

Studying the Properties of Polymer blends Sheets for Decorative Purposes

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Abstract:

Polymeric sheets with different mixing compositions of bakelite and polystyrene were manufactured using the hot pressing method. Microstructure examination, water absorption, impact strength, wear resistance and infrared thermography tests were performed. It was found that there was a homogenous distribution of the bakelite particles in polystyrene and a good bonding was observed between them. Water absorption test showed that the water absorption percent increases with the increase of bakelite material in the blend. Impact test results did not show significant changes.

Wear resistance test was carried out at different forces: (5, 10 and 20 N) and different velocities (150, 250 and 350 rpm). It was found that the wear increases with increasing the applied forces and velocities although, wear resistance shows an improvement with increasing of bakelite content.

In infrared thermography test was also conducted. It was found that the relative temperature change increases with the increase of bakelite content.

Wear resistance and water absorption of the manufactured sheets were compared to the same properties of commercial ceramic tiles (used for decorations) at the same testing conditions. It was found that the water absorption test results for the manufactured sheets are much better than the results of the ceramic tiles test. Moreover, wear resistance test results for the ceramic tiles were close to those of the manufactured sheets when the percent of the bakelite in the blend was 20%, but for higher percentages of bakelite, the wear resistance of the manufactured sheets was better than the tiles.

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1. Introduction

Polymer blends and composites have become a central part of polymer science and engineering because people could make composites that have properties substantially unattainable with homo-polymers. Such properties include greater toughness, higher strength, better ductility, better absorption properties, and more homogeneous microstructure. Researchers continue work in this field. For example investigators in [1,2,3] studied the mechanical properties of composite materials. They concluded that characteristics of composite materials depend mainly on their manufacturing process and the reinforcement type, percentage, size, and shape. Others [4,5,6] studied the effect of processing on certain composite properties such as stiffness and compression strength. Their studies led to formulate mathematical models to predict the mentioned properties. While Mousa and Karger-Kocsis [7] studied the behavior of styrene / Butadiene rubber organoclay nanocomposites and found that the tensile strength was improved by increasing

nanosilicate. Moreover, Robinson et al. [8] reported that the mechanical properties of polymer matrix composites reinforced with silica were superior to their unreinforced polymer matrix and their strength increased by increasing the reinforcement content. More information about the improvement of the strength of polymers and their composites can be found in the works of Jalham [9], and Sahnoune, et al. [10].

The wear and friction properties of polyamide 66/high density polyethylene blends was studied by Chen, et al. (2004). They produced Polyamide 66 (PA66)/high density polyethylene (HDPE) blends, having miscible structure by compatibilization of HDPE grafted with maleic anhydride (HDPE-g-MAH) and investigated their Mechanical and tribological properties. It was found that the polymer blends greatly improved the mechanical properties of PA66 and HDPE. Blending HDPE with PA66 significantly decreased the friction coefficient of PA66; the friction coefficients of blends with different compositions were almost the same and approximately equal to that of pure HDPE; the blends with 80 vol % PA66 exhibited the best wear resistance.

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Chen, et al. [11] continued the investigation of friction and wear mechanisms of PA66/PPS blend reinforced with carbon fiber (CF). It was found that CF reinforcement greatly increases the mechanical properties of PA66/PPS blend. The friction coefficient of the sample decreases with the increase of CF content. When CF content is lower (below 30%), the wear resistance is deteriorated by the addition of CF. However, the loading of higher than 30% CF significantly improves the tribological properties of the blend.

Jalham [12] studied The influence of process and materials variables on the surface properties of polystyrene matrix reinforced with silica sand. He concluded that the introduction of the SiO₂ hard particles significantly increases the abrasive wear resistance of polystyrene. The higher each of the process variables (load, velocity, and time), the higher the dimensionless wear rate and the less the difference between the highest and the lowest wear rate when going to a higher volume fraction content and a higher particle size. While the higher each of the material variables (reinforcement content and particle size), the less the wear rate for fixed process conditions. It was also found that abrasive wear of SiO₂ reinforced polymers occurred by three wear mechanisms: microploughing, microcutting, and microcracking

Moreover, a number of studies on polymer matrix composites subjected to sliding and abrasive wear indicate that wear resistance depends on the detailed properties of the material as well as the external wear conditions such as applied pressure and contact velocity [13,14,15]. Furthermore, fiber addition to polymers doesn't necessarily improve their wear resistance [16]. It is worth mentioning that the performance of polymer matrix composite materials is different when subjected to different modes of wear. For example, the wear behavior of polyetherimide composites in adhesive and fretting wear modes is different from their behavior in abrasive and erosive wear modes [17].

The impact strength of polymers and their composites was also studied. Wantinee, et al. [18] studied the impact resistance of selected Immiscible Polymer Blends. Immiscible polymer blends were prepared by melt extrusion using a single screw extruder in the systems PS/HDPE and PS/PP to assess the effect of composition and morphology on tensile Young's modulus and impact resistance. Results of this work showed that the PS/HDPE system has poor impact resistance although the 20% PS in PP blend possessed an impact strength that was 127% greater than the proportional value for this composition. Thermal and mechanical properties of poly (butylene/terephthalate) epoxy blends was investigated by Zhang, et al. [19]. They concluded that the presence of epoxy resin influenced the mechanical properties of the PBT/epoxy and the completely miscibility of epoxy resin was beneficial to the improvement of the impact performance of the PBT/epoxy blends. In addition, the modification of the PBT/epoxy blends were achieved at epoxy resin contents from 1 to 7%. The maximum increase of the notched Izod impact strength ($\approx 20\%$) of the PBT/epoxy blends was obtained at 1 wt % epoxy resin content.

The above mentioned studies concentrated on two fields; the first studied thermoplastic or thermoset polymer matrix only, which was reinforced with silica sand

particles of different concentrations and different particle sizes. The main performed test on them was the compressive strength test and rarely the wear properties; the second concentrated on studying the properties of the blends of two thermoplastic materials, thermoplastic and elastomeric materials and a reinforced matrix of them.

This work differs from the previous studies in using a combination of polystyrene (thermoplastic material) and Bakelite (thermoset material) of different mixing percentages. To use this product for decorative purpose water absorption, wear, impact, and infrared thermography tests will be performed.

2. Materials, Equipment and Experimental Procedure

2.1. Materials

The main materials, which were used in this investigation, are:

1. Bakelite (the trade name of thermosetting phenol-formaldehyde), which was supplied by Buehler Company.
2. General purpose polystyrene (Granular solid and colorless). This material is a thermoplastic material, which was supplied by Sabic Company
3. Commercial Ceramic Tiles, which are made primarily of clay mixed with various minerals and water. These tiles were brought from the Jordanian market.

2.2. Equipment

The main equipment used in this project are:

1. Laboratory Balance. It is of shimadzu type and used to weigh the specimens with accuracy of 0.01 mg.
2. Plasti Corder BRABENDER (Figures 1a and b). It is used to make the blend by mixing the polystyrene and bakelite materials with each other at controlled temperature and torque.
3. Hydraulic Press Machine. This machine is of carver type (CARVER, Model 389.4PR1A07) and was used to press the mixture which was prepared by the brabender mixer at controlled temperature and force in order to manufacture the polymeric sheets. Figure 2 shows the used hot press machine.
4. Water Absorption Testing Equipment (Figure 3). This machine is of GFL type and was used to conduct the water absorption test for the specimens.
5. Impact Testing Machine. This machine is of CEAST type and was used to perform the impact test for the specimens.
6. Wear Testing Machine. This machine is of METASERV type and was used to perform the wear test for the specimens.
7. Optical Microscope (MEIJI). This equipment is of (MEIJI) type and used for testing the microstructure of the specimens.

Digital Infrared Thermal Imaging Camera (Figure 4). This camera is of Chauvin Arnoux type and used for conducting the infrared thermography test for the specimens



Figure 1a. Front View of Mixing Machine

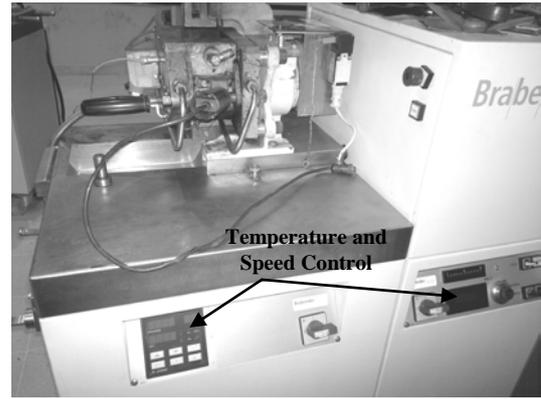


Figure 1b. Side View of Mixing Machine

Figure 1. Plasti Corder BRABENDER used for mixing Bakelite and Polystyrene



Figure 2. Hot Press Machine



Figure 3. Water absorption machine



Figure 4. Thermal Imaging Camera.

2.3 Experimental Procedure

To accomplish this study, Bakelite and polystyrene were mixed in a mixing pan with different proportions. The mixing compositions were based on weight and the proportions of mixing are shown in Table 1.

Table 1. Mixing Proportions

Bakelite (Wt %)	Polystyrene (Wt %)
0	100
10	90
20	80
30	70
40	60
50	50
60	40
70	30

The mixture was then fed into the mixer (Brabender) at a constant speed of 45 m/min to a chamber of a constant temperature (185°C) for 8 minutes. By the end of the mixing step, the mixed materials were in the form of putty-like material. The putty-like material was then put in the mold. The mold is composed of two metallic sheets with 30 × 30 cm size and hollow square sheet (Cavity) of 13 × 13 cm. Then putty-like material was placed in the cavity between these two sheets. Two polyester films were put above and below the material to prevent it from sticking to the metallic sheets.

The mold including the mixed materials was then put in the hot press machine between two preheated hot platens. The material was pressed between the hot platens to get a good and uniform compaction at conditions as shown in Table 2.

Table 2. Hot Pressing Conditions

Segment No.	Force (lb)	Dwell Time (min.)	Temperature (°C)
1	3000	2.0	185
2	15000	2.0	
3	30000	3.0	

The mold was then removed from the pressing machine and allowed to cool to room temperature. The pressed material was then removed from the mold and became a

sheet of 13 × 13 cm and 2 mm thickness. Figure 5 shows samples from the manufactured sheets.

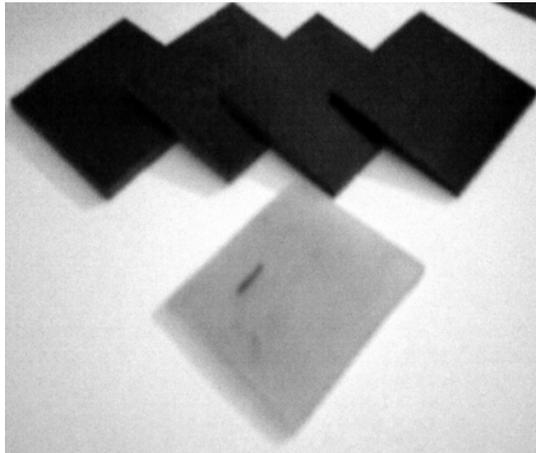


Figure 5. Samples from the Manufactured Sheets.

The sheets of the mixing proportions of (80% bakelite and 20 % polystyrene), (90% bakelite and 10 % polystyrene) and pure bakelite could not be manufactured under these available conditions of the equipment.

Then the microstructure was revealed to test the binding conditions of Bakelite and polystyrene. To accomplish this, the specimens were prepared according to the known standard procedure of grinding and polishing using ethanol as a cooling agent. Other tests were also conducted according to the ASTM standards. For example, water absorption test was accomplished according to ASTM D570 standard, Impact Strength Test according to ASTM D256 standard, Wear Resistance Test according to ASTM D3702 standard, and infrared thermography test was carried out on the manufactured sheets using digital infrared thermal imaging camera. To perform the infrared thermography test, specimens with 30 × 30 mm sheets were cut from the manufactured polystyrene of (20% bakelite and 80% polystyrene sheets), (40 % bakelite and 60% polystyrene sheets) and (60% bakelite and 40% Polystyrene sheets). Then specimens were placed onto a calibrated hot plate. The temperature of the hot plate was set to rise up to 70°C in an increment of 6 °C. The setup of the experiment for one of the ranges is shown in figure 6. While increasing the temperature of the hot plate, infrared images were continuously taken for the surface of the specimens every half second. The taken images for the tested specimens were processed using the camera processor to find the average temperature of the specimens surface versus time. Relative temperature change was expressed by Θ using the following formula:

$$\Theta = T_{avg} - T_o / T_o \dots\dots\dots (1)$$

where

T_{avg} - is the average temperature of specimen surface.

T_o -is the ambient temperature.

And finally, Θ was plotted versus the time up to the steady state

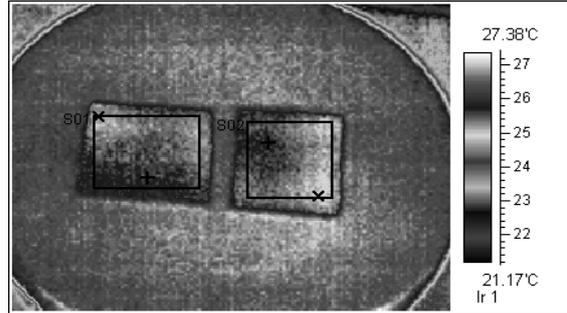


Figure 6. Thermal Image of the manufactured sheets The setup of the experiment for one of the ranges.

3. Results & Discussion

To end up with reliable results, twenty four specimens were manufactured and tested. Their testing results are discussed in the following sections.

3.1. Microstructure

The microstructure after polishing is shown in Figures 7 and 8. Figure 7 indicates that the distribution of mixed materials is homogenous and Figure 8 shows that bonding has occurred between bakelite and polystyrene. This bonding has been reflected positively on the performed tests. The mixing method showed successful results as can be concluded from the bonding.

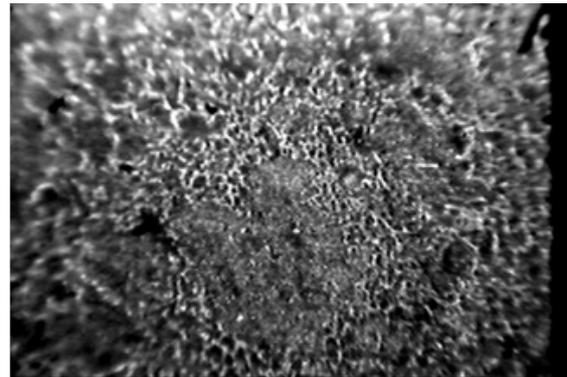


Figure 7. Homogenous Distribution of the Mixed Materials. Magnification 25x

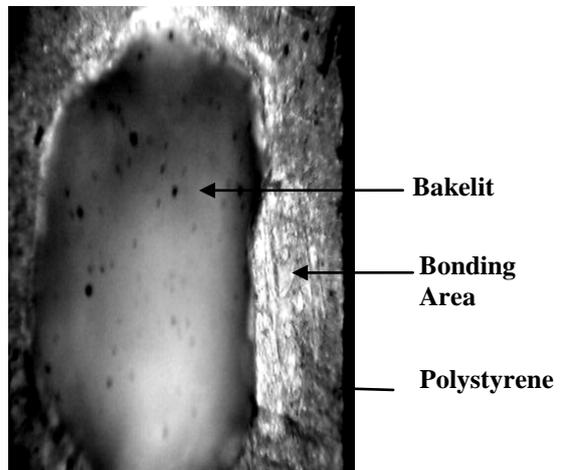


Figure 8. Bonding Between Bakelite and Polystyrene. Magnification 100x.

3.2 Water Absorption

Figure 9 shows the water absorption test results of the specimens. It is clear from this figure that the water absorption percent is increased by increasing the amount of bakelite material in the blend. On the other hand, the minimum percent of absorption was found for the pure polystyrene (0% bakelite). This behavior can be explained by the nature of the chemical structure of the two materials. The polystyrene has less tendency to absorb water than bakelite because its chemical structure contains only carbon and hydrogen, while the bakelite material contains carbon, hydrogen and oxygen.

This behavior is in agreement with Campo [20] who found that the polymers containing only hydrogen and carbon, such as polystyrene, are extremely water resistant, whereas polymeric materials that contain the oxygen group are very susceptible to water absorption.

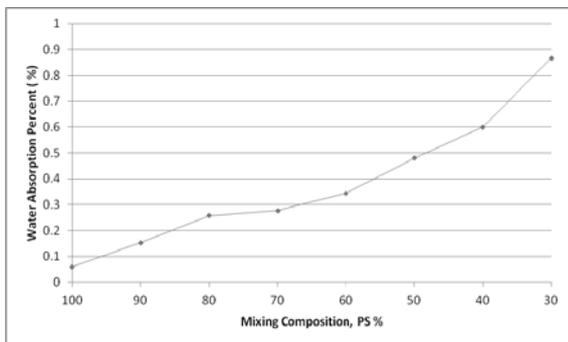


Figure 9. Water Absorption Test Results (PS indicates Polystyrene)

3.3 Impact Test Results

Referring to the impact test results, shown on Figure 10, it is clear that the variation of impact strength values of the tested sheets is about 1 J/m (between 13.5 to 14.5 J/m). This variation is very small and can be considered approximately the same for all mixing compositions. This behavior is due to the similarity in the impact strength of the mixed materials (The theoretical izod impact strength for polystyrene is 15 J/m and the izod impact strength for the bakelite is between 15 - 17 J/m). Moreover, it also indicates that a good bonding between the blended materials was achieved.

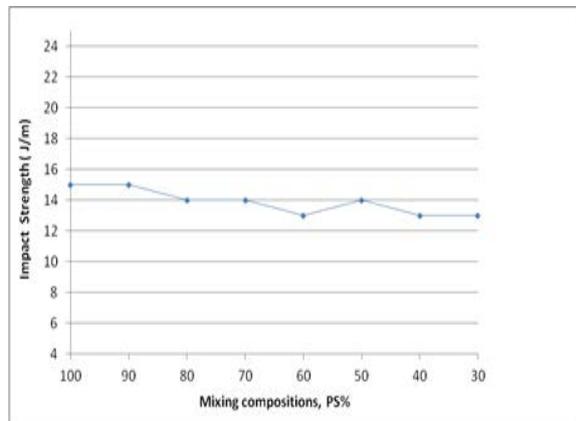


Figure 10. Impact Strength Test Results.

3.4 Wear Resistance Test

The wear resistance test for the manufactured sheets was studied based on the variation of the applied force and the variation of the velocity. The results shown on Figures 11, 12 and 13 indicate the effect of the variation of velocity and the PS % on the wear resistance of the blends for fixed loads. It is obvious from these results that the wear rate for all tested specimens increases with the increase of PS% for the fixed applied force and higher wear rates were obtained after 80% of PS. So, to get best results, the PS% should be less than 80%. Meanwhile, the effect of the velocity at a fixed PS% and Fixed load shows that the increase in velocity increases the wear rate especially when the content of PS exceeds 80% too.

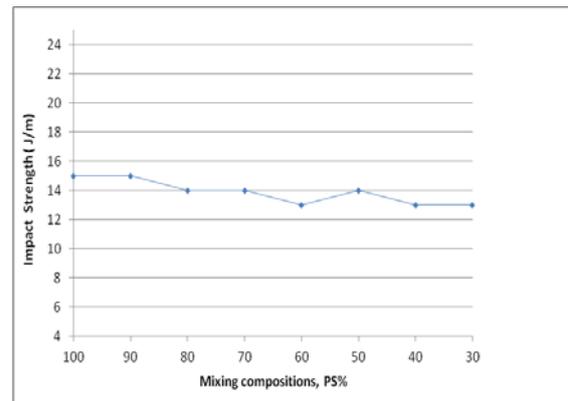


Figure 11. Wear rate at fixed 5N applied force and velocities of 150, 250 and 350 rpm.

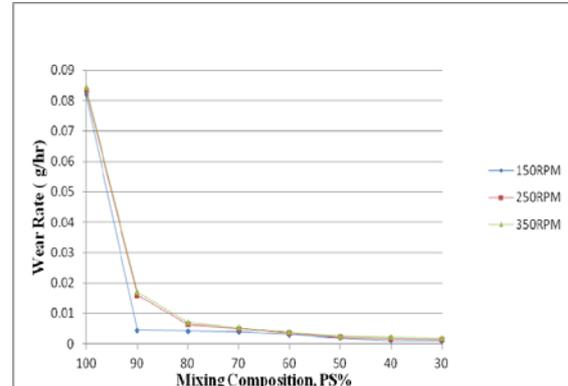


Figure 12. Wear rate at fixed 10 N applied force and velocities of 150, 250 and 350 rpm.

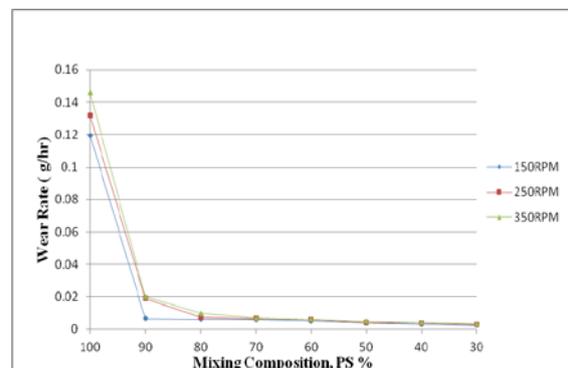


Figure 13. Wear rate at fixed 20 N applied force and velocities of 150, 250 and 350 rpm

The same trend was observed in Figures 14, 15 and 16 which indicate the effect of the load variation for the fixed velocities and different PS content. It is clear that the wear rate for all tested specimens increases with the increase of PS% for the fixed velocity and higher wear rates were obtained after 80% of PS. So, to get best were results, the PS% should be less than 80%. Meanwhile, the effect of the loads at a fixed PS% and Fixed velocity shows that the increase in load increases the wear rate especially when the content of PS exceeds 80% too.

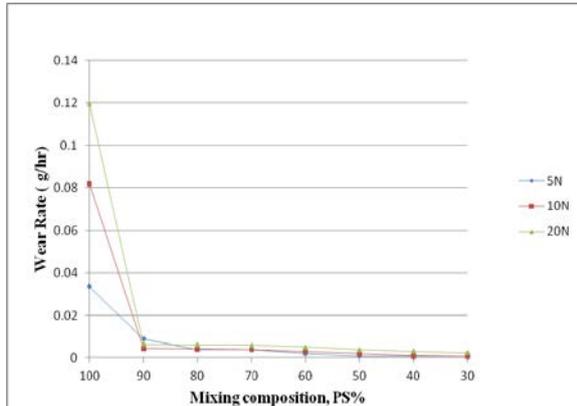


Figure 14. Wear rate at fixed 150 rpm velocity and loads of 5, 10 and 20 N.

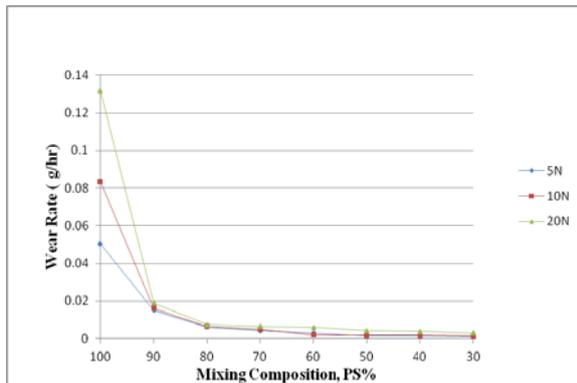


Figure 15. Wear rate at fixed 250 rpm velocity and loads of 5, 10 and 20 N.

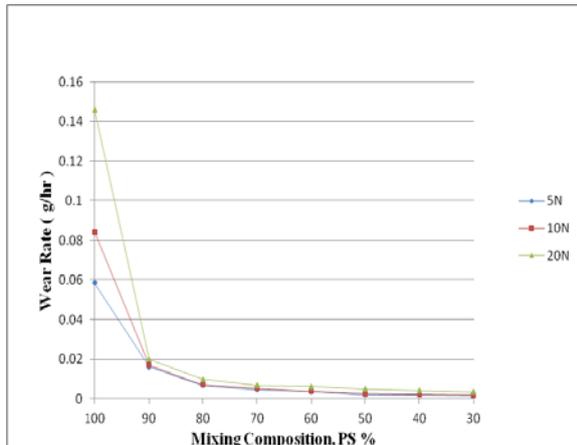


Figure 16. Wear rate at fixed 350 rpm velocity and loads of 5, 10 and 20 N.

It can be also concluded from the figures that the wear resistance of the tested specimens is increased dramatically by adding 10% of bakelite to the mixture, while at higher

percentages than 10% of bakelite the increase in wear resistance was not significant. The reason behind this is that bakelite is a hard material and the cross-linking involves the formation of covalent bonds between the polymer chains and the presence of cross-linked material can have a significant effect on the resulting properties of the material. This is in agreement with Stuart [21] when she explained. Uncross linked material like polystyrene tends to be softer and flexible, while heavily cross-linked polymers tend to be harder and brittle.

3.5. Infrared Thermography Test

Figure 17 shows the relative temperature change (Θ) test results for all tested specimens. It is shown that the relative temperature change of the specimens increases with the increase of the bakelite material in the blend.. Moreover, specimens with higher percentages of bakelite have a higher value of Θ . This behavior is in agreement with heat conductivity change due to a change in the percentages of mixed materials. This may due to the heat conductivity for Bakelite, which is 0.23W/m-°C and for polystyrene, which is 0.13 W/m-°C. Consequently, the material which has higher heat conductivity has a higher value of Θ (specimens which contain higher ratio of high thermal conductivity material will heat faster than those which contain lower ratio) as a results there was a changing in the value of Θ by changing in the composition of manufactured sheets.

From the above results, it is shown that there is a great potential for changing the conductivity of the manufactured sheets and this leads to using them in a various applications that need a certain level of thermal conductivity and insulation properties.

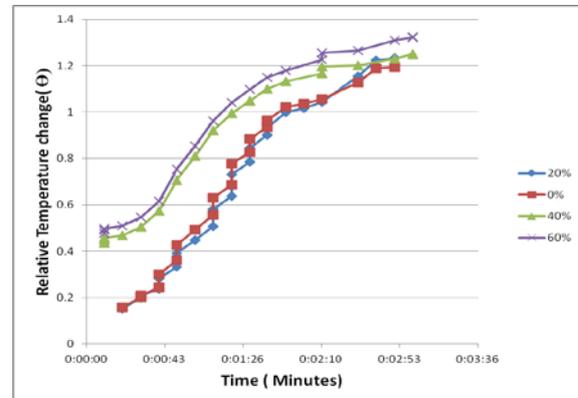


Figure 17. Relative Temperature change.

3.6. Comparison of the results of testing of the Manufactured Sheets and the results of testing of the Commercial Ceramic Tiles

To verify the results of this investigation, commercial ceramic tiles were randomly chosen from the commercial market and subjected to the same tests for comparison purposes.

Wear and water absorption tests were carried out on the ceramic tile at the same testing conditions of the manufactured sheets. Impact test for ceramic tiles was not performed because the sample preparation and testing conditions are totally different between the two materials. Also, according to the Jordanian standards, impact strength

test for ceramic tiles is not required and the testing equipments are not available.

3.6.1. Water Absorption Test Result for Commercial Ceramic Tile

The water absorption percent for the ceramic tile was 10.90% when tested at the same testing conditions of the sheets.

3.6.2. Wear Rate Test Result for Commercial Ceramic Tile

Table 3 Shows the test result at fixed 5, 10 and 20N forces and different velocities 150, 250 and 350RPM.

Table 3. Wear rate test results for the ceramic tile at fixed 5, 10 and 20 N forces and different velocities 150 , 250 and 350 rpm.

Material	Wear Rate (gram/hour) at5N			Wear Rate (gram/hour) at 10N			Wear Rate (gram/hour) at 20N		
	150 RPM	250 RPM	350 RPM	150 RPM	250 RPM	350 RPM	150 RPM	250 RPM	350 RPM
Ceramic Tile	<i>0.0024</i>	<i>0.0027</i>	<i>0.005</i>	<i>0.0024</i>	<i>0.0027</i>	<i>0.0068</i>	<i>0.0028</i>	<i>0.0034</i>	<i>0.0133</i>

Table 4. Wear rate test results for the ceramic tile at fixed 150,250 and 350 rpm velocities and different 5, 10 and 20N forces.

Material	Wear Rate (gram/hour) at 150RPM			Wear Rate (gram/hour) at 250RPM			Wear Rate (gram/hour) at 350RPM		
	5N	10N	20N	5N	10N	20N	5N	10N	20N
Ceramic Tile	<i>0.0024</i>	<i>0.0024</i>	<i>0.0028</i>	<i>0.0027</i>	<i>0.0027</i>	<i>0.0034</i>	<i>0.005</i>	<i>0.0068</i>	<i>0.0133</i>

4. Conclusions

The analysis of the results of the conducted tests led to the following main conclusions:

1. The mixing and manufacturing method helped in achieving a homogeneous distribution and bonding between the mixed materials.
2. The water absorption percent was increased directly by increasing the percent of bakelite material in the blend.
3. The impact strength was almost constant (unsignificant difference) for all mixing compositions because of the similar impact values of the two parents materials and this gave an indication that there was a good bonding between the mixed materials
4. The wear resistance of the manufactured sheets was increased dramatically by adding 10% of bakelite to the mixture, while at higher percentages of bakelite the increase in wear resistance was not significant for all applied forces and velocities.
5. The water absorption percent of the blend was less than the percent of the absorption of the commercial ceramic tiles.
6. The relative temperature change increases with the increase of bakelite in the blend.
7. The wear resistance results of manufactured sheets were close to the results of ceramic tile at (20%) of

Table 4 shows the test result at fixed velocities 150,250 and 350RPM and different applied forces 5, 10 and 20N.

The results in Tables 4 and 5 above were compared to the results of the tested ceramic tile. It was found that the water absorption percent of the manufactured sheets was better than the ceramic tile result. The percent of absorption for the tile was 10.9% and the maximum percent of the manufactured sheets was 0.87%. And wear resistance test results of the manufactured sheets were close to the ceramic tile when the percent of bakelite is 20% at higher bakelite percentages the results were better than those of the tile.

bakelite in the mixture and at higher percent of bakelite the wear resistance became better than that for the ceramic tile.

8. Wear resistance and water absorption tests results of the produced sheets compared to the tested ceramic tile make them of significant interest to the manufacturers to substitute the decoration materials as the later ones are heavy materials and have less potential to change their colors.

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