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Improvement of the physical, mechanical and thermal insulation properties to produce gypsum boards by using waste materials

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Abstract

In this paper, a study of improving the physical properties, mechanical and thermal insulation are conducted to produce gypsum boards with lightweight from waste materials. These boards can be used as an internal packaging wall or partitions tile of non-Bering with a high thermal insulation. Gypsum plaster mixed with waste material like (PET Polyethylene terephthalate, sawdust in size4.75mm and rubber) in different ratio (5%, 7%, 10%, 15%, 20%, 25%and 30%) of plaster to produce boards and then to find out the effect of these materials on the properties of boards, so that tests of consistency, setting time, flexural strength, density and thermal conductivity were achieved for all samples to find out this effect. The result shows that the best additive ratio to produce gypsum board with best physical, mechanical, and low thermal conductivity is 5,7% of PET.

Keywords: gypsum board, thermal insulation, flexural strength.

تحسين الخواص الفيزيائية والميكانيكة والعزل الحراري لانتاج الواح جبسية بأستخدام مخلفات المواد

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الخلاصة

تم في هذاالبحث ، اجراء دراسة لتحسين الخصائص الفيزيائية،الميكانيكة والعزل الحراري لإنتاج ألواح جبسية ، خفيفة الوزن من مخلفات المواد الصلبة. هذه الالواح يمكن ان تستخدم كتغليف داخلي للجدران او سقوف ثانوية لاغراض العزل الحراري والديكور او قواطع غير حاملة للاثقال ذات عزل حراري عالي، تم خلط الجص (الفني) مع المخلفات وهي (البولي اثلين ترفثاليت،نشارة الخشب (بحجم٤,٧٥ملم والمطاط).و بنسب مختلفة (٥،٧،١٠، ١٥، ٣٠،٢٥،٢٠ %) من الجص (الفني) لانتاج الواح جبسية ومن ثم معرفة تاثير تلك المواد على خواص الألواح ،كذلك تم فحص كافة النماذج لمعرفة تاثير القوام القياسي ، زمن التجمد، ،حمل الكسر ،الكثافة والموصولية الحرارية .اظهرت النتائج انه افضل نسبة اضافة لتحسين انتاج الالواح الجبسية ذات خواص ميكانيكية وفيزيائية وذات عزل حراري جيد كانت باضافة (٥،٧%) من(مادة البولي اثلين ترفثاليت).

Introduction

Building and construction are increasing with developing human and social demands in our country. But most of it are far away from prospecting principles concerning energy consuming .The main reason for this might be the absence of controlling system and legislations which can lead

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designers to build up ideas of inhabiting thermal insulation characters in building and construction. Considering environment of each country It is now very important to choose kind of construction system which are known to be intelligent in controlling heat transfer within the building and very efficient in energy consuming and saving power. Some research and studies started with how to reuse or recycle waste materials through making or producing new building materials which is known as thermal insulators. [1] The sustainable world's economic growth and people's life improvement greatly depend on the use of alternative products in architecture and construction, such as industrial wastes conventionally called "green materials". This research concerns with the development of new composite materials into the raw materials based on gypsum incorporating waste material. to produce new construction material contribute in reducing environmental pollution [2].

Gypsum wall boards

Gypsum wall board is a modern material of construction, used for a variety of applications ceiling, wall paneling, partition decoration , ducting, Insulation and acoustic purposes because they having characteristics of thermal insulation and sound barrier, usually produced from gypsum β -hemihydrate, which is used extensively for interior walls or ceilings due to its easy fabrication features, excellent fire resistance properties, environmental friendliness, low price.(Iraqi Standard Specification ,1676,1991) .These boards are made of gypsum core covered by special paper bonded strongly to the board; this core may contain additives for different purposes.

Materials

1. Sawdust is composed of fine particles of wood. The physical and chemical property varies significantly depending on several factors such as different of wood with geographical location and industrial processes. Sawdust used in this research is a mixture of wastes from both hard and soft woods. Preliminary analysis was conducted on the sawdust to determine their suitability for board making. Tests conducted include: physical analysis (particle size) using sieve 4.75mm for coarse sawdust, chemical analysis that includes moisture content, CO_3, Solubility in cold and hot water), and solubility in NaOH, H_2SO_4, as shown in Table -1. The use of sawdust as a partial admixture provides an economic use of the by- product and consequently produce cheaper boards for low cost building materials, as well as, light weight. [3].
2. PET (Polyethylene terephthalate). Sometimes written poly ethylene terephthalate, commonly abbreviated PET is a thermoplastic polymer resin of the polyester family and is used in synthetic fibers; food and other liquid containers, thermoforming applications. It is a long-chain polymer (C10H8O4) belongs to the polyesters family [4].
3. Rubber waste: Crumb rubber is a term given to recycled rubber produced from scrap tires. Production of crumb rubber consists of removing steel and fluff then using a cracker mill or mechanical means, to reduce the size of the tire particles. The rubber particles are then sized by passing them through a set of sieves No.8. [5]. Rubber tires are a ductile, non-biodegradable material that can exist for a long time without any degradation.

Preparation of raw materials

1. Gypsum plaster produced from the company (The United Iraqi plaster Limited – BAGHDAD) (mark Al malaj), had been used as essential binding material, gypsum plaster (without addition) was submitted to the physical, chemical, mineralogical tested to ensure that this product coincides with the Iraqi standard specification no.(26,27,28)1988,as shown in Tables -2 and -3.
2. Sawdust: were obtained from carpentry and wood - working. Chops sized by sieving into 4.75mm (sieve No.4) Sawdust were immersed in tap water, colorless, odorless, tasteless and organic free, for 24hour in order to get rid of dust powder and carbohydrate content, then dried in the furnace at 80˚C for 24 hours to remove moisture and other volatile impurities that present before using, also to assure good bonding with the paste, preventing the wood to swell affecting bonding strength. Wet sawdust cannot be used with the plaster paste immediately because it is difficult to be blended with it. Making it homogeneous in distribution, as well as losing precision in fixing proper water content.
3. Bottles (PET) : were collected, chopped into 0.5-4 mm size. after consumer PET soft drink bottles were washed, dried, and grinded.

4. Rubber Waste: rubber was Chopped and sized by sieving on sieve No. 8, 2.36 mm size for the purpose of obtaining grains of a specified size.

Mix design:

Plaster was mixed with the PET, saw dust, and rubber wastes grains in the dry state in percentage of 5%, 7%, 10%, 15%, 20%, 25% and 30%(by weight) of plaster to prepare gypsum boards were mixed thoroughly by hand, then tap water was added with fixed amount. Mixed and casted in molds prepared previously, clean and well-oiled in order to prevent sticking of the paste prepared, especially at the edge. Plaster board with dimensions of: 400 × 300 × 100 mm for testing flexural strength in longitudinal and transverse dimensions according to (Iraqi Standard Specification NO- 1676, 1991).The mean of 5 samples tested for longitudinal and 5 samples for transverse that mean (10) samples were tested for additive ratio, for plaster boards, there are 7 admixtures, so 70 tests had been done for one waste materials as listed in the tables from -4 to -6. All specimens were demoled after hardening, then cured in the moist cabinets (temperature 23˚C and moisture 65%) for (7, 14, 28) days then removed and dried in oven (temperature 40-45˚C) to get completely drying for 3days before testing, and until constant weight .

It should be noted that all plaster board samples must be held vertically in the cabinet to prevent distortions of the body during the process of curing.

Experimental part

1. **Test thermal conductivity:**

This value can be determined by Linseis Heat Flow Meter (HFM 300), where a square sample (50x300x300mm) is located between a hot and a cold plate (temperature gradient). The heat transfer coefficient can be calculated from the measured heat flow through the sample divided by the cross-section area. There are differences between temperature of upper and lower plate and the applied temperature. For the tested samples, the upper plates calibrate at 30˚, whereas the lower plate at 10˚, then the test continues until it reaches to thermal equilibrium.

2. **Flexural strength analysis:**

The samples were taken by cut five specimens300× 400 mm for the longitudinal and transvers. The edge of board specimen should be squared, the spacemen is placed on the supported of testing machine, the spacemen shall be tested face up and face down. The average breaking load should not be less than the 360longtudinal and 140 transverse according to Iraqi Standard Specification 1676 (1991).

3. **Consistency:**

This test is carried out to find the percentages of water (in milliliter) to be add to the plaster as Standard consistency. 100 gm minimum of gypsum plaster was used to determine the Standard consistency. And then dispersed with a known amount of water 40-50 cm^3 in a mix container for 15 seconds then it was left again for 30 seconds with slow stir of container to get rid of the air's bubbles. The mixture is mixed by knife for 30 - 40 seconds and placed to the dry clean mold and oiled carefully to avoid staking of the paste, and then the mold is raised after two minutes.The mixture is spread over a glassy board and then the minimum and maximum diameter (inner and outer diameter) resulted from material after spreading is determined. The process is repeated by changing the amount of water until obtaining the standard spread from arithmetic comparable to (100± 3) as:

Water percentage to powder w/p = water cm^3 /100 ×100%

4. **Setting time:**

To determine the setting time, a mixture of water/sample of standard percentage was prepared according to consistency test, and preferably 3 samples of 200 gm of gypsum plaster have been weighed. The mixture is shaken continuously in the mold; the surface of the mold is equalized by knife without pushing a knife or metallic ruler. The mold left and put under the vicat base. The vicat needle is dropped until contact with paste's surface, and the needle is allowed to penetrate inside the paste. The process is repeated at different locations in the pastes surface with condition that the distance is not less than 12mm between the edge of the mold , and the location of the test to another test .Setting time is considered complete when the vicat needle didn't arrived to the base of the glassy board.

5. Density Test:

The density of the samples was determined by their volumes and masses. The sample overall dimensions were measured using a digital vernier caliper. Measurements were made on (3) samples. The mass of specimen was measured after conditioning the specimen in 65% relative humidity ,and dried at 40-45 temperatures until weight becomes constant, The density was calculated by the following equation;

Density = mass (gm)/volume (cm^3)

Result and discussion

1. For the plaster board with PET the most important test is the flexural strength; this is approved by all standard and first of all Iraqi standards (No, 1676, 1991). The longitudinal and transvers values of this test must not be lower than 360 N and 140 N respectively. The references board sample failed at 480 and 230N respectively (for 7 days age), as shown in table-4, at 5% PET replacement this strength increases to 487 N for longitudinal and 240 N for transverse respectively, this is due to the reinforcement action of PET in the broad. There was also increase in the value of flexural strength when the ratio of additive PET reaches to 7% within the demand of the standard. Because the PET granules were arranged parallel to the long axis of the broad and this means they strength the tensile feature of the broad.
2. In (10, 15%) additions the value decreases from the previous additive ratio but it is still within the standard. More additive of PET (20%) reflects bad result for longitudinal flexural (325 N) (out of demand of standard), whereas the transverse (140 N), when the samples tested at 25%, 30% with PET, this addition makes the sample fail before testing**.** Table-4 shows the results of plaster consistency, setting time, and flexural strength of board with PET additive. For additive ratios (5-10%) of PET there are increase of consistency (w/p) that reach from (55- 57) ml/gm ,then for the ratio of PET additive (15-30%)the value of w/p decreases until it reaches (45) ml/gm for (30%) of PET , Whereas the setting time remained constant for all additive ratio (10) minute.
3. The addition of 5% sawdust with plaster boards showed no significant reduction (2.08%) in strength value of the longitudinal plasterboard, yet there was little increase in water amount (about3.6%)this means that 5% sawdust has very little effect on the board strength .Increasing the additive from 7% and 10% by weight of the plaster raised the w /p that needed to get appropriate slurry with ability work .This leads to decrease in the strength but keeping the value within the standard limits.
4. The high water content leaves after evaporation of voids and pores causing this reduction in the strength of board. When more of sawdust is added to the plaster about 15, 20%, more water content needed, and decreasing the amount of plaster, causing a high porosity of the board that reflect low value of longitudinal flexure (150 N, 135N) and (60 N, 45N) for transverse flexure (for 7days age) .More sawdust means, 25% caused board failure in test. Table-5 shows the results of plaster consistency, setting time, and flexural strength of board with sawdust additive.
5. For the flexural boards. When (5%) of rubber particle are added the flexural strength decreased in (385) N longitudinal and (222) N transvers. But still in demand standard specification (1676, 1991). All board samples containing rubber particles show low value when tested for flexural strength and with all additive percentage (7%, 10%, 15%20%) this is because the particles could not be bonded with the gypsum plaster due to their surface smoothness, and also when these particles were increased in amount, in the mixture caused a larger demand of water amount in order to insure homogeneity of the mixture, this also was another reason for the flexural strength drop down. While the 25, 30% of rubber failed in test Table-5 shows the results of plaster consistency, setting time, and flexural strength of board with rubber additive. Figure-1and -2 shows the relationship between longitudinal and transverse flexural strength with the additive materials.
6. When the ratio of additive waste material increased the density decreased, because all the added materials have a light weight ,the upper limit of density appears with 5%PET additive and reach (1.39 gm/cm^3), while ,lower limit (0.6 gm/cm^3)in 30% PET, Figure 3 shows the relationship between density with the additive materials.
7. Thermal conductivity and density: According to the values of densities all samples show a decreasing in value of density with the increase of additive materials. Thermal conductivity

values start with (0.481) w/k.m for (neat plaster board) , the higher value of thermal conductivity for the plaster with additive materials reaches to 0.470 w/ k.m in 5% with rubber , whereas the lower value is 0.200 w /k.m in 30%PET, and all values for all percentages of additive started to decrease by adding different types of waste materials mentioned previously, the best results recorded for insulation of the wasted materials were found in boards containing PET with percentages of 20%and 30% addition (0.210 and 0.200 w / k.m) respectively, Figure 4 shows the relationship between thermal conductivity with the additive materials.

Conclusions

1. Gypsum plaster boards can be prepared as light weight and thermal insulation from the addition of sawdust, PET and rubber with ratio 5%, 7%, 10%, 15%, 20%, 25%, and 30%.of specific weight of gypsum plaster.
2. The consistency of samples can be increased when we increase additive ratio. Because of high absorptive water for sawdust and rubber of some percentage ratio, except the PET the consistency was decreased when was increased the added ratio.
3. The value of setting time had been increased for all the additive ratio of the waste materials, except in PET where the setting time is constant with the entire ratio in (10minute).
4. When the ratio of additive waste material increased the density decreased, because all the added materials have lightweight materials, so when these materials added to the gypsum boards the weight will be decreased, and then less weight of construction material can be gotten, which can be used in non-bearing weights walls.
5. The best added ratio to produce gypsum board from PET is (7%) because it has high flexural strength (490N, 250N) for longitudinal and transverse respectively, compared with neat plaster (480N, 230N). No more than 15% weight of chopped (PET) can be used in making internal packing board because the flexural strength was out of limited standard
6. The setting time increases to (27mintue) when 30% of sawdust was added in size (4.75mm) because the saw dust have high absorptive of water, subsequently the setting time would be out of demand for Iraqi standard specification.
7. Gypsum boards can be produced by added (5%) only of rubber waste, because the flexural strength is out of demanded Iraqi standard specification if the ratio exceeds more than 5% of rubber.
8. For all the waste materials that used in this search, rubber and PET gave a better result for compressive and flexural strength.
9. Upper limit of thermal conductivity for all tested samples was (0.470k/W.m) for board mixed with rubber and the lower limit was (0.200k/W.m) (with PET), this indicated when the additive ratio of waste materials increasing the thermal conductivity decreased, and then the insulation increases.
10. The best of thermal conductivities for all tested samples, when added PET with ratio of 20%, 25%and 30%, are (0.210, 0.207and 0.200k/w.m). Preferably use this type of polymer and these ratios to produce board use as ceilings for the purposes of decoration, Painting and thermal insulation.

Table 1-The Physical, chemical analyses of wood sawdust.

Physical analyses	Content %
Moisture content	63.5
CO_3	7.2
Solubility in cold water	17.17
Solubility in hot water	4.5
Solubility in NaOH1%	28.46
Solubility in H_2SO_4 1%	22.51
particle size 4.75mm	5

Table 2- Physical and mechanical analyses results of gypsum Hemihydrate

Physical test	Stander Iraqi specification	result
Softness	All the sample pass from sieve No 100	All the sample pass from sieve No 100
w/p ratio(ml/gm	------	55
Setting time(min.)	25-8 minute	10
Compressive strength(N/mm^2)	Not less 50	60
Flexural strength (N/mm^2)	Not less 15	23

Table 3- Chemical analysis results of gypsum Hemihydrate.

Oxides	%	Iraqi standard specification
L.O.I	6.88	Not more than 9%
SO3	53.35	Not less than 45%
CaO	35.22	Not less than 25%
R2O3	0.41	—
SiO2	0.94	—
MgO	0.63	Not more than 0.25%
NaCl	0.13	—
Combined water	5.90	Not less than4%& Not more than 9%
Free water	0.98	—

Table 4- Shows the results of plaster consistency, setting time, and flexural strength of board with PET additive.

material	Added ratio%	Consistency (ml/gm)%	Setting time(min.)	Flexural strength(N)	
				Longitudinal	transvers
Plaster without additive	________	55	10	480	230
POP+ PET 0.5-4mm	5%	55	10	487	240
	7%	56	10	490	250
	10%	57	10	375	190
	15%	55	10	360	166
	20%	50	10	325	140
	25%	45	10	failed	failed
	30%	45	10	failed	failed
Standard Specification				360	140

Table 5- Shows the results of plaster consistency, setting time, and flexural strength of board with SD (4.75mm) additive.

Material	Added ratio%	Consistency (ml/gm)%	Setting time(min.)	Flexural strength(N)	
				Longitudinal	transvers
Plaster without additive	-------	55	10	480	230
POP+ Sawdust(4.75mm)	5%	57	11	470	230
	7%	59	12	450	225
	10%	60	13	410	190
	15%	64	15	150	60
	20%	68	17	135	45
	25%	**70**	**20**	failed	Failed
	30%	**77**	**27**	failed	Failed
Standard Specification				360	140

Table 6- The results of plaster consistency, setting time and flexural strength of board with Rubber additive.

Material	Added ratio%	Consistency (ml/gm)%	Setting time(min.)	Flexural strength(N)	
				Longitudinal	transvers
Plaster without additive	________	55	10	480	230
POP+ Rubber (2.36)mm	5%	55		385	222
	7%	57	10	280	180
	10%	60	13	275	177
	15%	61	16	240	170
	20%	64	17	225	155
	25%	*66*	19	failed	Failed
	30%	*68*	22	failed	Failed
Standard Specification				360	140

Table 7-The results of thermal conductivity, density for the studied samples with PET additive.

Type of added material	Added ratio%	Density gm/cm^3	Thermal conductivity W/K·m
Plaster without additive	——	**1.39**	**0.481**
POP+ PET 0.5-4mm	5%	1.39	0.411
	7%	1.25	0.361
	10%	1.10	0.310
	15%	0.90	0.230
	20%	0.8	0.210
	25%	0.67	0.207
	30%	0.6	0.200

Table 8-The results of thermal conductivity, density for the studied samples with SD (4.75mm).

Type of added material	Added ratio%	Density gm/cm^3	Thermal conductivity W/K·m
Plaster without additive	——	**1.39**	**0.481**
POP+ Sawdust(4.75)mm	5%	1.26	0.415
	7%	1.16	0.402
	10%	1.10	0.310
	15%	1.07	0.305
	20%	0.99	0.295
	25%	0.96	0.294
	30%	0.92	0.293

Table 9-The results of thermal conductivity, density for the studied samples with rubber (2.36mm).

Type of added material	Added ratio%	Density gm/cm^3	Thermal conductivity W/K·m
Plaster without additive	——	**1.39**	**0.481**
POP+ Rubber(2.36)mm	5%	1.32	0.470
	7%	1.29	0.455
	10%	1.25	0.430
	15%	1.20	0.400
	20%	1.18	0.332
	25%	1.13	0.327
	30%	1.10	0.285

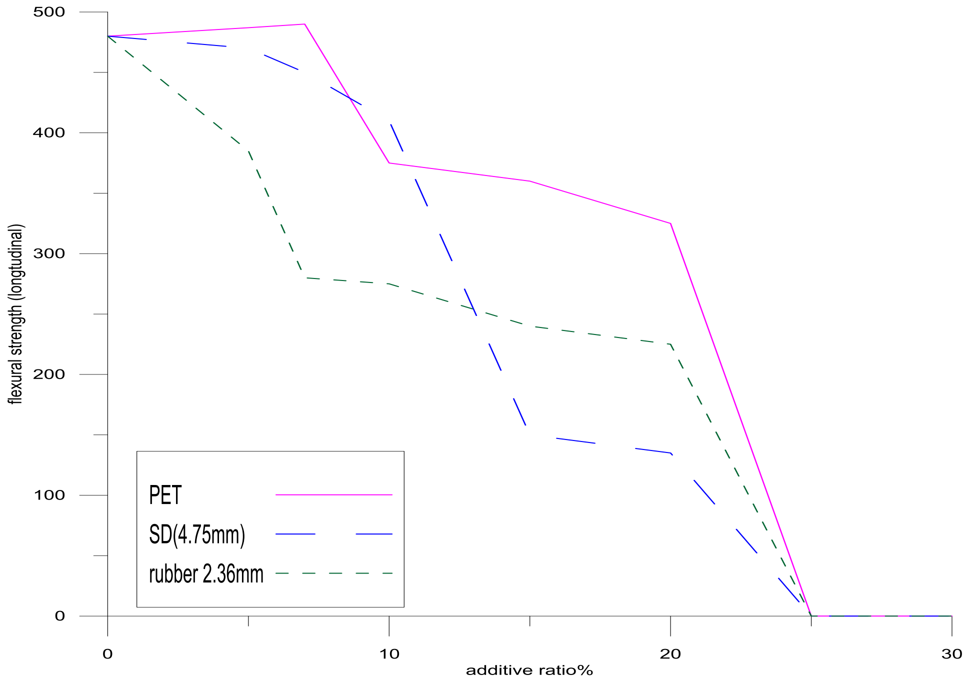

Figure 1- Relationship between flexural strengths in longitudinal gypsum board.

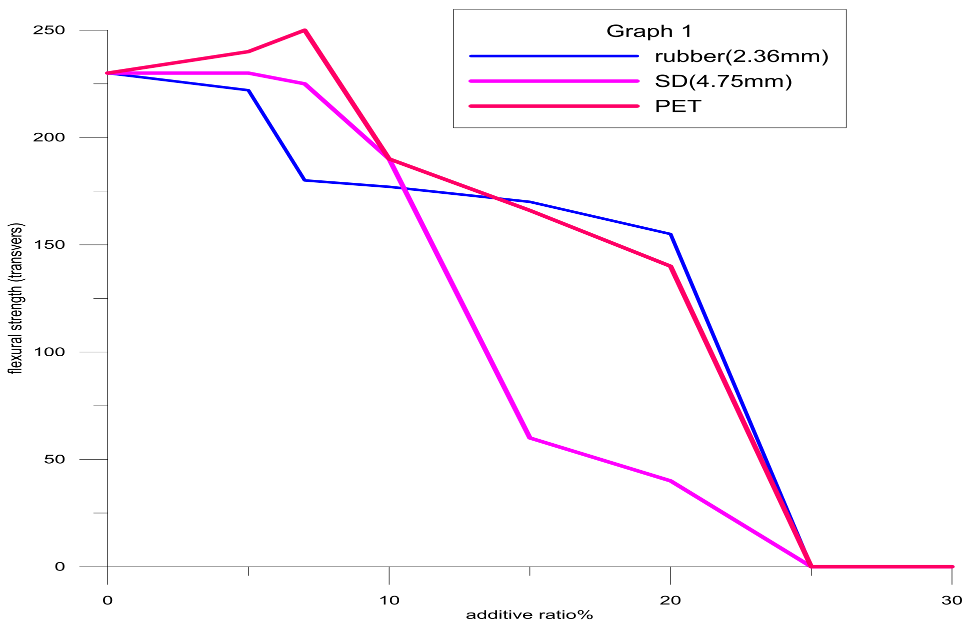

Figure 2-Relationship between flexural strengths in transvers gypsum board.

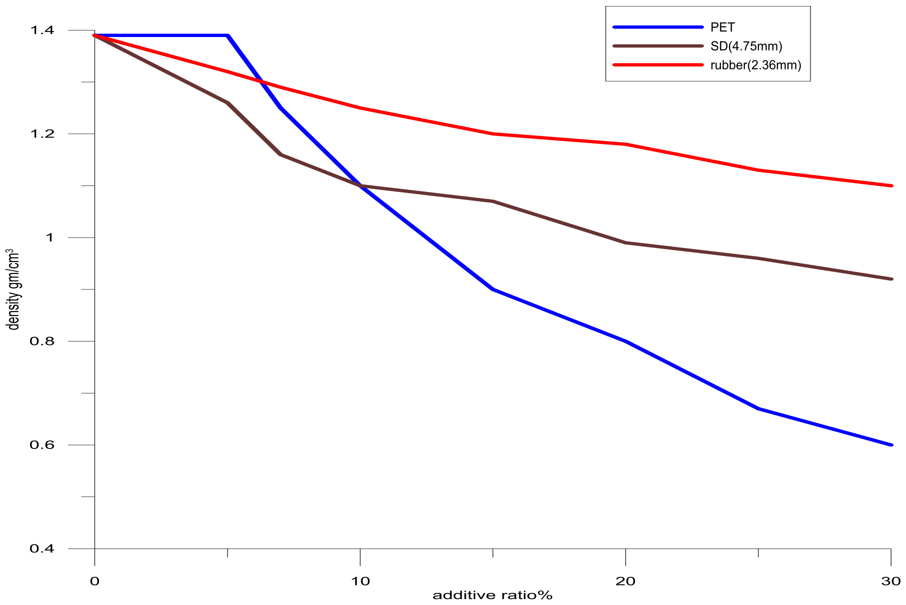

Figure 3- Relationship between density with additive ratio

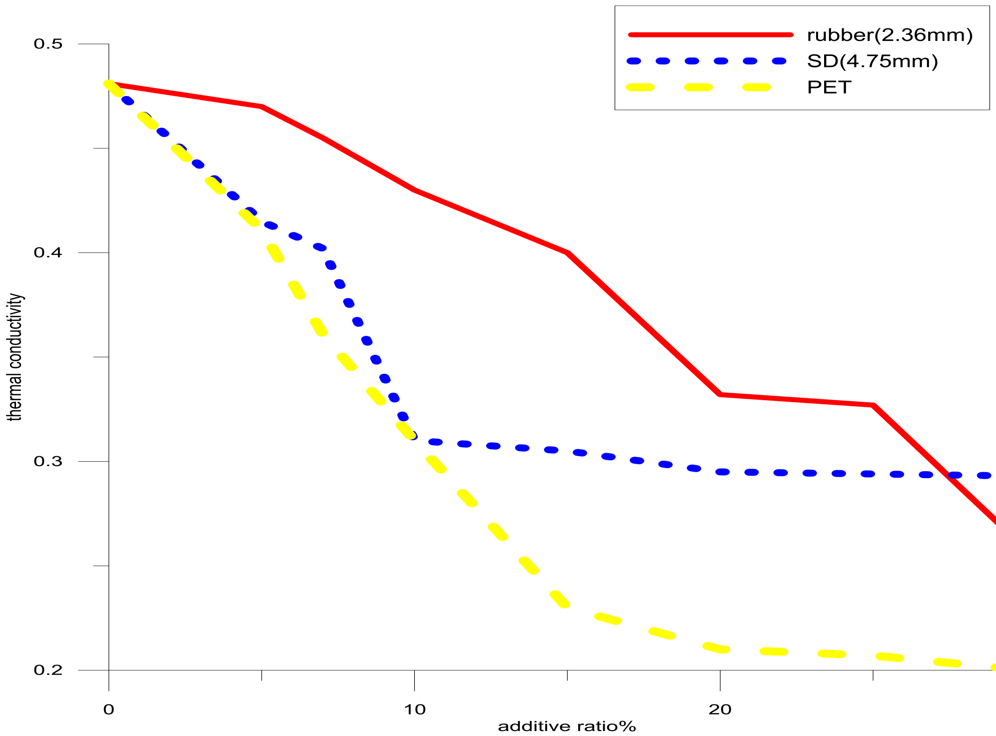

Figure 4-Relationship between thermal conductivity with additive ratio

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