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Estimating Optimal Combination Of Palm Oil Fuel ASH In Kaolin As Landfill Linner Using Statistical Experimental Design Approach

Mohd.Badruddin Bin Mohd. Yusof[1,*],OyelekeRaifu Brown[1, 2], Binta Abdu Umar[2]

[1]Department of Environmental Engineering, Faculty of Civil Engineering, UniversitiTeknologi Malaysia, 81310, Skudai, Johor Malaysia.
[2]Department of Civil Engineering, Kaduna Polytechnic, Kaduna, Nigeria
*Corresponding Author. Tel.: +6016-9681963
E-mail: mbadruddin@utm.my

Abstract

The optimization level of ground palm oil fuel ash combined with industrial kaolin clay for sanitary earthen landfill liner design was investigated. Corresponding effect of % palm oil fuel ash (POFA) dosage level on two critical compaction parameters; optimum moisture contents [ω_{opt}] and [ρ_{dmax}] was examined. Optimization process was performed using one-factor-at-a-time [OFAT] response methodology. The relationships between the responses of interest, [ω_{opt}] and [ρ_{dmax}] with respect to % POFA dosage level, as single variable factor was determined. Invoking Analysis of Variance [ANOVA] on response data in Design-Expert software reports that outcome of both parameters are statistically significant at 99% confidence level. An optimal % POFA dosage level of approximately 14% was achieved using the one variable at time graphical response method and MATLAB programming software.

Keywords: Kaolin clay; POFA; earthen landfill liner; optimisation; statistical experimental design

1. Introduction

A common technique adapted for the improvement of earthen landfill liner material is mechanical stabilization. The technique involves compacting remoulded geo-material in lifts, at specified density and moisture content. However, the effectiveness of earthen liner material prior to compaction may further be improved through structural modification of its constituted material-particles. Modification process may be in the form of introducing additives, and usually play the role of filler or binding agent; where candidate liner material is further structurally improved, and hydraulic conductivity reduced. In the same vein, the process enhances the uptake capacity of toxic ions of heavy metals, when used as co-sorbent in the design of earthen landfill liner (Olayinka*et al.,* 2007).

Many research have been published on the use on natural geo-sorbents as additives (Tanit*et al.,* 2009;Du *et al.,* 2009; Tanit*et al.,* 2008; Alexandre*et al.,* 2008; Serap*et al.,* 2007; Leton and Omotosho, 2004), and processed soils (Fall *et al.,* 2009;

Hyang-Sig and Jo, 2009; Anel and Shimaoka, 2008; Madalena*et al.*,2006; Reyad, 2005), for the removal of toxic metal ions present in wastewater. Other published works dwelled on the re-use of plant-based bio-residues as chemical additives (Nuntachai*et al.*, 2009a; Rejini*et al.*, 2009; Nuntachai*et al.*, 2009b; Chindaprasirt and Rukzon, 2008; Ganesan*et al.*, 2008; Vanchai *et al.*, 2007).

The interest of this paper is channelled toward using statistical experimental designapproach in estimating the optimal percentage of palm oil fuel ash (POFA) dosage. The level signifies quantity of the ash required to adequately combine with fixed dry mass of processed kaolin to achieve optimal compaction as sanitary landfill liner material. The approach is used for objective decision making on laboratory-based data generation that are subjected to experimental errors (Douglas, 2009; Shweta*et al.*, 2009; DidiDwi and Istadi, 2008;Kwanchai and Arturo, 1984). The two fundamental strategic processes to experimental problem are implored in the study; dwell on the planning and conducting research experiment(Douglas, 2009;Kwanchai and Arturo, 1984).

In this research, since processed POFA has been chosen as the only input variable, traditional one-factor-at-a-time [OFAT] experimental strategy was adapted as the most expedient methodology. This is because, no other factor has been considered as possible interacting input variable. In addition, kaolin was treated as held-constant factor, following the geotechnical procedures for determination of the moisture-density relationship of a given compacted soil sample. Also, a region of interest was kept at a broad range of 0 – 30 % over which POFA (design factor) was varied, and to make the dosage level relatively acceptable for geo-environmental use. In addition, Design-Expert software [*version: DX 8.0.4*] was used for all statistical analysis, while MATLAB programming language [*version: R2009b*] was coded and implored in plotting the maximum dry density, ρ_{dmax} versus optimum moisture content, ω_{opt} interaction curves. The curves were later used as decision making tool; in the estimation and graphically locating the optimal % POFA dosage. This ash dose will be considered adequate for effective mix with kaolin prior to compaction, for the design of sanitary landfill liner.

2. Materials and methods

2.1 Preparation of Materials Used

In this investigation, the strategy of experimentation commenced from the shipment of the POFA from the waste repository of a modern palm oil processing mill at Kota Tinggi, Johor State of Malaysia peninsular. The mill utilises two boiler systems for oil milling operations. Both boilers are co-fired with pressed palm mesocarp fibre [PMF] and palm kernel shell [PKS], for the generation of electric power as well as steam energy. **Plate 1** shows heap of processed PMF after palm oil has been pressed from ripe bunch fruits. The second, **Plate 2** depicts firing of both PMF and PKS after been fed into the boiler, while **Plate 3** is a heap of raw POFA, as solid waste material ready for disposal to a landfill.

The initial pre-treatment exercise, of all the raw ash shipments include sun drying and subsequently sieving via ENDECOTTS automatic mechanical test sieve shaker. Prior to sieving, the appearance of the sundried ashes was black in colour, after which it changes to greyish colour. The observed gray colour signifies the removal of all impurities and un-burnt carbon present in the dry ash (Weerachart*et al.*, 2009). All batches of sieved ash were subjected to two stages of grinding mill systems, via the Los Angeles Abrasion machine and bench top Pulverisette 6 mechanical grinder, respectively. For each grinding process, the quantity of the ash was kept constant. This is to avoid introducing systematic bias and other extraneous factor errors into the experimental results (Douglas, 2009;Kwanchai and Arturo, 1984). Average particle size of the ground ash was determined using a bench-top particle size analyzer(PSA-CILAS 1180).



Plate 1 Heap of processed PMF**Plate2** Firing PMF and PKS**Plate3** Heap of raw POFA

On the order hand, the industrial kaolin clay (refined) used for the research was produced by GYMTECH FEEDMILL (Malacca) SDN.BHD. The shipments were also made by Tai Tak Oil Mill Kota Tinggi, Johor state Malaysia. Principal activity of the kaolin clay company includes the manufacturing of varieties and different grades of livestock feeds. Major constituted ingredient in the feed mill includes kaolin clay; the feeds are marketed under in-house brand name, "GT".

2.2 Experimental Design Hypothesis

Hypothesis testing allows the comparison of the two formulations to be made on objective terms, with knowledge of the risk associated with reaching the wrong conclusion (Douglas, 2009; Kwanchai and Arturo, 1984). The research performed experimental exercise to investigate if increase in % POFA dosage level will result in corresponding increase in optimum moisture content (ω_{opt}) and maximum dry density (ρ_{dmax}) of kaolin clay as geo-liner material.

2.3 Formulating Earthen Landfill Liner Material Using One-Factor-at-a-Time Design Approach

In the investigation, OFAT experimental design approach was adapted, for estimating optimal combination of compacted palm oil fuel ash and kaolin clay as landfill liner (Shweta*et al.*,2009). The design involvesstudying the effect of POFA (independent variable) on two soil parameters; $\omega_{opt}$and ρ_{dmax} of compacted kaolin clay-POFA mixtures. Two extreme levels of the ash was initially assumed, where the control experimental condition (0 % POFA) was chosen as lower extreme case, while

30 % POFA dosage level as upper case. The research assigned 0, 10, 20 and 30 % POFA levels as suitable treatment combination when the ash is pre-mixed with 2500 g of kaolin clay. Equal replication (3 nos.) of Standard Proctor compaction test was performed on each liner material formulation. The process enables the research to investigate the effect of POFA (main factor) on compaction of kaolin clay and come out with objective decision on optimal combination of both materials.

2.3.1 Blocking of Materials

A block is a set of relatively homogeneous experimental conditions, having small variability within and large variability between treatment conditions (Douglas, 2009). The experimental design technique may be utilized for the improvement in the precision of comparison among the factors of interest. The technique may as well be used in reducing or complete elimination of variability transmitted from nuisance factors. The factors may influence the experimental response but are not directly considered of interest. Thus, in the landfill liner material design, two batches (shipment) of raw POFA where processed (dried, sieved and pulverized), and adequately quantity stored to perform all the required experimental runs. Variability between each treatment processed POFA (physico-chemical composition) was eliminated through blocking technique. The technique involves complete homogenization of the two batches of fine ground POFA, to produce a newly designed block of relatively homogeneous POFA. The final homogeneous ash was used as admixture in kaolin clay. In addition, adequate quantity of the shipped kaolin clay was empty in plastic-bags, thoroughly mixed within to form a completely new block of relatively homogeneous clay for the experiment. Finally, each test coupon (Kaolin-POFA combination at varying % POFA dosage level) was thoroughly and adequately mixed prior to proportionate sharing into three test coupons for replication of compaction test.

2.3.2 Replication of Factor Combinations

Replication of each factor combination is an experimental design technique which allows for estimation of experimental error. Estimating experimental error is a basic unit of measurement for determination whether observed defences in the data are really statistically different(Douglas, 2009; Kwanchai and Arturo, 1984). Also, where sample mean ($\bar{Y}$) is applied in estimating the true mean response for a factor level in laboratory-based experiment, replication allows the experiment to obtain a more precise estimate of the parameter. In addition, without replication, there is no way of knowing why two observations are different; hence, the technique reflects sources of variability within a run. In the investigation, independent repetition of the kaolin clay as control specimen, and each modified formulation of the clay admixed with POFA at each dosage level was performed, to obtain 3 different package of each tests coupon. Table 1 presents the replication pattern of all the liner specimens (Col.3).

Table 1 Replication Pattern and Randomized Layout of The Standard Proctor Compaction Experiment

Standard order	*Standard replicate order*	*Independent replicate order*	*Randomized Run order*	*Block Day$_{(i)}$*
1	KP_{00-1}	2	3	Day 3
2	KP_{00-2}	1	2	Day 2
3	KP_{00-3}	3	12	Day 12
4	KP_{10-1}	2	7	Day 7
5	KP_{10-2}	3	9	Day 9
6	KP_{10-3}	1	4	Day 4
7	KP_{20-1}	2	6	Day 6
8	KP_{20-2}	3	8	Day 8
9	KP_{20-3}	1	5	Day 5
10	KP_{30-1}	3	11	Day 11
11	KP_{30-2}	2	10	Day 10
12	KP_{30-3}	1	1	Day 1

2.3.4 Randomization of Test Coupons

Research materials and individual experiment trial randomization are critical activities in the use of statistical methods of experimental design. Proper statistical randomization of test coupons may results in both the observations and expected errors to be independently distributed as random variables. The technique may also assists in “averaging out” the effects of extraneous factors that may be present (Douglas, 2009; Kwanchai and Arturo, 1984). In addition, randomly allocating each experimental trail may alleviate introduction of systematic bias into the experimental results. In the investigation, the allocation of both kaolin clay and POFA (experimental materials), and the order in which the individual compaction-run of the experiment was performed are randomly determined. Proper randomization of the experiment was generated through the complete randomized design method [CRD], a non-replacement, and mutually exclusive sampling technique. The CRD exercise was performed by drawing from a lot (rolling approximately equal size 12 nos. pieces of papers). Each paper has nomenclature of each test coupon written on it prior to uniformly fold. All the folded papers were placed in a dark polythene bag, and thoroughly mixed. Each rolled paper has equal chance of been picked at random, from the pool without replacement. Each draw signifies the treatment order (compaction-run) of the test sample whose nomenclature appeared (already tagged on each sample container). Table 1 also shows the randomized layout of the Standard Proctor compaction experiment (Col. 4), as sequentially performed. Column 2 depicts the control and the 3 % POFA dosage levels used in the experiment.

2.3.5 Blocking of Test Coupons, Compaction Mould and Hammer Weight

For the purposes of the traditional one-factor-at-a-time experiment adapted, the processed kaolin clay and compaction energy adapted were chosen as the held-constant factors, thus assumed not of interest. However, both variablesmay exert some effect on the response parameters (ω_{opt}andρ_{dmax}). For the compaction test, kaolion clay was held at 2500g dry mass, while compaction of all kaolin clay-POFA mixtures were performed at same energy level; using the 2.5 kg Standard Proctor hammer and 1 Ltr.compaction mould all through the test period(12 days). Compaction procedure was carried out in accordance as specified by BS 1377: Part 4 (BSI, 1990)

Grain particles from the liner materials are assumed susceptible to crushing during compaction; hence, replicate specimen from each control sample at all the 3 % POFA treatment levels, were subjected to nine-point incremental moisture contents. In order to allow individual soil particle of the liner matrix attain state of complete mellowing and moisture homogeneity, each test coupon was placed in an airtight plastic bag for 24 h. Geometrically, all the nine observations from both replicated control specimen and modified formulations were used as data points for compaction curve. From each curve, maximum dry density (ρ_{dmax}) and optimum moisture content (ω_{opt}) was obtained through the use of MATLAB programming language. True mean value of ρ_{dmax} and $\omega_{opt}$was then obtained from each peak of compaction curve with respect to treatment level. The average ω_{opt} and ρ_{dmax} data from the experiment are shown in Table 2.

Table 2 Mean MDD and OMC Value of Kaolin Clay-POFA From Each Treatment Condition

Kaolin-POFA reconstituted	**Kaolin clay**	**Kaolin clay + 10% POFA**	**Kaolin clay + 20% POFA**	**Kaolin clay + 30% POFA**
Identification symbol (treatment level)	KP_{00}	KP_{10}	KP_{20}	KP_{30}
Mean OMC, ω_{opt} (%)	29.07	29.40	30.22	32.61
Mean MDD, ρ_{dmax} (Mg/m^3)	1.275	1.266	1.255	1.252

3.0 Discussion of Results

3.1 Average Value of Response Parameters

Some degree of variability was observed in the measured response parameters within replicate test coupon of each % POFA dose. This show there is fluctuation, or nose (experimental error) in the compaction processes, and also implies the response parameters are of random variable (Douglas, 2009). Hence, average values of response parameters are presented, as shown inTable 2. Examining the Table shows what seems to be modest amount of variability between the recorded average values of the ω_{opt} and ρ_{dmax}among the different kaolin-POFA mixtures. The impression is supported by slight variability observed in the range of average value between each liner formulation. Perhaps the observed difference in the result is due to minimal stepwise dosage level of % POFA adapted in formulating each test condition.

3.2 Response of Optimum Moisture Content (ω_{opt}) to % POFA Dosage Level

Graphical analysis of the variation in optimum moisture content (ω_{opt}), as one of the response variable of interest versus POFA dosage level is shown in Figure 1. From Figure 1, it can be seen that, there is a gradual increase in average moisture contents, ω_{opt} as percentage dose of ground POFA increases. Gentle steepness of 0.75 % was observed between 0 to 20 % POFA modified level. Explanation for this may be that, control test coupon and the two subsequent modified formulations (10 and 20 % POFA) moderately differ in their mean ω_{opt} .

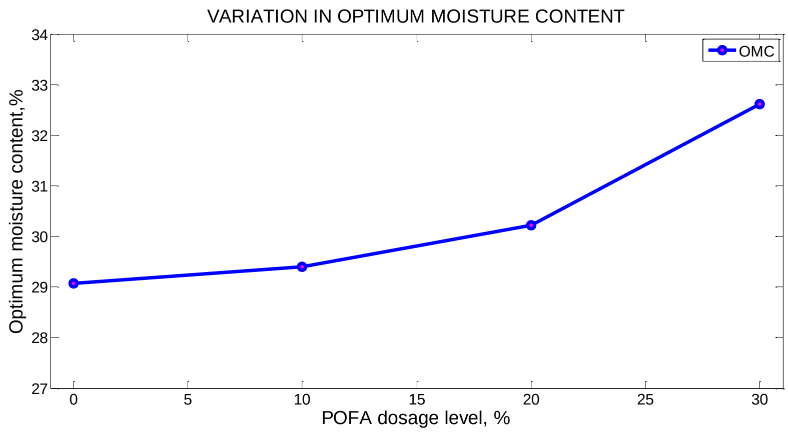

Figure 1 Response of optimum moisture content (ω_{opt}) to % POFA dosage level

However, % POFA dosage level above 20 % to 30 % (maximum region of interst) produced a steep gradient of 24 %; an indication of significant change in ω_{opt}. Strong explantion for the possitive steep gradient may be due to crowdingout effect experienced from higher concentration of calcium ions released from the fine POFA during ionic dissociation of hydrolyzed calcium oxide in the ash (Oyeleke*et al.*, 2011a,b; O'Flaherty, 1976). In addition, there may be high possibility for the initiation of pozzolanic reaction between dissociated calcium ions (Ca^{2+}) from hydrate CaO in the POFA chemically reacting with silica ions (Si^{4+}) from silicaoxides,SiO_2, released from the kaolin clay and fine POFA (Oyeleke*et al.*, 2011a,b ; Weerachart*et al.*, 2009;Deepa*et al.*, 2006). Both chemical reaction processes usually results in moisture content increase in pore spaces of clay medium after agglomeration of colloidal clay particles. Thus, increase in optimum moisture content ω_{opt} at relatively higher % POFA dose. The increase in$\omega_{opt}$is detrimental to the design of earthen landfill liner material. By this explanation, it may be generally said that sanitary landfill liners having high ω_{opt} are liable to high hydraulic conductivity, low retardation factor and low diffusion coefficient (Tanit*et al.*, 2009). The overall effect result to low effcient landfill liner system, resulting from high contaminant transport in the fill. Toxic ions of heavy metals are obviously paranoid to natural groundwater contamination. Hence, the need to introduce optimazation technique, in determining optimal level of % POFA dosage level that will minimise the optmum moisture content level.Invoking Analysis of Variance (ANOVA) on response data, using Design-Expert reveal that ω_{opt} is statistically significant at 99 % confidence level.

3.3 Response of Maximum Dry Density (ρ_{dmax}) to % POFA Dosage Level

Maximium dry density (ρ_{dmax}), is the most influentialparameter on hydraulic conductivity of geo-materials. Figure 2 reveals in graphical presentation the variability of maximum dry density,ρ_{dmax},as the second response variable of interest, within the region of interest of % POFA (0 – 30 %). As can be seen, average maximum dry density$\rho_{dmax}$of the test coupons gradually decreases as % fine POFA treatment level increases. The graph also shows that no significant differences were observed in the average ρ_{dmax} of the four test coupons. This may be explained by the steady decline orientation observed in the in the plot. Strong explanation for the experienced negative slope trend in ρ_{dmax} may be due to ingress of moisture into the connected pore spaces formed in the soil, during flocculation reaction. The introduction of water into pore spaces in soils usually leads to particle buoyancy, hence reduction in material weight (O'Flaherty, 1976), and corresponding decrease in dry density of the material.

Also, agglomeration process of calcium oxide (CaO) from the ground POFAresult in further increase in liner pore volume, which simultaneously, give rise to increase in pore moisture in the presence of leachate generated in the landfill (O'Flaherty, 1976). Supportive explanation for the downward orientation of the graph is the initiation of pozzolinic reaction as explained in section 3.2 above. One of the detrimental effects of moisture ingress in pore spaces of compacted geo-material pre-mixed with bio-related additives is material swelling(O'Flaherty, 1976). Low ρ_{dmax}materials are generally detrimental in compaction view point. Engineered earthen landfill liner constructed from such material are liable to perform dysfunctionally. Similar consequential effects are as well highlighted in section 3.2 above.

Hence, the need to introduce optimazation technique, in determining optimal level of % POFA dosage level that will maximize the maximum dry density level.Invoking Analysis of Variance (ANOVA) on response data, using Design-Expert also reports that ρ_{dmax} is statistically significant at 99 % confidence level.

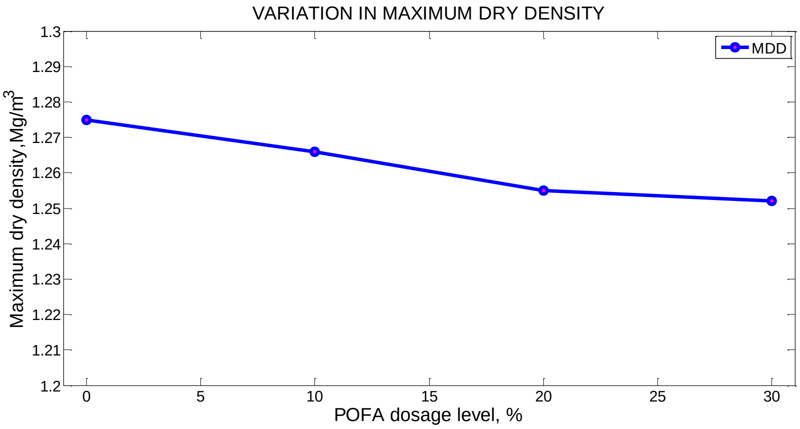

Figure 2 Response of maximum dry density (ρ_{dmax}) to % POFA dosage level

3.4 Estimating Optimal Combination of Compacted Palm Oil Fuel Ash and Kaolin Clay

The estimation of optimal % POFA dose as the most suitable fixation point when pre-mixed with kaolin clay and compacted for landfill liner use is eminent from the discussions in sections 3.2 and 3.3. Figure 3 aptly illustrates the trend ofparameters being investigated. That is, it depicts the interaction and the optimization region of % POFA dosage level (main factor). In the graph, lines of ω_{opt} and ρ_{dmax} with respect to various % POFA dosage levels are separately connected to form plots of both responses. These response curves connect data points ofω_{opt} versus % POFA and ρ_{dmax} versus % POFA respectively. The responses observed from the ω_{opt} /ρ_{dmax} interaction indicates that we may move in the general direction of increasing ρ_{dmax} and decreased ω_{opt} to optimize % POFA dose (right to left).

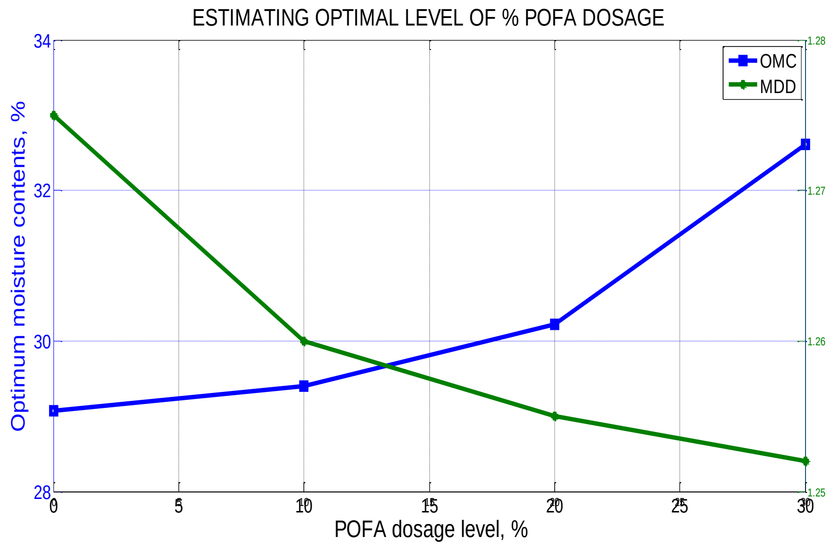

Figure 3 Interaction and the optimization region of % POFA dosage level

The result from the one-factor-at-a-time experiment indicates an estimated value of 13.75 % POFA dosage level (≈ 14 %) is best interaction point of both compaction parameters, which will produce qualitative earthen liner when the ash and clay are mixed together and compacted.

4. Conclusions

Conclusions that can be drawn based on responses of two critical compaction parameters (ω_{opt} and ρ_{dmax}) in kaolin clay pre-admixed with different % POFA dose, to produce optimal combination may be encapsulated as follows:

a) Pre-mixing of kaolin lay with POFA result in increase in the optimum moisture contents ω_{opt}, with a steep gradient recorded between 20 to 30% POFA, due to crowdingout effect experienced from higher concentration of calcium ions released from the fine POFA during ionic dissociation of hydrolyzed calcium oxide in the ash.
b) The ρ_{dmax} of kaolin clay slightly decreases with increase in POFA dosage, due to bouyancy effect experienced by the soil-matrix, as a result of water absorbed during cat ion exchange reaction, crowingout effect and initiation of pozzolanic reaction.
c) An estimated value of 14 % POFA dosage level dry mass of the kaolin clay is considered optimal for the composite earthen landfill liner design, given the 0 to 30 % dosage level region.
d) Estimating fixation point of palm oil fuel ash at optimal dosage level in engineered earthen landfill liner realization may result in earthen liner that is produced from the waste material and have enhanced field performance and

reliability, lower product cost, and at shorter product design and development time.

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