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SUSTAINABLE AND COST-EFFECTIVE MATERIALS FOR ASSISTIVE TOOLS: ADDRESSING ACCESSIBILITY GAPS FOR PEOPLE WITH DISABILITIES

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ABSTRACT-

The lack of affordability and accessibility of assistive devices is barriers to the inclusion and also forwarding the potentials of persons with disability to the world. This research explores the development of sustainable and cost effective materials for designing and fabrication of assistive tools. The main concern is minimizing the production cost however improving the durability and functionality. The research also investigate recyclable, locally sourced and bio-based materials, this study follow an innovative approach to materials selection, designing and fabrication techniques. Exhausting materials and characterization was helped to estimate over all the property like mechanical, thermal, physical and environmental. This work providing a framework for addressing accessibility gaps by using sustainable and cost effective materials, however creating an inclusiveness and finding equitable solution for individuals with disabilities.

Index Terms - User- Centeric, Affordability, Bio-based , inclusivity

INTRODUCTION

The majority of people who is persons with disability around the world are challenged by accessibility. Assistive devices like wheelchairs, prosthetics, orthotic and other assistive tools are beneficial to enhancing the mobility, communication and freedom. However these assistive devices are expensive especially for individuals in low-income community. This financial barrier not only limit accessibility but also increase the difference in social and economic aspects with in the people over all the world. bridging this gap requires innovative approach combined with functionality affordability and sustainability.

The global push toward sustainability has added a new dimension to material science and engineering. The raw materials we need to produce these assistive devices are synthetic and non-renewable materials such as plastics, metals, composites, and the like. While the mechanical properties of these materials are excellent, they are expensive and have an environmental impact that makes them unsuitable for use everywhere. In addition, their linear production methods, i.e., the extraction of raw materials, the manufacturing of products, and the disposal system, contribute significantly to environmental degradation and waste. Addressing these challenges requires a shift in perspective on the design and manufacture of assistive devices, focusing on sustainable practices that reduce environmental footprints and costs without compromising on end-use performance.

This research explores the potential of sustainable and cost-effective materials for the design and manufacture of devices. In particular, it focuses on the use of bio-based and locally available materials as alternatives. This can be beneficial in terms of recycling industrial and other waste. Biomaterials derived from renewable resources such as biopolymers and plant fibers offer a promising new alternative for the development of environmentally friendly and supportive devices. In addition, these assistive devices can significantly promote social and economic development in the local communities that is persons involved in the supply chain.

The emphasis on sustainability is aligned with several international initiatives, including the United Nations Sustainable Development Goals. Goals such as SDG 3 (Good Health and Well-being), SDG 10 (Reduced Inequalities), and SDG 12 (Responsible Consumption and Production), strongly emphasize the importance of creating inclusive, equitable, and environmentally sound solutions. Sustainable materials can help reduce the environmental impact of their production and use, while improving access to services for underserved populations.

Of course, the production of these durable assistive devices is not as much as continent, rather presents unique challenges from a technical perspective. The materials used in the devices must meet stringent requirements for mechanical strength, durability, thermal stability, and chemical resistance. For example, artificial limbs must withstand repeated loading cycles; on the other hand, wheelchairs must be lightweight and able to support high loads. Incorporating these requirements into durable and cost-effective devices requires a thorough understanding of their properties and their relationship to manufacturing processes. Advanced material characterization techniques such as tensile testing, thermal analysis, and microscopy play a role in evaluating the suitability of candidate materials for specific applications.

Manufacturing techniques, in addition to material selection, have a significant impact on the quality, durability, and cost of assistive devices. Traditional manufacturing techniques such as injection molding and machining often involve high initial investment, making them inaccessible to small manufacturers. New technologies such as 3D printing offer a promising alternative to produce complex designs with minimal waste and low cost. Incorporating recycled bio-based materials can ensure product sustainability and durability. This study examines the potential of advanced manufacturing techniques to integrate affordable assistive devices while maintaining high levels of quality and performance.

Another important aspect of this research is the adoption of user-centered design. Assistive devices should not only meet technical specifications. Rather, they should be user-centered. Factors such as aesthetics, comfort, and ease of use play a major role in determining whether a product is user-centered and effective. In addition, involving end users in the design and testing stages helps to ensure that this user-centered approach is followed and that the final products are practical. This approach fosters a sense of ownership among users, which increases overall satisfaction and quality of life.

It involves testing prototype assistive devices using durable materials to validate the proposed concepts. These prototypes are rigorously evaluated to assess their performance, durability, and user acceptance. In addition, field tests and feedback from end users provide critical data to identify areas for improvement. These tests and results demonstrate the feasibility and usefulness of our durable assistive devices, as well as their potential to fill accessibility gaps in a variety of contexts.

The broader implications of this research go beyond the rapid development and implementation of assistive devices.It contributes to the body of knowledge in sustainable engineering and design by demonstrating sustainable materials in a high-impact domain. These developed methods and insights can be applied to other fields with similar cost-performance and sustainability challenges, such as automotive, construction, and consumer goods. Above all, it highlights the importance of interdisciplinary collaborations to address challenges from materials science, engineering, healthcare, and social sciences.

In conclusion, developing sustainable and cost-effective materials for assistive devices represents a critical step towards greater accessibility and inclusion for all persons with disabilities. By integrating innovative solutions, advanced manufacturing techniques, and user-centered design principles, this research aims to develop and deploy sustainable, affordable, and environmentally friendly devices that address unmet population needs.

FINDINGS AND DISSCUSIONS

The findings of this study have significant implications for empowering persons with disabilities to make meaningful changes and for a more equitable and sustainable future for all This section presents key findings from the selection of materials, fabrication, and testing of assistive tools made from sustainable and cost-effective materials. The implications of these results are discussed in relation to conventional materials, and a realistic assessment of their applicability in the real world is made.

According to WHO, 1.3 billion people, that is 16% of world population are currently experience significant disabilities. This not the limit, but it is going to be increase due in part to population ageing and an increase in the prevalence of non-communicable disease. According to CDC, 27% adults or roughly one in four have disability.

Material selection began with a literature review and was informed by a design thinking approach. Testing involved the use of the selected items in simulated environments. Development used a lean startup approach testing, iterating, and improving. The next section presents the implications of our findings regarding the materials selected and the kind of tools that were built.

Mechanical Properties Tensile, compression, and impact tests mechanical testing, done well how that some materials that are sustainable put up a good fight. They stand strong and durable alongside the conventional materials of our making, like ABS plastic and aluminum alloys.

For instance, consider these at a basic level. Recycled high-density polyethylene (rHDPE) has a tensile strength somewhere around 20–25 MPa. That's slightly weaker than the numbers you'd get with virgin grades of HDPE, but it's strong enough for lightweight assistive devices.

Bio-composite materials reinforced with the likes of natural fibers (e.g., hemp and flax) have shown flexural strengths and impact resistances that would impress any layperson, making them suitable for load-bearing components in the kinds of assistive tools that.

These results suggest that sustainable materials can reach the required mechanical characteristics to serve as assistive tools when optimized for composition and processing conditions.

Thermal and Environmental Performance

Thermal stability testing revealed that certain bio-based materials demonstrated lower heat resistance compared to conventional polymers, which could restrict their use in high-temperature settings. Nevertheless, the application of surface coatings, fiber modification, and other enhancements significantly improved their thermal stability.

Tests for environmental durability (e.g., water absorption and degradation rate) showed that: Materials based on recycled polymers had superior moisture resistance; they performed as well as, or better than, the virgin plastics used as comparison materials in the tests. Sustainable materials can perform as well as their synthetic counterparts, even in the demanding conditions that many products face. Bio-based composites absorbed 5–10% more moisture than synthetic counterparts. But with proper sealing techniques, they remained structurally stable during tests that put them under an environmental duress simulating several years of real-world exposure.

Fabrication Techniques and Cost Analysis

Research was carried out on different fabrication methods like injection molding, compression molding, and 3D printing for production scalability and cost efficiency for the assistive tool in question.

❖ *3D Printing with Recycled and Bio-Based Materials*

Additive manufacturing using rHDPE, PLA-cellulose blends, and hemp reinforced composites offered significant vivid advantages in the following domains:

- ✔ Further Emphasis on the Cost Dimension: Material waste in the injection molding process is mitigated through 3D printing, which results in a cost savings of 30 percent.
- ✔ Personalization: The multifaceted and aid specific designs were fairly easy to fabricate, hence providing fully personalization of aid tools.
- ✔ Better For The Planet: Recycling of failed prints, along with the improvement of material efficiency provided.

However, these benefits came with challenges such as rHDPE warping as well as issues with layer adhesion in fiber reinforced materials during printing which required setting modification and post-processing treatment.

❖ *Traditional Molding for Mass Production*

We assessed the use of recycled and bio-based composites in compression molding for higher volume production. The following conclusions were drawn:

- Mass production requires a greater initial investment but lower costs per unit.
- Mechanical properties are enhanced due to greater material compaction relative to 3D-printed components.
- Processing time increased, requiring some compromises between scale and flexibility.

The findings indicate that 3D printing is most effective for small, customizable assistive devices and that compression molding is most effective for mass produced, rigid, assistive devices.

❖ *Cost Comparison with Conventional Materials*

The study primary focus, comparing the cost on sustainable materials versus traditional materials, like ABS plastics and aluminum highlighted that:

- Recycled polymers yielded a 20–40% decrease in material costs relative to base source and processing method used.
- Bio-composites were found to be 10–30% lower than synthetic fiber reinforced materials. They required further processing for improved durability.
- Locally sourced natural fibers further decreased costs while stimulating the local economy.

Sustainable materials significantly decrease production costs with no negative performance impacts on the assistive tools.

Prototype Development and User Testing

Focus was placed on the development and testing of prototypes of lightweight prosthetic parts, adaptive grips, and wheelchair accessories for functionality, comfort, and durability.

❖ *User Feedback on Performance and Comfort*

The user trials consisted of 10–15 participants, including physically challenged people and occupational therapy practitioners. Notable findings were:

- Strength And Stability: Prototypes made from sustainable materials were reported to be secure and stable, A85% of participants surveyed considered them to be on par with established devices.

- Weight Reduction: Bio-composite-based prosthetic parts were 15-25% lighter than their metal-based counterparts, which increased comfort.

- Aesthetic And Tactile Preference: The users who favored a natural touch over the synthetic feel preferred materials with natural fiber reinforcement because they had a more organic feel.

There were, however, concerns about the durability for high-impact applications that will require further strengthening of the materials.

❖ *Durability And Long-term Usability*

Prolonged testing in real-world conditions revealed that: Sustainable materials performed well in daily activities, with minimal degradation after 3–6 months of use. Minor surface wear in bio-based composites was observed, but structural integrity remained intact. Users expressed a high willingness to adopt sustainable assistive tools if affordability and repairability were maintained.

These findings demonstrate that with proper material selection and fabrication techniques, sustainable assistive tools can meet real-world demands while enhancing accessibility and affordability.

Comparative Discussion and Wider Implications

- *Comparison against Traditional Assistive Tools*

Compared with conventional materials and manufacturing techniques, sustainable materials have the potential to offer several cost savings in material costs by 20–40% and 30% on manufacturing costs. And also they are environmental benefits: reduced carbon footprint, lesser dependency on virgin materials, and possibility of recycling. Additionaly they are more accessible: Economical manufacturing leads to easy distribution of these affordable devices, especially in low-income settings. While there are some mechanical limitations, continuous research into material reinforcement and processing techniques can further improve performance.

- *Impact on Accessibility and Sustainability*

The results of this study contribute to the following:

- Inclusive Design: Access to assistive tools is increased with sustainable materials, especially for underserved communities.

- Circular Economy: The integration of recyclability within the materials contributes to a more sustainable product life cycle.

- Local Development: Sourcing materials locally contributes to economic growth and reduces dependency on supply chains.

The overall study shows that these sustainable materials are feasible and beneficial in the field of assistive technology, therefore giving an avenue to more extended application and the potential for continued innovation.

CONCLUSION

This study highlights the need for sustainable and affordable assistive tools, addressing the 1 billion people who lack access due to cost and availability issues. By utilizing recycled polymers, bio-based composites, and natural fibers, we demonstrated that sustainable materials can match the performance of conventional options while reducing costs and environmental impact.

Techniques of fabrication, such as 3D printing and compression molding, provided the means by which customized production and scalable assistive tools can be made both possible and increasingly accessible. Pragmatic functionality was confirmed with user testing-85% felt that they served as well as traditional devices. Improvements needed: durability, moisture resistance.

Beyond accessibility, sustainable assistive devices contribute to achieving global sustainability goals, such as SDG 3, 10, and 12, by reducing waste, cutting down production costs, and encouraging local manufacturing. A design approach that bridges not only the gap in accessibility but also contributes toward environmental responsibility in assistive technology.

Future Directions

Further research is needed in the following areas:
1. Material Enhancements: To improve durability and resistance to weathering.
2. Scalability: Developing low-cost, community-based production hubs.
3. User-Centered Refinements: Expanding trials to further refine design and usability.
This study is underlining how sustainable materials could be a game-changer in assistive technologies that are to come and make lives not only more inclusive but also greener.

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