project is specific to the roof of an automobile as it is the area that mainly intakes the most damage from a rollover. From a business and financial point of view, restricting the CNT-reinforced aluminum to one specific area allows both parties to a mutual agreement as safety is being prioritized at a reasonable price. Above all, the increase of tensile strength should be tested to determine whether it’s going to play a major role in a rollover or any type of crash. In order to determine its efficiency, a CNT-reinforced car would have to go through automobile safety tests as the aluminum nanocomposites will be ideally implemented in a car’s roof.

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