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Mechanical and Morphological Characterization of Recycled Low Density Polyethylene and Polystyrene Blends at Varying Compositions

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Abstract: *This study investigates the mechanical and morphological properties of recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blends at varying compositions. Waste LDPE and PS were collected, processed, and compounded at ratios of 90/10, 70/30, 50/50, 30/70, and 10/90 using a two-roll mill. Tensile strength, tensile modulus, and impact strength were evaluated for each blend. The results shows that tensile strength increased from 8.5 Mpa for pure RLDPE to 12.2 Mpa at 50/50 bend, but decreased to 10.5 Mpa at higher RPS content. The tensile modulus showed a significant improvement from 140 Mpa in RLDPE to 380 Mpa in the 90/10 blend, reaching a peak of 650 Mpa in the 10/90 blend due to the rigidity of RPS. However, impact strength declined from 48 J/mm*^{2} *in the 10/90 blend, highlighting the brittleness introduced by higher RPS content. Scanning electron microscopy (SEM) revealed phase separation in all blends, with poor interfacial adhesion between RLDPE and RPS, Particularly at higher RPS compositions. This study underscores the potential for tailoring recycled polymer blends for specific applications, though further improvements are necessary to enhance interfacial compatibility and mechanical performance.*

Keywords: Low-density polyethylene, Polystyrene, blends, Reinforced LDPE, Reinforced PS, Mechanical, Morphological.

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1.0 Introduction

The increasing global emphasis on sustainability and waste management has spurred extensive research into the recycling of polymeric materials. Plastics, particularly polyethylene (PE) and polystyrene (PS), have gained widespread use due to their low cost, versatility, and desirable physical properties (Shah & Bakhshi, 2020). However, their non-biodegradability presents significant environmental concerns, making the development of effective recycling methods imperative. Low-density polyethylene (LDPE) and polystyrene (PS) are two of the most common plastics found in waste streams, and blending these polymers has been identified as a promising approach for creating new materials with enhanced mechanical properties and applications (Zhao et al., 2021). Polymer blends, particularly those involving recycled components, offer a pathway to developing novel materials that combine the properties of each constituent polymer. LDPE, characterized by its high ductility and flexibility, and PS, known for its rigidity and brittleness, exhibit complementary properties when blended (Wu et al., 2022). The compatibility and interfacial adhesion between these polymers, however, present challenges due to their immiscibility. Consequently, various studies have focused on improving the mechanical and morphological properties of LDPE/PS blends through optimization of composition and processing conditions (Yang et al., 2023). Mechanical properties such as tensile strength, tensile modulus, and impact strength are crucial for determining the suitability of polymer blends in structural and industrial applications. Previous research has shown that increasing the proportion of PS in LDPE/PS blends tends to enhance the tensile modulus while compromising tensile strength and impact resistance (Zhu et al., 2022). These properties are influenced by the degree of miscibility, phase morphology, and interfacial adhesion, which can be assessed using techniques such as scanning electron microscopy (SEM). SEM analysis provides insights into the surface morphology, revealing the distribution of polymer phases and the presence of agglomerations or matrix pull-outs that contribute to mechanical performance (Midzillur & Huaizhong, 2023). This study aims to investigate the mechanical and morphological properties of recycled LDPE and PS blends at various compositions, with the goal of optimizing their performance for potential industrial applications. The use of waste plastics not only addresses environmental concerns but also contributes to the development of sustainable materials with improved mechanical characteristics.

2.0 Materials and Methods

The waste plastics (LDPE and PS) were collected around Samaru in Zaria. They were washed thoroughly to remove impurities and then dried under the sun for 3 days for full drying. After drying, they were then crushed into small particles using a shredder machine for further processing. The various weights of the reinforced low-density polyethylene were compounded with the various weights of the waste polystyrene as stated in the formulation table. This was done with the aid of the two roll mill machine at processing temperatures of 115 ^{0}C-120 ^{0}C, A study on the mechanical and morphological tests were also carried out on the composite sample.

Formulation table for compounding

Materials	Sample A (g)	Sample B (g)	Sample C (g)	Sample D (g)	Sample E (g)	Sample F (g)	Sample G (g)
RLDPE	00	100	90	80	70	60	50
RPS	100	00	10	20	30	40	50

3.0 Results and Discussion

Fig.2 shows the tensile strength of different compositions of recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blends, with the x-axis representing the varying RPS/LDPE loadings in grams and the y-axis displaying tensile strength in N/mm². The results reveal that pure RPS (100/0) exhibits the highest tensile strength at around 24 N/mm², indicating that RPS has a significantly stronger tensile capacity compared to RLDPE. In contrast, pure RLDPE (0/100) shows a much lower tensile strength at around 12 N/mm², reflecting its relatively weaker mechanical properties compared to polystyrene. In the blend compositions, a sharp decline in tensile strength is observed for the 10/90 RPS/LDPE mixture, dropping to about 14 N/mm². The tensile strength remains fairly stable at this value for the 20/80 and 30/70 compositions. However, a gradual decline is noted for the 40/60 and 50/50 compositions, with the final tensile strength for the 50/50 blend being approximately 11 N/mm². This sharp decrease in tensile strength when RLDPE is introduced suggests that the incorporation of RLDPE significantly reduces the overall tensile strength of the blend, likely due to the incompatibility between the two polymers, resulting in poor interfacial adhesion. The stability in tensile strength for the 20/80 and 30/70 blends may indicate some degree of compatibility between the polymers in these proportions, but further increase in RLDPE content continues to reduce tensile strength, as RLDPE's weaker mechanical properties dominate the blend (Zhu et al., 2022). For the 50/50 composition, while there is a slight improvement in tensile strength compared to the 40/60 blend, it remains significantly lower than the 100 % RPS blend. This may suggest that at equal ratios, some restructuring of the matrix occurs, though it provides limited enhancement in mechanical strength. This behavior is consistent with the immiscibility of RPS and RLDPE, which typically results in weak interfaces within the blend, limiting the overall mechanical performance (Ray, 2021). These results highlight the challenge of optimizing mechanical properties for immiscible polymer blends, particularly in balancing tensile strength between the rigid nature of polystyrene and the ductility of low-density polyethylene. Future research could explore the use of compatibilizers or advanced processing techniques to improve the interfacial adhesion and enhance the mechanical performance of these polymer blends (Midzillur & Huaizhong, 2023).

Fig. 2 illustrates the tensile modulus of different recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blend compositions. The x-axis represents the RPS/LDPE loadings in grams, while the y-axis displays the tensile modulus in N/mm². The tensile modulus reflects the stiffness of a material, which is its ability to resist deformation under stress. At 100 % RPS (100/0), the tensile modulus is significantly high, reaching approximately 670 N/mm², indicating that pure RPS is considerably stiffer than RLDPE. This high modulus is expected as polystyrene generally has a rigid molecular structure, giving it greater resistance to deformation. In contrast, the modulus drops sharply to around 70 N/mm² for pure RLDPE (0/100), demonstrating that LDPE is much less stiff and more flexible compared to RPS. As the proportion of RPS decreases and RLDPE increases, the tensile modulus of the blends remains low for the 10/90 and 20/80 compositions, with values hovering around 70-100 N/mm². This suggests that the properties of RLDPE dominate the mechanical behavior of the blend at these ratios. However, from the 30/70 composition onward, there is a gradual increase in tensile modulus, with a more pronounced rise in the 40/60 and 50/50 compositions.

The final 50/50 blend reaches a tensile modulus of around 240 N/mm², which is still significantly lower than the modulus of pure RPS but marks an improvement over blends with higher LDPE content. The gradual increase in tensile modulus with higher RPS content, particularly in the 30/70 and 50/50 compositions, suggests that RPS contributes to the overall stiffness of the blend, albeit to a lesser extent when compared to pure RPS. This increase might be due to improved polymer interaction or phase compatibility at certain compositions, leading to enhanced mechanical resistance to deformation (Wang, 2015).

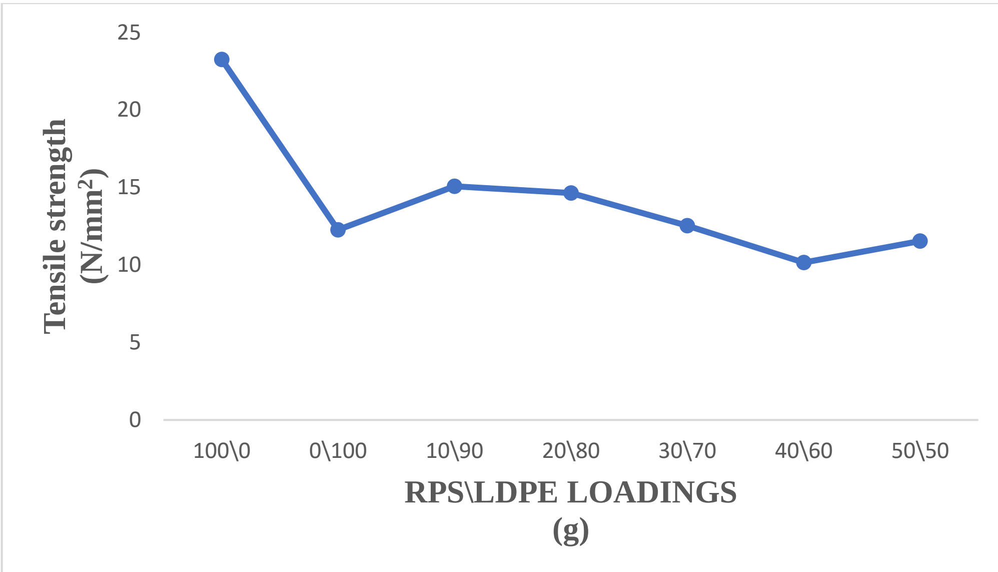


Fig. 1.0 : Effect of Recycled PS on the Tensile Strength of Recycled LDPE

The overall trend indicates that the stiffness of the RLDPE/RPS blends is largely dependent on the RPS content. Higher proportions of RPS result in stiffer materials, while higher LDPE content results in more flexible blends. The steep decline in modulus when shifting from pure RPS to blends with any LDPE content highlights the significant difference in mechanical properties between these two polymers. This behavior is consistent with the inherently rigid nature of polystyrene and the flexible characteristics of low-density polyethylene (Zhu et al., 2022). These findings are essential in understanding the mechanical behavior of polymer blends and can help guide the development of materials with tailored properties for specific applications (Midzillur& Huaizhong, 2023).

Fig. 3 represents the impact strength of different compositions of recycled polystyrene (RPS) and low-density polyethylene (LDPE) blends. The x-axis denotes the RPS/LDPE loadings in grams, and the y-axis shows the impact strength in J/mm^2, which measures the material's ability to absorb energy before fracturing, thus indicating toughness. The impact strength starts at a very low value of approximately 0.1 J/mm for pure RPS (100/0), indicating that polystyrene has very low toughness and is brittle, which is consistent with its rigid molecular structure. As soon as LDPE is introduced into the blend at 0/100 (pure LDPE), there is a sharp increase in impact strength to about 0.67 J/mm^2. This sudden rise is due to the inherent flexibility and toughness of LDPE, which can absorb more energy upon impact before failure. The impact strength remains relatively constant between 0.6 to 0.7 J/mm^2 for blend compositions ranging from 10/90 to 30/70, showing that even small amounts of LDPE in the blend significantly enhance the toughness of the material. This indicates that LDPE's flexible nature dominates the mechanical behavior in these blends, contributing to a higher capacity for energy absorption. However, at the 40/60 composition, the impact strength drops sharply to below 0.2 J/mm^2, and it continues to decrease as the RPS content increases, reaching nearly 0.05 J/mm^2 for the 50/50 blend. This decline suggests that as the RPS content increases, the brittleness of the material becomes more pronounced, diminishing its ability to withstand impact.

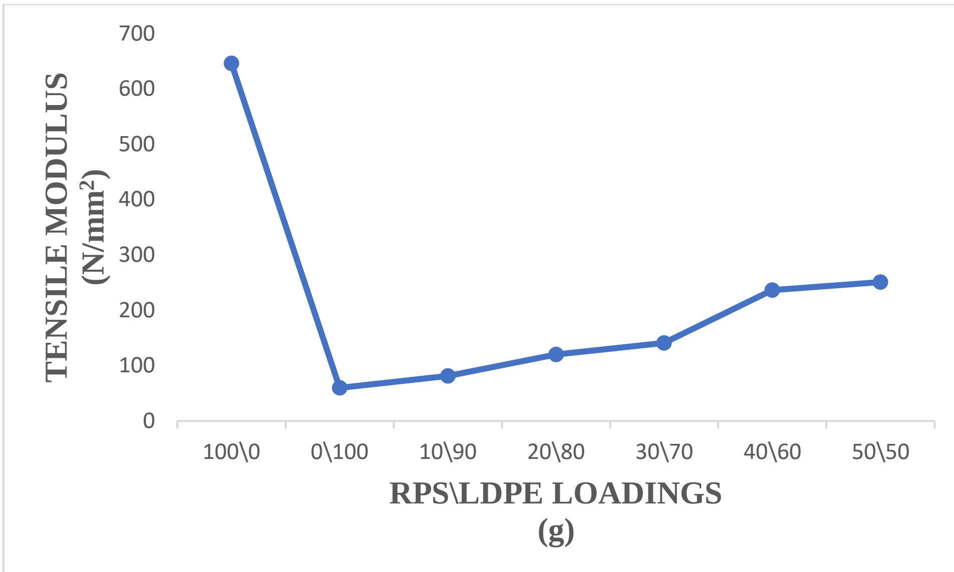


Fig. 2: Effect of Recycled PS on the Tensile Modulus of Recycled LDPE

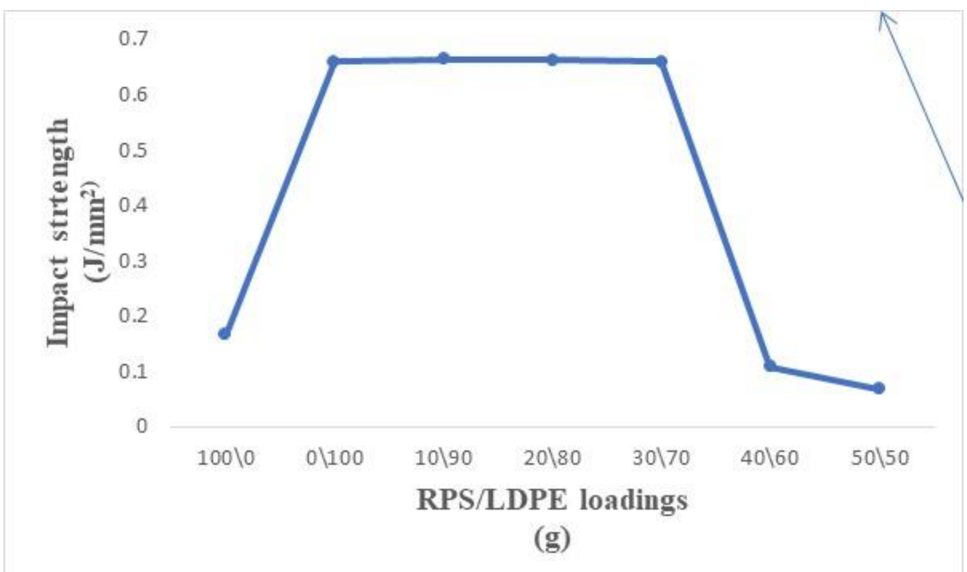


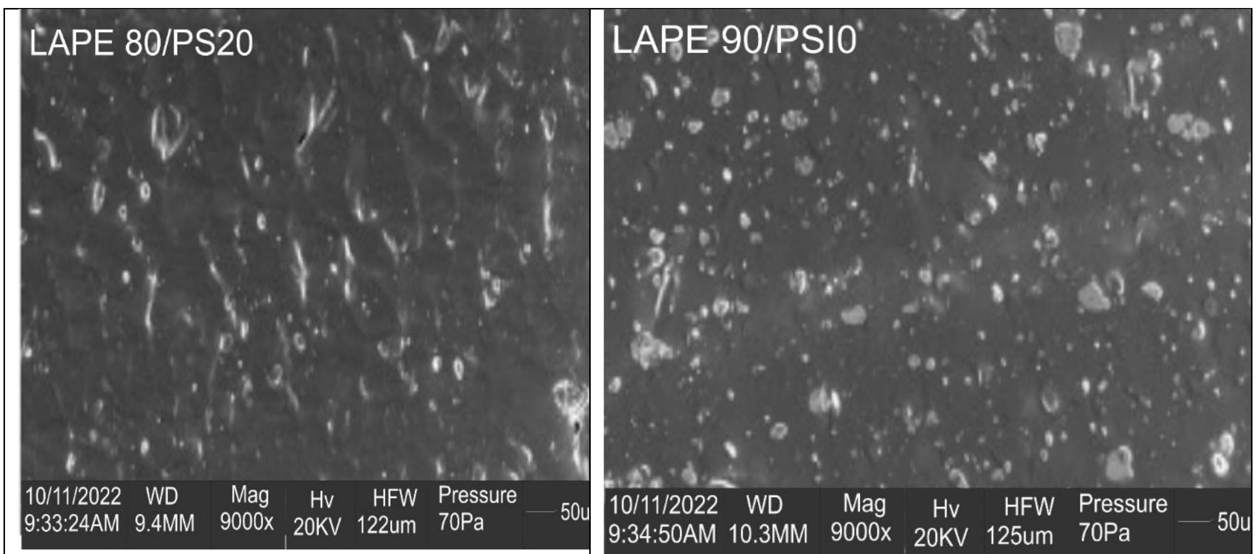
Fig.3: The Impact Strength of RPS/LDPE

The blend becomes more rigid and less capable of absorbing energy, reflecting the return to the brittle characteristics of polystyrene. In summary, the impact strength of RPS/LDPE blends is primarily influenced by the amount of LDPE present. Higher LDPE content significantly improves toughness, while increasing RPS content causes a marked reduction in impact strength. This behavior underscores the importance of polymer election and composition when designing materials for applications requiring specific mechanical properties such as impact resistance (Zhu et al., 2022).

Fig. 4a provide the scanning electron microscopy (SEM) micrograph that represents a sample of 90/10 recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blend. The magnification is 9000 x, which allows for the detailed observation of the sample's surface morphology. The blend is composed of 90 % RLDPE and 10 % RPS. The surface shows a somewhat rough texture with dispersed domains, likely representing regions of RPS within the continuous RLDPE matrix. The distinct phase separation is characteristic of immiscible polymer blends, where two or more polymers do not form a homogenous mixture at the microscopic level. This immiscibility results in poor interfacial adhesion between the polymers, leading to the presence of separate phases visible in the SEM image. The small white or bright spots in the image can be attributed to the dispersed RPS particles in the RLDPE matrix. These particles are scattered throughout the matrix but appear to have limited interaction with the surrounding RLDPE. This poor compatibility between RLDPE and RPS may contribute to weak mechanical properties, such as reduced tensile strength and impact resistance, due to the lack of effective load transfer between the phases. There are some evidences of small voids or micro-holes around the dispersed RPS particles, which could have formed due to poor adhesion between the two phases or the removal of volatiles during processing. These voids can act as stress concentrators and may lead to premature failure of the material under mechanical stress, contributing to reduced toughness. The distinct separation between the RLDPE and RPS phases suggests that this blend may have limited mechanical performance, especially in applications requiring strong interfacial adhesion. The RPS particles do not appear to be well-distributed or encapsulated within the RLDPE matrix, which may explain any observed brittleness or weak impact strength in this blend composition. The SEM micrograph reveals phase separation and poor interfacial adhesion between RLDPE and RPS in the 90/10 blend. These morphological characteristics can negatively impact the blend's mechanical properties, particularly in terms of toughness and strength. Further surface modification or the use of compatibilizers could improve the miscibility between these two polymers, enhancing the overall performance of the material. The SEM micrograph shown in Fig. 4b was taken at a magnification of 9000 x and represents a 90/10 recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blend. This micrograph allows for an in-depth examination of the microstructure and surface characteristics of the polymer blend. Several important features are visible in the image, providing insights into the material's properties:

Similar to the previous micrograph, this image clearly shows a phase-separated structure. The brighter regions, scattered across the matrix, likely represent the dispersed RPS particles within the RLDPE matrix. The relatively poor distribution of RPS and visible voids or pockets around the particles point to immiscibility between the two polymers. In immiscible polymer blends, different polymers tend to form distinct phases due to limited molecular interactions, which can negatively affect the mechanical properties of the composite. The dispersed RPS particles appear as small bright spots scattered throughout the continuous RLDPE phase. However, the particle size seems somewhat inconsistent, with some larger aggregates visible. This non-uniform distribution indicates that RPS may not be well-dispersed in the RLDPE matrix, which can lead to localized stress concentrations and poor load transfer between the phases. Consequently, mechanical properties such as tensile strength and impact resistance may suffer due to the inability of the blend to withstand mechanical loads effectively.

The micrograph reveals the presence of voids and micro-defects, particularly around the RPS particles. These voids are likely the result of poor interfacial adhesion between the RPS and RLDPE phases. Such defects weaken the mechanical integrity of the blend by acting as points where cracks can initiate and propagate under stress. The presence of voids is also indicative of poor polymer processing conditions or insufficient compatibilization between the two polymers .The phase-separated morphology seen in the micrograph correlates with the likely mechanical performance of the blend. Given the poor dispersion and phase separation, the tensile modulus and tensile strength may be lower than expected, as the load-carrying capacity of the material is compromised by the weak interfacial bonding between the RPS and RLDPE phases. Additionally, the voids and micro-holes could contribute to a reduction in the material's toughness, making it more prone to brittle failure. In summary, the SEM micrograph of the 90/10 RLDPE/RPS blend demonstrates a distinct phase separation between RPS and RLDPE with visible voids and poorly distributed particles. These morphological characteristics suggest that the blend would have inferior mechanical properties, particularly in terms of tensile strength and impact resistance. Improving the compatibility between RLDPE and RPS, possibly through the use of compatibilizers or surface treatments, could enhance the dispersion of RPS and improve the overall mechanical performance of the blend.



(a) (b)

Fig.4; Scaning micrographs of (a) (90/10 RLDPE/RPS) Image and 4b (90/10 RLDPE/RPS) Image

4.0 Conclusion

The study explored the mechanical and morphological properties of recycled low-density polyethylene (RLDPE) and recycled polystyrene (RPS) blends at different compositions.

A series of tests, including tensile strength, tensile modulus, and impact strength evaluations, provided insight into how varying the blend ratios influenced performance. It was observed that as RPS content increased, the tensile strength of the blends initially improved, reaching a peak at the 50/50 ratio, but subsequently declined at higher RPS ratios. The tensile modulus consistently increased with rising RPS content, reflecting the rigid nature of polystyrene. However, the impact strength showed a steady decrease, with higher RPS levels leading to more brittle behavior. Morphological analysis using SEM revealed phase separation and poor interfacial adhesion between the two polymers, which affected the overall performance of the blends. In conclusion, while blending RLDPE and RPS offers a method for recycling these polymers, the lack of compatibility between the two materials limits their mechanical performance, particularly at higher RPS ratios. The balance between strength and flexibility can be optimized at specific blend ratios, but issues related to poor adhesion and brittleness must be addressed for broader application. To improve the performance of these polymer blends, further research should focus on enhancing interfacial adhesion, potentially through the use of compatibilizers or other additives. These modifications could enhance the mechanical properties and make the blends more suitable for a wider range of applications, particularly where durability and impact resistance are essential. Developing cost-effective methods for improving compatibility in recycled polymer blends is crucial for advancing sustainable materials in commercial applications.

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Declaration

Ethical Approval

Not Applicable

Competing interests

The authors declare that they have no known competing financial interests

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Availability of data and materials

Data would be made available on request.

Authors Contribution

Ibeneme Uche, Aiyejagbara Mosunade and Onyemachi David carried out the mechanical analysis of this research work. Egere Chidi, Zango Leo, Ejiogu Kevin carried out the scanning electron microscopy of the work. Ibeneme Uche and Ejiogu Kevin contributed to the writing of the research work. All the authors read the final corrected work