The Potential and Exploration of Ethyl Cyanoacrylates as a Synthetic Plastic (C.A.S.P)

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This study investigates Ethyl Cyanoacrylate as a potential recyclable synthetic plastic by controlling polymerization through initiators and solvents. Mechanical Testing of the resulting plastic materials through tensile strength and load-bearing capacity, identifying optimized formulations for durability and reuse. These findings highlight cyanoacrylate-based plastics as a promising alternative to conventional polymers with potential environmental benefits.

I. Summary

Plastic pollution is one of the most pressing environmental challenges, threatening ecosystems, wildlife, and human health. Traditional plastics are often non-recyclable and degrade in quality after limited reuse, contributing to increasing waste accumulation. This project investigates ethyl cyanoacrylate as a potential synthetic plastic. If successful, this approach could contribute to plastic reduction by offering an alternative, recyclable synthetic material. We hypothesized that varying the concentration of initiators and solvents during polymerization would allow ECA to form durable plastic materials with tunable strength and load-bearing performance suitable for repeated use. ECA could be engineered into strong, lightweight, and renewable adaptable plastics. Compared to other plastics the property that makes it unique is its ability to form many uses, while many plastics can't return back to the same quality and could only be down cycled once or twice before no continuous use; ECA could last longer and reduce the consumption of plastic. If further optimized, these findings could lead to the development of durable, reusable plastics that mitigate environmental impacts, representing a significant step toward sustainable material science.

II. Introduction

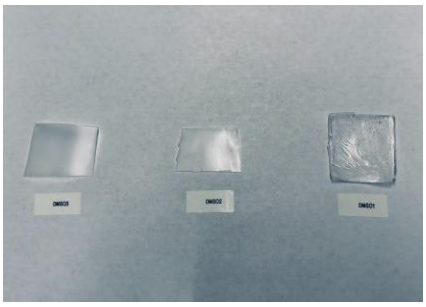

Figure 1: Ethyl cyanoacrylate plastic samples. This image shows the three different samples of ethyl cyanoacrylate plastic samples produced under controlled polymerization conditions following curing. The resulting materials formed continuous, solid sheets with visibly uniform structure, indicating successful polymerization and stabilization of the cyanoacrylate monomers. We can infer that polymerization conditions influence the physical characteristics of plastics.

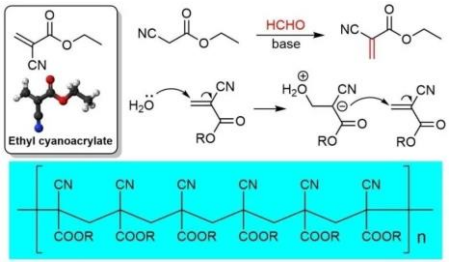

Figure 2: Depicts the polymerization mechanism of ethyl cyanoacrylate. This figure shows the hydroxyl ions initiate the reaction by attacking the electron-deficient carbon–carbon double bond. Following initiation, successive monomer units add to the growing polymer chain, forming long, linear cyanoacrylate polymers. The reaction proceeds rapidly and results in a phase transition from liquid monomers to a solid polymer network, which underlies the material's fast curing behavior and mechanical stability. This structural arrangement explains the rapid reactivity of ethyl cyanoacrylate and its tendency to undergo chain polymerization when exposed to trace amounts of moisture.

Ethyl cyanoacrylate forms strong bonds when it comes into contact with air because it contains water vapor molecules, which are polar molecules. Because ECA are polar molecules, they form extremely strong bonds with other polar materials. They fill all the micropores. Then, through polymerization, the small monomers form long chains and turn into complex polymers. From the reaction, there is a phase change that occurs from liquid to solid. When attempting to glue in flat and frictionless surfaces, it becomes extremely difficult due to low surface area and the absence of micropores. When attempting to glue in moist and rough surfaces, environments that contain high concentrations of water, the bonds become stronger and more durable. This is due to water containing OH^- ions and reacting with the electron deficient carbon in the cyanoacrylate that contain the –C≡N and –COOR group which causes a chain polymerization

reaction. Also, because hydroxyl is found in the humid air, the superglue begins to react immediately after contact.

Adhesion is the ability for any substance to hold materials together in a functional manner by surface attachment that resists separation. There are three types of adhesion: chemical, molecular, and mechanical. Chemical Adhesion is more usable for the demanding structural strength and resisting environmental conditions we require.

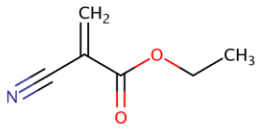

Figure 3: Ethyl cyanoacrylate ($C_6H_7NO_2$) molecule. The image highlighting the reactive vinyl group adjacent to both a nitrile (–C≡N) and an ester (–COOR) functional group. The chemical composition of ethyl cyanoacrylate is unique in the fact that there are two double bonds (C=C double bond between the CH_2 and the carbon bearing the cyano –CN and ester groups and the C=O double bond in the ester group) connected to a nitrile/cyano and to an ester group which allows it to be extremely reactive. Due to the C=C double bonds, it makes it very electron deficient and the nitrogen and oxygen form a partially negative charge, creating a dipole with the carbon becoming positively charged; the molecule becomes so reactive that anything electronegative can start the chain reaction with the nucleophiles starting the chain reaction (Figure 3). When a negative ion is introduced, the carbon double bond breaks and the nitrite and ester groups pull the loose electron towards them. This causes the C=C carbon linking the nitrile and ester groups to be negatively charged, so when a positive carbon from a different cyanoacrylate molecule comes close into contact, it initiates a chain reaction.

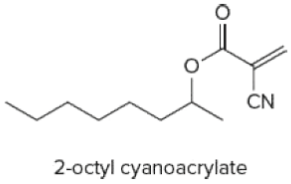

Figure 4: 2-Octyl cyanoacrylate. It is a long-chain cyanoacrylate monomer composed of a reactive vinyl group adjacent to nitrile and ester functional groups, with an eight-carbon alkyl side chain. The extended alkyl chain slows polymerization and increases flexibility in the resulting polymer, producing a material that is less brittle and more durable than short-chain cyanoacrylates.

Different types of cyanoacrylates are distinguished by the length of their alkyl group, which affects how the glue behaves: Ethyl cyanoacrylate is has an alkyl group of C_2H_5, while Octyl Cyanoacrylate has an alkyl group of C_8H_{17} (Figure 4). Short chains like methyl and ethyl

cyanoacrylate bond very quickly and strongly but tend to be brittle. Longer chains such as butyl and octyl cyanoacrylate bond more slowly but create more flexible and better durable plastics. While it may seem like a longer alkyl group is more ideal for our plastic base, when looking at a cost to production model it is ineffective at providing a cheap plastic. It is important to note that when buying in bulk in an industrial capacity, it can reduce costs. For testing, ECA is our clear option when factoring strength and cost.

Current state-of-the-art approaches to creating new plastics focus primarily on petroleum-based polymers and biodegradable plastics like PLA and PHAs. These materials are optimized for mass production and cost efficiency, but they often rely on fossil fuels and require energy-intensive processing. While biodegradable plastics aim to reduce environmental impact, many degrade only under specific industrial conditions and suffer from limited mechanical strength, heat resistance, or long-term durability. As a result, these materials frequently cannot be reused multiple times without a significant loss in performance, leading to continued plastic waste through downcycling rather than true recyclability. In contrast, ECA-based plastics offer a fundamentally different approach by leveraging rapid chemical polymerization and strong molecular bonding at ambient conditions. Existing plastics lack the ability to chemically rebond or reform into materials of similar quality once processed, whereas cyanoacrylate polymers can potentially be reactivated and restructured through controlled depolymerization and repolymerization. Additionally, many current plastics require additives to achieve strength or flexibility, which complicates recycling and introduces environmental concerns. We hypothesize that due to these limitations, current solutions remain insufficient and support the exploration of ECA as a novel, adaptable, and potentially renewable plastic alternative.

III. Results

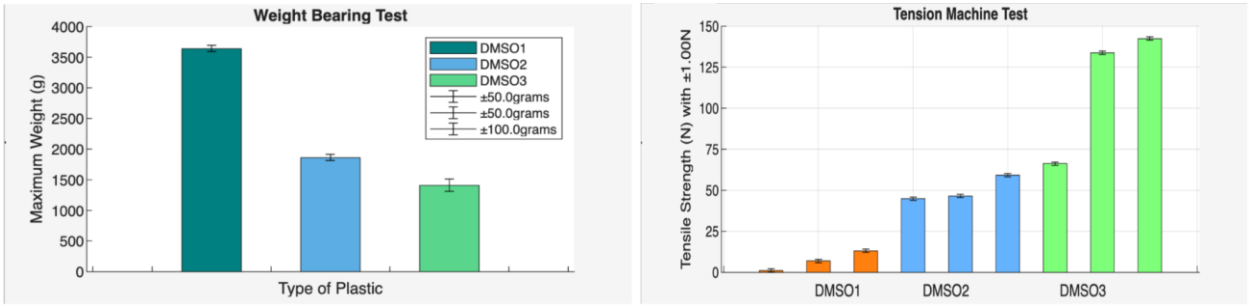

Figure 5: Weight bearing test graphed data. Results for the three synthesized plastics, showing the maximum load each material was able to support before structural failure. **Tension machine tests graphed data.** Results for the three synthesized plastics, measuring the maximum tensile force sustained before tare. Three trials were conducted for each plastic to improve measurement reliability.

We aimed to evaluate the effectiveness of plastics through different testing. To test our hypothesis, we developed and created specialized machines and coded the data to have a clear understanding of the best plastic. This experiment was conducted to determine how polymerization conditions influence the mechanical performance of ethyl cyanoacrylate when engineered into a bulk plastic material. Mechanical testing provides a direct and quantitative

method to evaluate whether controlled polymerization can produce materials suitable for structural applications. Measuring load-bearing capacity allows for an assessment of different stress modes relevant to real-world use, where plastics must resist deformation.The plotted data above from both graphs showcases three plastics. Other combinations with different amounts of solvents and initiators were used, but all varied and produced no feasible plastic to perform tests on. The data from the Weight Bearing Test graph shows that the Maximum Weight threshold is negatively correlated with the amount of DMSO added to the plastic (Figure 5). The data from the Tension Machine graph shows that tensile strength is directly correlated with an increase with DMSO (Figure 5). In terms of both experiments, we can surmise based on the evidence presented that DMSO2 is the best plastic, because it performs well in both categories.

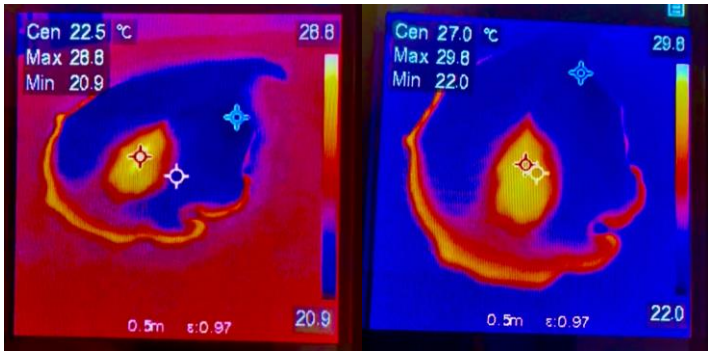

Figure 6 and 7: The infrared cameras capture the maximum and minimum temperature, reaction, and the cooling of the plastics with a degree of ± 0.5% accuracy. The curing of plastics is an exothermic reaction and releases extreme amounts of energy, but due to the fact that the heat capacity is unknown it is impossible to exactly calculate. Using other similar compounds, we can estimate with an account of all the temperatures calculated throughout the experiment and get 6.75kJ released with a heat capacity of 1.5 J/g. While it may not seem large, if used on an industrial scale the amount of energy released could be a concern.

IV. Discussion

The study investigated the behavior of cyanoacrylate plastics and the potential for use in industrial applications. The properties that set ECA apart from other plastics are rapid curing time, easy application, strong and flexible bonding, non-flammable, waterproof, sweat resistant, heat-resistant, and renewability. Mechanical testing revealed that variations in DMSO concentration produced measurable and systematic differences in both tensile strength and load-bearing capacity. While no single formulation maximized all mechanical properties simultaneously, the DMSO2 formulation exhibited the most balanced performance across both testing methods. These findings support the hypothesis that polymerization conditions can be used to tune cyanoacrylate-based plastics for specific applications, rather than optimizing a single mechanical metric.

The inverse relationship observed between tensile strength and load-bearing capacity highlights a materials tradeoff. As DMSO concentration increased, tensile strength improved, suggesting more uniform polymerization. However, these same conditions resulted in reduced load-bearing

performance, indicating increased brittleness to bending stresses. This divergence suggests that cyanoacrylate plastics optimized for tensile applications may not perform optimally under compressive loads, reinforcing the need for application-specific formulation rather than a universal plastic design.

Several experimental constraints may have influenced the observed results. Mechanical testing was conducted using custom-built instruments, while effective for comparative analysis, may not fully replicate standardized industrial testing conditions. Additionally, only three trials were conducted per formulation, limiting statistical power and increasing sensitivity to sample variability. Some polymerization conditions produced materials that were too brittle or irregular to test, which constrained the range of formulations analyzed and may bias conclusions toward mechanically stable samples. These limitations do not invalidate the trends observed but indicate that further standardized testing is necessary before extrapolating performance to industrial scales.

Thermal imaging revealed that cyanoacrylate polymerization is highly exothermic. While this energy release was manageable at laboratory scale, it raises important concerns for industrial processing. The inability to directly calculate heat capacity further limits precise thermal modeling, emphasizing the need for future studies focused on heat dissipation, controlled curing environments, and reactor-scale polymerization dynamics.

Unlike conventional petroleum-based plastics, which undergo irreversible degradation during recycling, cyanoacrylate-based plastics offer a fundamentally different materials paradigm. The potential for controlled depolymerization and repolymerization suggests a pathway toward true material reuse rather than downcycling. However, while ECA plastics demonstrate promising bonding and curing properties, their brittleness and limited flexibility currently restrict their use as standalone bulk materials. These findings suggest that cyanoacrylates may be best suited for composite systems or hybrid materials rather than direct replacement of traditional plastics.

Future studies should expand mechanical characterization to include impact resistance, fatigue behavior, and flexural strength using standardized testing protocols. Investigating alternative cyanoacrylates, such as butyl or octyl cyanoacrylate, may improve flexibility while preserving strength. Additionally, composite approaches incorporating fibers or fillers could mitigate brittleness and enhance load distribution. Together, these efforts would clarify whether cyanoacrylate plastics can transition from laboratory materials to practical, sustainable industrial solutions.

In summary, this study demonstrates that ethyl cyanoacrylate can be transformed into multifaceted plastic materials with tunable mechanical properties through controlled polymerization. These findings contribute to the broader effort to rethink plastic design beyond petroleum-based systems and support the optimization for this technology in the near future, which is a small step towards a renewable plastic.

V. Materials and Method

The High-Density Polyethylene Sheets are organized in a structure that prevents the long polymer chain of ethyl cyanoacrylate from sticking to the surface as it can't be bonded with adhesives. The compound is first heated to a temperature of 210°C to return the polymers to monomers, and high concentrations of heat are released during this exothermic reaction. To create a long polymer chain or sheet instead of single monomers, Dimethyl Sulfoxide (DMSO) initiators start the polymerization and control the rate of reaction, and the testing will involve using different concentrations. Then a solvent is used to soften cyanoacrylate and create a medium that dilutes the conditions. The compounds which will be interchangeable during the experiment are Pure Acetone, Dimethylformamide, Methylene chloride, and Propylene carbonate, and water. The name of the plastics for the experiment is related to the amount of DMSO added. For instance, DMSO2 is the original amount of DMSO 2x. Our base materials include 1.25mL of DMSO, 10mL of the interchangeable solvent, and 15mL of our ethyl cyanoacrylate. After the reaction has occurred, a long stable chain of cyanoacrylate should remain which can be used in tests to determine the most apt material used for the industrial capability required for the product.

Machine Design

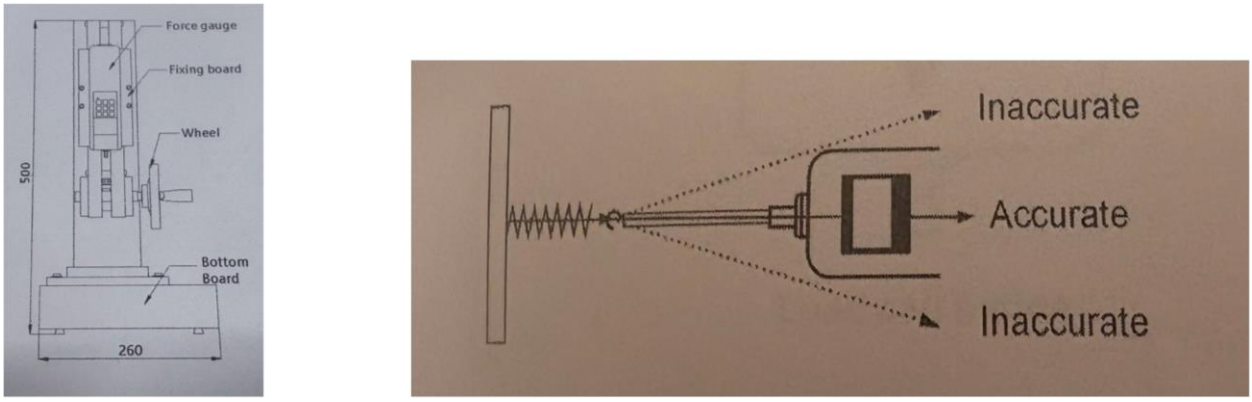

Figure 8: Tension Machine. The diagram represents the set up in order to address the maximum potential of the plastics measured in Newtons in a theoretical situation. Experimental setup used for force measurements, providing controlled stability and force readings with an accuracy of ±0.5 N.

Next for the Load Weight Testing, two glass cylinder materials were placed with a 4.00cm separation. The plastic sample was placed where the center is parallel to the ground and created a bridge-like formation. On opposite ends, a weight was placed with more weight (with ±100.0 grams) added to the center of the sample to determine the maximum potential load for the plastic.

VI. Acknowledgement

I would like to express my sincere gratitude to Jaime Cortes-Vilaplana, Rupali Dixit, and Mr. Todd Hatch for their support and guidance throughout the development of this project. Their

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VIII. Figures

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