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Selecting Optimal Molding and Material Conditions of Reinforced Polymeric Nanocomposites with MWCNT Using a Multi-Criteria Decision Making Model

In order to solve conflicting decision problems, multi-criteria decision making (MCDM) methods are used to make the best choice among many criteria. In this research, sixteen different samples of melt compounded polyamide 6 (PA6) and multi-walled carbon nanotubes (MWCNTs) were studied. The raw materials were compounded using a twin-screw extruder and the samples were chosen based on an L_{16} orthogonal array of Taguchi approach. The alternatives of the problem were samples produced under different injection parameters including holding pressure, injection temperature, and with various weight percentages of MWCNTs. The chosen criteria were tensile strength, elastic modulus, Charpy impact strength, Rockwell hardness, and cost. Analytical hierarchy process (AHP) was used to weight the criteria and due to the results, tensile properties were the most important criteria with the weight of 0.319. In the next step, a technique for order preference by similarity to an ideal solution (TOPSIS) and the multi-objective optimization on the basis of ratio analysis (MOORA) were implemented to rank the alternatives. Based on the considered criteria the samples containing 1 wt% of MWCNTs was selected as the best alternatives.

1 Introduction

Polymers are among famous light materials but they need to be reinforced because of their lower mechanical properties compared to metals (Ward and Sweeney, 2012). In recent studies, nanomaterials with low concentration (less than 10% by weight) have been used as reinforcement. Because of the unique physical and mechanical properties and high strength to weight ratio of nanocomposites, their applications are expanding (Boholm and Arvidsson, 2016; Lu et al., 2014; Ghanbari et al., 2014; Liu et al., 2014; Kumar et al., 2013).

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Many researchers have investigated polymer-based nanocomposites. The mechanical properties of epoxy composites reinforced by MWCNT were studied (Starkova et al., 2012). The mechanical properties were enhanced about 2% by addition of 0.1 wt% of MWCNT compared to that of pure epoxy. The results revealed that Young's modulus, yield strength and stress at break-point of the polypropylene nanocomposites linearly increases with the increase of the wt% of nanotubes. In another study, the possibility of enhancing the mechanical properties of PMMA/MWCNT nanocomposites with the use of the injection molding procedure was investigated (Navidfar et al., 2016). The MWCNT concentration, injection temperature, and holding pressure were chosen as variable parameters. They observed that carbon nanotubes have a positive effect on the mechanical properties of nanocomposites in comparison to pure polymer. Also, some studies were performed on the effect of the addition of multi-walled carbon nanotubes on the flammability of polymers. The effect of nanoclay and MWCNTs on the high temperature thermo-mechanical properties of thermoplastic polyurethane was studied (Ambuken et al., 2012; Ambuken et al., 2014). The results showed that the degree of separation was reduced by addition of nanoclay while this value was increased by adding MWCNTs.

Multi-criteria decision making (MCDM) is concerned with structuring and solving decision and planning problems involving multiple criteria. Typically, a unique optimal solution for such problems does not exist and it is necessary to use decision-making preferences to differentiate between solutions (Mardani et al., 2015). An incorrectly selected material for a given product may cause premature failure of the final product. The best material for the tool holders working under hard milling conditions using different MCDM methods is selected (Caliskan et al., 2013). Reinforced natural hybrid and glass fibers polymer composites material selection using AHP process for the automotive brake lever design were investigated (Mansor et al., 2013). The improvement of mechanical properties of PMMA nanocomposites for dentistry applications was investigated (Rashahmadi et al., 2017).

In the present research work, the usage of MCDM procedure has been investigated in the field of polymer nanocomposites.

For this purpose, nanocomposites of PA6 reinforced with multi-walled carbon nanotubes (MWCNTs) were produced according to Taguchi's L_{16} orthogonal array and were considered as different choices. Mechanical properties and the cost of the samples are obtained and considered as the criteria of this paper to make a decision. Then using MCDM methods (MOORA and TOPSIS) the best sample(s) were selected. Accordingly, the best level of each parameter is introduced.

2 Experimental Methods

2.1 Materials

In this study, PA6 (Tecomide NB40 NL E, Eurotec, Tekirdag, Turkey) with a density of 1.13 g/cm^3 , appropriate for extrusion and molding processes, is selected as a matrix. MWCNTs are used as reinforcement supplied by US Research Nanomaterials, Inc., Houston, USA, with purity of 90%, inner diameters, outer diameters and length of 5 to 10 nm, 10 to 30 nm and 10 to 30 μm , respectively.

2.2 Experimental Design

Variable parameters have been analyzed including weight percentage of carbon nanotubes, holding pressure and injection temperature which were set at four levels. An L_{16} orthogonal array of Taguchi method was used to design experiments which caused reduction of the number of experiments and therefore reduction of cost.

According to the previous studies, it was observed that in most researches adding 1 wt% of nanotubes leads to the best properties, therefore in this study three levels of 0.5, 1 and 1.5 percent of nanotubes were chosen. On the other hand, the pure polymers were produced to be used in comparison. To determine the levels of holding pressure, by performing some pre-tests it was concluded that with less than 55 MPa of holding pressure the samples are not filled completely, therefore the lowest level was chosen to be 55 MPa. On the other hand, the highest possible pressure of the injection machine (115 MPa) was chosen as the highest level. The two other levels were chosen between these two limits by equal intervals. Finally, 55, 75, 95 and 115 MPa levels were chosen for holding pressure. To choose the injection temperature levels the lowest and highest practically possible temperatures (210 and 240°C) were chosen as maximum and minimum levels and two other tempera-

tures were chosen in between. The levels of injection temperature were set as 210, 220, 230 and 240°C . The parameters and adjustments levels are given in Table 1.

Required experiments in accordance with Taguchi's L_{16} orthogonal array using Minitab software are indicated in Table 2.

2.3 Preparation of Nanocomposites

Firstly, in order to eliminate the granules moisture, PA6 is dried in the laboratory oven at 120°C for 2 h. Then a ZSK-25 (Coperion Werner & Pfleiderer, Stuttgart, Germany) twin-screw extruder with 10 kg/h extruding capacity, $D = 25 \text{ mm}$ of the screw and $L/D = 48$ has been used for melt compounding of the materials. For the production of granules, barrel temperature and other parameters were adjusted according to Table 3. The rotational speed of the screws was 250 min^{-1} . This high speed increases the shear stress between the layers of materials which leads to homogenization and better material composition.

After re-drying, the nanocomposite granules were injected using the NBM HXF-128 injection molding machine (Nekoo Behine Machine Company, Tehran, Iran) with $L/D = 21.1$ and $D = 37 \text{ mm}$ of the screw. The specimens were produced according to the standard ASTM D256 for impact tests and ASTM D638 for tensile tests. Some of the produced specimens are shown in Fig. 1.

2.4 Characterization of the Mechanical Properties

In order to measure the tensile properties of produced samples a Gotech-AI-7000 M tensile test machine (GOTECH, Taichung, ROC) with 200 kN maximum force and ± 0.25 accuracy is used. The strain rate during the tensile test was 10 mm/min. Also, a Charpy impact test machine has been used to determine the impact strength of samples with pendulum mass of 2.036 kg. An Indentec universal hardness test machine (Zwick/Roell, Herefordshire, UK) is used to determine Rockwell hardness based on M type with an accuracy of 0.1.

2.5 Analysis of Data

The results of the tests were analyzed using different MCDM methods. All the analyses are performed using the software Expert Choice version 11 (Expert Choice, Arlington, USA).

Level	1	2	3	4
Parameter				
MWCNT (wt%)	0	0.5	1	1.5
Holding pressure (MPa)	55	75	95	115
Injection temperature ($^\circ\text{C}$)	210	220	230	240

Table 1. Processing parameters and their levels

3 Multi-Criteria Decision-Making Methods

The case study is selecting the best combination of materials with respect to mechanical properties. Since the problem involves multiple criteria, MCDM methods can be applied to provide a solution. Suppose there are m alternatives to be selected based on n criteria. A decision matrix is a $m \times n$ matrix in which each element $i.e.$ x_{ij} is the j th attribute value of the i th alternative (Govindan et al., 2015).

3.1 AHP Method

The AHP method was developed by Saaty to model subjective decision-making processes based on multiple criteria in a hierarchical system. AHP uses the pairwise comparison of the same hierarchy elements using Saaty scale and indicates the importance of one element over another element using the Saaty's relative importance 1–9 point (Althwaynee et al., 2014; Kayastha et al., 2013). The consistency ratio is calcu-

Parameter \ Sample	MWCNT wt%	Holding pressure MPa	Injection temperature °C
1	0	210	55
2	0	220	75
3	0	230	95
4	0	240	115
5	0.5	220	55
6	0.5	210	75
7	0.5	240	95
8	0.5	230	115
9	1	230	55
10	1	240	75
11	1	210	95
12	1	220	115
13	1.5	240	55
14	1.5	230	75
15	1.5	220	95
16	1.5	210	115

Table 2. L_{16} orthogonal array of Taguchi method

Regulative parameter	Unit	Value
Barrel temperature	°C	210–220–230–235–240–240
Screw speed	min ⁻¹	250
Melt pressure in the outlet nozzle	bar	80

Table 3. Extruding parameters

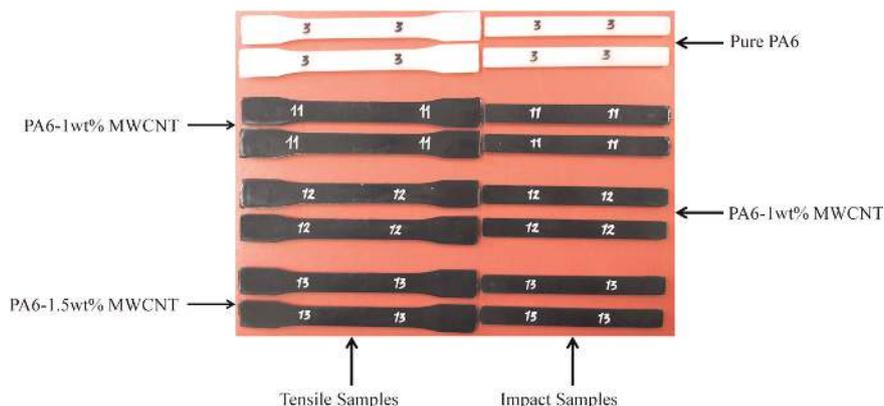


Fig. 1. Produced samples

lated based on the following steps (Althuwaynee et al., 2014; Kayastha et al., 2013):

1. Calculate the eigenvector or relative weights and λ_{max} for each matrix of order n.

2. Compute consistency index (CI) for each matrix of order n using Eq. 1:

$$CI = (\lambda_{max} - n)/(n - 1), \tag{1}$$

3. Consistency ratio (CR) is then calculated using Eq. 2:

$$CR = CI/RI, \tag{2}$$

where RI denotes average random index, and its value is 1.12 for n = 5. For consistency, CR value should be less than 0.1.

3.2 TOPSIS Method

The technique for order preference by similarity to an ideal solution (TOPSIS) is a typical MCDM tool. The TOPSIS procedure consists of the following steps (Karaman et al., 2014):

1: Calculate the normalized decision matrix as Eq. 3:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^m x_{kj}^2}}, \tag{3}$$

where y_{ij} is the normalized value, m is the number of criteria, x_{ij} is the value of the observed data, and x_{kj} is that of the observed data in the same row as x_{ij} .

2: Normalization of weights using Eq. 4:

$$v_{ij} = y_{ij} * w_{ij}, \tag{4}$$

where v_{ij} is the weighted normalized value, y_{ij} is the normalized value, and w_{ij} is the weight of the each criterion.

3: Determine the ideal and negative ideal solution using Eqs. 5 and 6, respectively:

$$A^* = \{v_1^*, \dots, v_n^*\} = \{(\max_j v_{ij} | i \in I'), (\min_j v_{ij} | i \in I'')\}, \tag{5}$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \{(\min_j v_{ij} | i \in I'), (\max_j v_{ij} | i \in I'')\}, \tag{6}$$

where I' is associated with benefit criteria and I'' is associated with cost criteria.

4: The distance (D) of each alternative from positive and negative ideal solution was calculated as Eqs. 7 and 8, respectively:

$$D_j^* = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^*)^2}, \tag{7}$$

$$D_j^- = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^-)^2}, \tag{8}$$

5: The closeness coefficient (C) of each alternative was calculated via Eq. 9:

$$C = \frac{D_i^-}{D_i^* + D_i^-}. \tag{9}$$

The ranking of the alternatives was determined based on the highest C values.

3.3 MOORA Method

The multi-objective optimization on the basis of ratio analysis (MOORA) method starts with a decision matrix showing the performance of different alternatives with respect to various attributes (objectives). The normalization of the decision matrix is performed using Eq. 3.

The normalized assessment value calculated by Eq. 10:

$$z_i = \sum_{j=1}^g y_{ij}^* - \sum_{j=g+1}^n y_{ij}^*, \tag{10}$$

where g is the number of attributes to be maximized, (n-g) is the number of attributes to be minimized, and z_i is the normalized assessment value of ith alternative with respect to all the attributes. The ranking of the alternatives was determined based on the highest z_i values (Gorener et al., 2016).

4 Results and Discussion

In the present study, tensile strength, elastic modulus, impact strength, and hardness were considered as mechanical properties and cost as economic criteria. According to the opinions and experience of authors, the pairwise comparison matrix has been demonstrated in Table 4.

By importing the matrix of pairwise comparisons in the Expert Choice software, the weight of each criterion was calculated according to the AHP method in Fig. 2. Due to the results, the tensile strength and elastic modulus with the weight of 0.319 are in the first place. Impact strength, hardness, and cost are in the next ranks, with weights of 0.184, 0.110 and 0.068, respectively.

By performing the mechanical tests on the produced nanocomposites samples, the decision matrix is computed as Table 5. Also, the normalized decision matrix is given in Table 6. It is noteworthy that for each data the test was repeated 3 times and the average of these iterations was reported as final data. It is observed that the tensile properties were improved dramatically by the addition of carbon nanotubes especially in samples containing 1 wt%. Tensile strength and elastic modulus increased almost 31 % and 54 %, respectively by the addition of 1 wt% of MWCNTs. By increasing the weight percentage to 1.5 tensile properties decreased which is probably due to agglomeration of carbon nanotubes inside polymer blends. By the addition of carbon nanotubes to the polymer matrix, hardness and impact strength increased and decreased, respectively.

By analysis of tensile strength results with the Minitab software, the interaction of parameters can be illustrated in Fig. 3. As it can be seen, by considering the interaction between nanotube weight percentage and holding pressure, it is concluded that to achieve the maximum tensile strength the best way is to add 1 wt% of nanotubes and use the holding pressure of 95 MPa. Under the holding pressure of 55 MPa, the least and

	Tensile strength	Elastic modulus	Impact strength	Hardness	Cost
Tensile strength	1	1	2	3	4
Elastic modulus	1	1	2	3	4
Impact strength	1/2	1/2	1	2	3
Hardness	1/3	1/3	1/2	1	2
Cost	1/4	1/4	1/3	1/2	1

Table 4. Pairwise comparison matrix

the most tensile strengths are related to pure polymer and sample with 1 wt%, respectively. Moreover, by considering the interaction between nanotube weight percentage and injection temperature, it is concluded that to achieve the maximum tensile strength the best way is to add 1 wt% of nanotubes and use injection temperature of 210°C. Under the condition of using 230°C as injection temperature, the tensile strength of

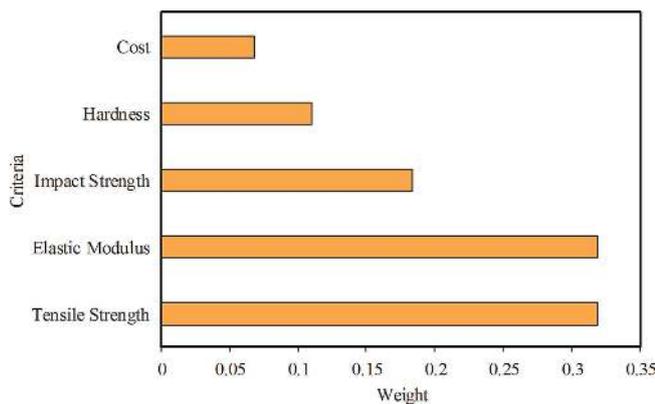


Fig. 2. Weighting results of AHP method

pure polymer sample will be higher than the sample with 1.5 wt% of nanotubes. By considering the interaction between holding pressure and injection temperature, it is concluded that to achieve the maximum tensile strength the best way is to use holding pressure of 95 MPa under injection temperature of 210°C. Under the condition of using 230°C as injection temperature, it would be better to set the holding pressure on 55 MPa.

By analyzing the decision matrix, the alternative ranking using TOPSIS and MOORA methods is obtained as Table 7. Also, Fig. 4 shows the graphical plot of these rankings.

As a result, in the TOPSIS and MOORA methods, sample No. 12 and sample No. 11 were selected respectively as the best samples. Sample No. 12 has more impact strength and higher hardness compared to No. 11, while elastic modulus and tensile strength of sample No. 11 is better than No. 12. According to both procedures, sample No. 9 was selected as the third choice. In other words, the first three samples are chosen based on the two methods and are the nanocomposite samples containing 1 wt% of MWCNTs. According to both TOPSIS and MOORA methods, samples containing 1.5 wt% of MWCNTs were found to be within the last ratings. Although by adding of 1.5 wt% of carbon nanotubes there will be an increase in hardness, tensile strength, and elastic modulus, due

Criteria alternative	Tensile strength MPa	Elastic modulus MPa	Impact strength kJ/m ²	Hardness RM	Cost \$/kg
1	31.49	1385.89	329.93	70.40	4.12
2	38.76	1386.48	239.79	73.27	4.12
3	39.93	1393.21	329.93	73.43	4.12
4	38.83	1322.62	263.36	72.83	4.12
5	42.30	1515.42	241.26	71.67	15.90
6	49.76	1524.48	263.36	70.83	15.90
7	43.40	1742.46	267.41	78.13	15.90
8	41.69	1640.41	232.17	82.33	15.90
9	48.51	2098.56	187.55	77.80	27.68
10	45.85	2033.64	175.52	83.20	27.68
11	52.66	2169.77	203.78	82.60	27.68
12	47.95	2140.67	238.04	82.83	27.68
13	38.15	1801.41	187.55	82.27	39.46
14	37.82	1866.35	187.55	82.37	39.46
15	40.99	1908.45	139.72	83.53	39.46
16	48.21	1858.96	163.92	85.30	39.46

Table 5. Decision matrix

to the reduced impact strength and increased cost, use of carbon nanotubes in high percentages is not affordable.

5 Conclusions

A multi-criteria decision making (MCDM) analysis was conducted on PA6 nanocomposites that were reinforced with multi-walled carbon nanotubes (MWCNTs). The mechanical tests including tensile, impact and hardness were done on

the nanocomposite samples. The results showed that tensile and hardness properties increased by the addition of MWCNTs while the impact strength decreased. Different MCDM methods were used for the decision problem of the polymeric nanocomposite. Samples containing 1 wt% of MWCNTs were chosen as the best specimens. The MCDM results showed that more addition of MWCNTs had a negative effect due to the decrease of impact strength and an increase of cost of materials.

Sample	Tensile strength	Elastic modulus	Impact strength	Hardness	Cost
1	0.1821	0.1969	0.3520	0.2243	0.0405
2	0.2242	0.1970	0.2558	0.2334	0.0405
3	0.2309	0.1979	0.3520	0.2339	0.0405
4	0.2246	0.1879	0.2810	0.2320	0.0405
5	0.2446	0.2153	0.2574	0.2283	0.1561
6	0.2878	0.2166	0.2810	0.2257	0.1561
7	0.2510	0.2476	0.2853	0.2489	0.1561
8	0.2411	0.2331	0.2477	0.2623	0.1561
9	0.2805	0.2982	0.2001	0.2479	0.2718
10	0.2652	0.2889	0.1873	0.2651	0.2718
11	0.3045	0.3083	0.2174	0.2632	0.2718
12	0.2773	0.3041	0.2540	0.2639	0.2718
13	0.2206	0.2559	0.2001	0.2621	0.3875
14	0.2187	0.2652	0.2001	0.2624	0.3875
15	0.2370	0.2712	0.1491	0.2661	0.3875
16	0.2788	0.2641	0.1749	0.2718	0.3875

Table 6. Normalized decision matrix (yij)

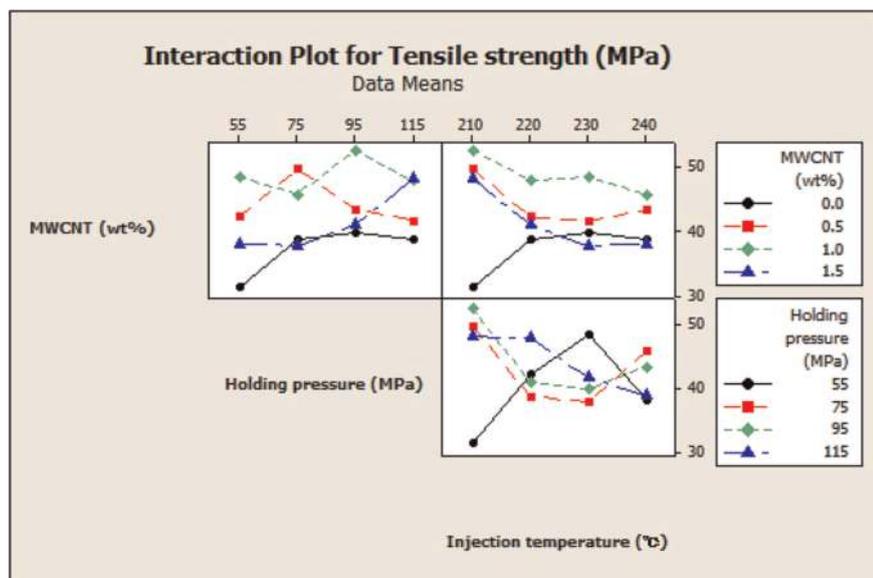


Fig. 3. Interaction of parameters plot for tensile strength

Sample	Rank	
	TOPSIS	MOORA
1	10	11
2	13	13
3	7	6
4	12	12
5	11	10
6	5	5
7	4	4
8	9	8
9	3	3
10	6	7
11	2	1
12	1	2
13	16	16
14	15	14
15	14	15
16	8	9

Table 7. Alternative ranking using TOPSIS and MOORA methods

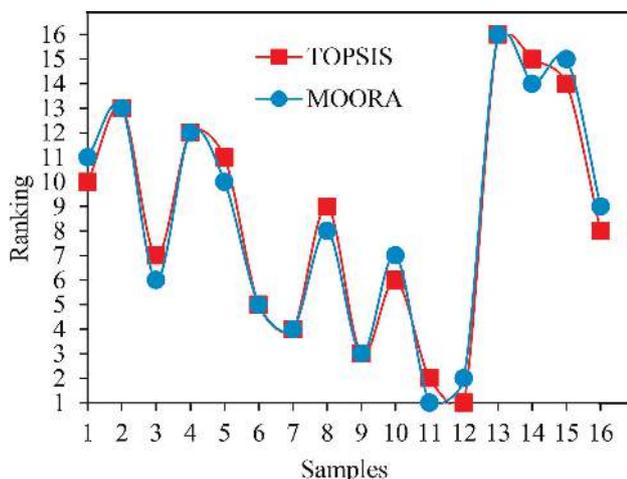


Fig. 4. Ranking results of TOPSIS and MOORA methods

References

- Althuwaynee, O. F., Pradhan, B., Park, H. J. and Lee, J. H., "A Novel Ensemble Bivariate Statistical Evidential Belief Function with Knowledge-Based Analytical Hierarchy Process and Multivariate Statistical Logistic Regression for Landslide Susceptibility Mapping", *Catena*, **114**, 21–36 (2014), DOI:10.1016/j.catena.2013.10.011
- Ambuken, P., Stretz, H., Koo, J., Lee, J. and Trejo, R., "Chapter 2 High-Temperature Flammability and Mechanical Properties of Thermoplastic Polyurethane Nanocomposites, in *Fire and Polymers VI: New Advances in Flame Retardant Chemistry and Science*, Oxford University Press, Oxford, p. 343–360 (2012)
- Ambuken, P. V., Stretz, H. A., Koo, J. H., Messman, J. M. and Wong, D., "Effect of Addition of Montmorillonite and Carbon Nanotubes on a Thermoplastic Polyurethane: High Temperature Thermomechanical Properties", *Polym. Degrad. Stab.*, **102**, 160–169 (2014), DOI:10.1016/j.polymdegradstab.2014.01.017
- Boholm, M., Arvidsson, R., "A Definition Framework for the Terms Nanomaterial and Nanoparticle", *Nanoethics*, **10**, 25–40 (2016), DOI:10.1007/s11569-015-0249-7
- Çalışkan, H., Kurşuncu, B., Kurbanoglu, C. and Güven, Ş. Y., "Material Selection for the Tool Holder Working under Hard Milling Conditions Using Different Multi Criteria Decision Making Methods", *Mater. Des.*, **45**, 473–479 (2013), DOI:10.1016/j.matdes.2012.09.042
- Ghanbari, D., Salavati-Niasari, M., Karimzadeh, S. and Gholamrezaei, S., "Hydrothermal Synthesis of Bi₂S₃ Nanostructures and ABS-Based Polymeric Nanocomposite", *J. Nanostructures*, **4**, 227–232 (2014)
- Görener, A., Dincer, H. and Hacıoglu, U., "Application of Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) Method for Bank Branch Location Selection", *International Journal of Finance & Banking Studies* (2147–4486), **2**, 41–52 (2016)
- Govindan, K., Rajendran, S., Sarkis, J. and Murugesan, P., "Multi Criteria Decision Making Approaches for Green Supplier Evaluation and Selection: A Literature Review", *J. Cleaner Prod.*, **98**, 66–83 (2015), DOI:10.1016/j.jclepro.2013.06.046
- Karaman, S., Toker, Ö. S., Yüksel, F., Çam, M., Kayacier, A. and Dogan, M., "Physicochemical, Bioactive, and Sensory Properties of Persimmon-Based Ice Cream: Technique for Order Preference by Similarity to Ideal Solution to Determine Optimum Concentration", *J. Dairy Sci.*, **97**, Pp. 97–110 (2014), PMID:24268400; DOI:10.3168/jds.2013-7111
- Kayastha, P., Dhital, M. R. and De Smedt, F., "Application of the Analytical Hierarchy Process (AHP) for Landslide Susceptibility Mapping: A Case Study from the Tinau Watershed, West Nepal", *Computers & Geosciences*, **52**, 398–408 (2013), DOI:10.1016/j.cageo.2012.11.003
- Kumar, S. K., Jouault, N., Benicewicz, B. and Neely, T., "Nanocomposites with Polymer Grafted Nanoparticles", *Macromolecules*, **46**, 199–3214 (2013), DOI:10.1021/ma4001385
- Liu, M., Jia, Z., Jia, D. and Zhou, C., "Recent Advance in Research on Halloysite Nanotubes-Polymer Nanocomposite", *Prog. Polym. Sci.*, **39**, 1498–1525 (2014), DOI:10.1016/j.progpolymsci.2014.04.004
- Lu, H., Yao, Y., Huang, W. M., Leng, J. and Hui, D., "Significantly Improving Infrared Light-Induced Shape Recovery Behavior of Shape Memory Polymeric Nanocomposite via a Synergistic Effect of Carbon Nanotube and Boron Nitride", *Composites Part B*, **62**, 256–261 (2014), DOI:10.1016/j.compositesb.2014.03.007
- Mansor, M. R., Sapuan, S. M., Zainudin, E. S., Nuraini, A. A. and Hambali, A., "Hybrid Natural and Glass Fibers Reinforced Polymer Composites Material Selection Using Analytical Hierarchy Process for Automotive Brake Lever Design", *Mater. Des.*, **51**, 484–492 (2013), DOI:10.1016/j.matdes.2013.04.072
- Mardani, A., Jusoh, A., Zavadskas, E. K., Cavallaro, F. and Khalifah, Z., "Sustainable and Renewable Energy: An Overview of the Application of Multiple Criteria Decision Making Techniques and Approaches", *Sustainability*, **7**, 13947–13984 (2015), DOI:10.3390/su71013947
- Navidfar, A., Azdast, T. and Karimzad Ghavidel, A., "Influence of Processing Condition and Carbon Nanotube on Mechanical Properties of Injection Molded Multi-Walled Carbon Nanotube/Poly(methylmethacrylate) Nanocomposites", *J. Appl. Polym. Sci.*, **133**, 43738 (2016), DOI:10.1002/app.43738
- Rashahmadi, S., Hasanzadeh, R. and Mosalman, S., "Improving of Mechanical Properties of Poly Methyl Methacrylate Nanocomposites for Dentistry Applications Reinforced with Different Nanoparticles", *Polym. Plast. Technol. Eng.*, **56**, 1730–1740 (2017), DOI:10.1080/03602559.2017.1289402
- Starkova, O., Buschhorn, S. T., Mannov, E., Schulte, K. and Aniskevich, A., "Creep and Recovery of Epoxy/MWCNT Nanocomposites", *Composites Part A*, **43**, 1212–1218 (2012), DOI:10.1016/j.compositesa.2012.03.015
- Ward, I. M., Sweeney, J.: *Mechanical Properties of Solid Polymers*. John Wiley & Sons, New Jersey (2012)

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Bibliography
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