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STRUCTURAL AND DISCRETE ELEMENT ANALYSIS OF COAL MINE CONVEYOR SYSTEM

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Abstract: *The aim of this study is to determine the relationships between the operation speed and occurred stresses on the designed coal mine conveyor system. Coal mine system was designed using solid state modelling in CAD (Computer Aided Design) software. The loads caused from the granular material (coal) were calculated with DEM (Discrete Element Method) analysis. The structural analysis was applied to the system with Finite Element Analysis (FEA) Method in the Ansys Workbench Static Structural environment through the results from DEM analysis. The operation speeds of the system for the analysis were defined as 1, 2 and 4m/s. The loads were obtained as compressive forces from the DEM according to the velocity of the conveyor belt and these loads were applied to the conveyor in structural analysis. The occurred stresses on the structure were calculated as about 72, 96 and 118MPa for 1, 2 and 4m/s velocities, respectively. These results showed that the operation speed had a significant effect on the loads acting on the system and structure.*
Key words: *Coal Mine Conveyor, Discrete Element Method, Finite Element Analysis, Granular Material.*

1. INTRODUCTION

The traditional approach used for painted Coal is the non-renewable fossil fuel resource. Organically, coal consist primarily of carbon, hydrogen and oxygen with lesser amounts of sulfur and nitrogen [1]. It can be classified as thermal or metallurgical. Thermal is lower at the carbon content and calorific, higher at the moisture value. Coal is the most important fossil that primarily used to produce energy and also it is used in cement-making process. Metallurgical coal is used to production of coke that is an important part of the integrated steel mill process [2].
For mining machinery, design of each machine for production have been conducted by the industry with or without calculations and FEA-DEM analyses. This introduces the production of many prototypes, inefficient machines and broken sold products in-site. Additionally, this cost a lot to manufacturer, customer and the countries and the world in terms of technical, economic and environmental issues. In order to improve designs of mine machinery, it is important to apply DEM solutions to the engineering design process.

1.1.Coal Mining Methods

Coal mining methods can be categorized as surface and underground. Surface mining methods include area, contour, mountaintop removal, and auger mining. It can be used when the coal locates less than 60 meters below the surface [3]. Underground mining methods include drift, slope and shaft mining (Figure 1).

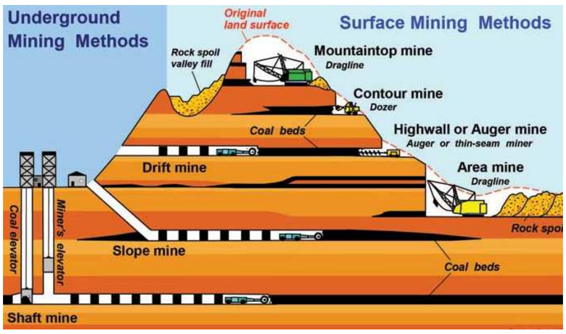


Fig. 1 Surface and underground mining methods [4]

These methods are used more than 150 meters depth. Furthermore, the deepest mine that uses underground mining methods ranged from between 2.4km to more than 3.9 km below the surface [5]. Today; Underground mining is the most common mining type. In the underground mines, two main methods named as room-and-pillar (Figure 2) and long wall are commonly used [6,7].

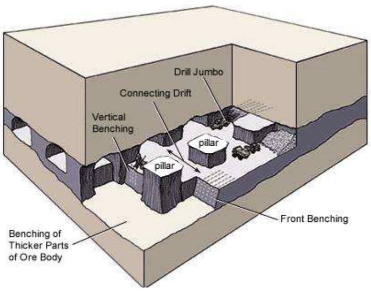


Fig. 2. Room and pillar method [8]

1.2.Conveyor Systems

Conveyor systems are systems to transport products one place to another within the desired specifications. These systems are commonly used in many industries such as mining, automotive, agricultural, computer, electronic, food processing, aerospace, pharmaceutical and packing.

Conveyor systems have several subsystems to make transportation. In the mining industry, pipe and belt type conveyors are the most commonly used [9].

Pipe conveyor is a modern transportation system to handle some problems caused from external influences

(climatic conditions and also spillage of material) [10]. It is a suitable method to transport materials contain small particles like powder or liquid (Figure 3).

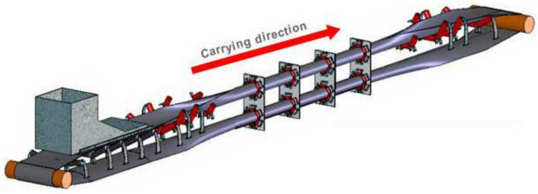


Fig. 3. Pipe conveyor

Belt conveyor system is a material handling method used in transportation of bulk materials. Many industries use this conveyor as it provides noiseless and high capacity working conditions. They can be used up to 20 degrees inclined slope. In the mining industry, belt conveyors are commonly used as it is suitable to transport the material from 3-4km depth. Belt conveyors are consisted of three pulleys two of them as the tail, and one as the head pulley to stretch the belt. Head pulley is driven by the actuator and rotates the conveyor belt. There are the rolls called as idlers to increase carrying capacity and reduce spillage. Take up pulley in the belt conveyor system is used to keep belt tension in the proper level [11]. The structure of the belt conveyor system is shown in Figure 4.

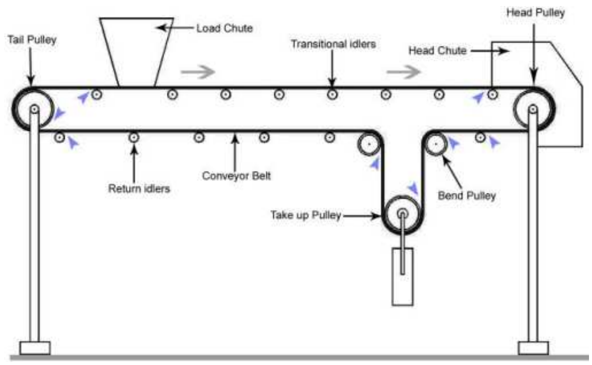


Fig. 4. The structure of conveyor belts system

1.3. Discrete Element Method

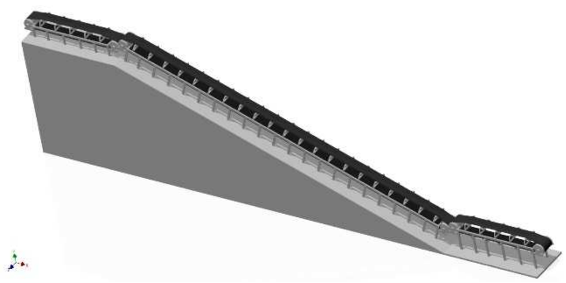
The discrete element method (DEM) is a method that mode sinter-particle forces based on elasticity parameters and on the overlap of unreformed particle shapes [12,13]. The penalty-method for finite element analysis (FEA) method in structural mechanics for contact dynamics simulations uses the overlap between finite element shapes in a similar way. The overlap between particles can be understood as the amount of deformation necessary that the particles could physically occupy the space in their actual configuration. Compared to a finite element method of deformable particles which need a discretization of the elastic particles, the discrete element method needs only the degrees of freedom which is necessary for rigid bodies: Three in two dimensions and six in three dimensions. For the accuracy, there are hardly any drawbacks, as the only additional information one could gain from the finite element method, internal stresses and strains, are

either not of interest, or unreliable due to the fact that the microscopic surface asperities will lead to random alterations of the FEA results [14].
Today, many computer-based tools are available to help design and analysis of the systems [15]. Solid modelling using CAD methods assists the designers to define the parts and assembly of the system and to utilize the geometry in applications such as simulation, analysis and prototyping. Virtual prototype simulations, static, kinematic, dynamic and thermal analyses can be conducted with CAE methods [16].
In this study, the relationship between the operation speed and the occurred stresses on the designed coal mine conveyor was analyzed with DEM and FEA methods. The forces act on the conveyor belt system were obtained through DEM and these forces were applied to get structural effect of the coal and operation speed.

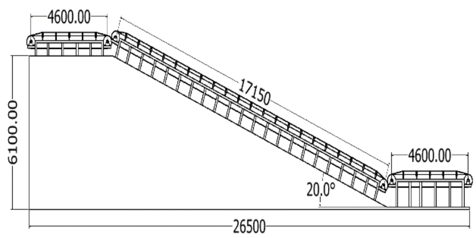
2. MATERIAL AND METHOD

2.1. Design of the Coal Mine Conveyor

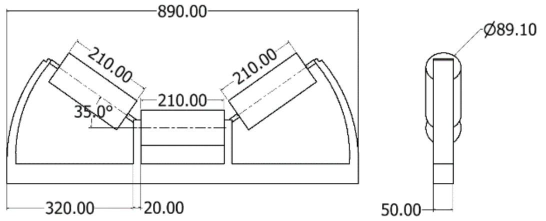
Coal mine conveyor was designed using CAD tools and parametric solid modelling technique (Figure 5). For the design Autodesk Inventor software was used. The assembly model was created to check some technical requirements such as dimensions and model compatibility. After the check, the details of the model were reduced for DEM and FEA analyses.



(a)



(b)



(c)

Fig. 5. Design of a conveyor a) Design view b) General dimensions c) Carrier idler dimensions

For the structural analyses, the materials of the carrier structure and the belt were defined as St 37 steel and rubber. The mechanical properties of them are given in Table 1.

Table 1: Mechanical Properties of materials [17]

	Value	
Parameters	**St 37**	**Rubber**
Yield-Tensile Strength (MPa)	315	145
Elastic Modulus (GPa)	200	650
Poisson's Ratio	0.3	0.5
Density (g/cm^3)	7.85	3.80

2.2. Discrete Element Analysis

In the DEM analysis; coal shape was designed as the combination of spherical particles (Figure 6). Coal was assumed as coarse coal and the size was defined larger than 25mm. The detailed coal properties for the analysis are given in Table 2.

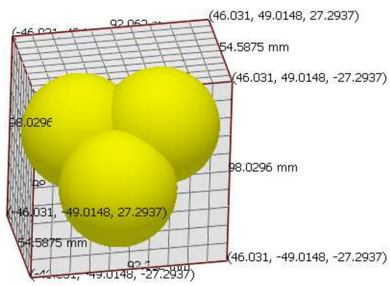


Fig. 6 Designed coarse coal

Table 2. Mechanical and frictional properties of coal [17]

Mechanical Properties	**Value**	
Solid density (g/cm^3)	315	
Shear Modulus (GPa)	200	
Friction Properties	**Coal-coal**	**Coal-steel**
Static friction coefficient	0.5	0.5
Rolling friction coefficient	0.01	0.01
Coefficient of Restitution	0.5	0.5

For the carrier geometry, all geometries were defined as St 37 steel. For the analysis; the belt operation speeds were defined as 1, 2 and 4m/s. The simulation was conducted for 60s time interval to create the realistic coal transportation process (Figure 7). Producing rate that provide the coal flow was also assumed as 500kg/s.

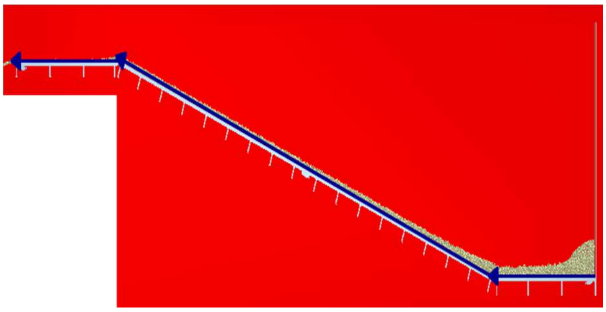


Fig. 7. Coal transportation process in DEM analysis

The compressive forces caused from the coal motion were obtained from the DEM analysis and these values were used as pressure and strength check of the structure in structural analysis.

2.3. Structural Analysis

Structural analysis was applied to structure of the designed coal mine conveyor system to find the critical region and to get the information about occurred stresses, strains and safety factors. Ansys Workbench Static Structural tool was used to conduct the analysis (Figure 8). The obtained force values from the DEM were applied as remote force to the surface of conveyor system to create the pressure.

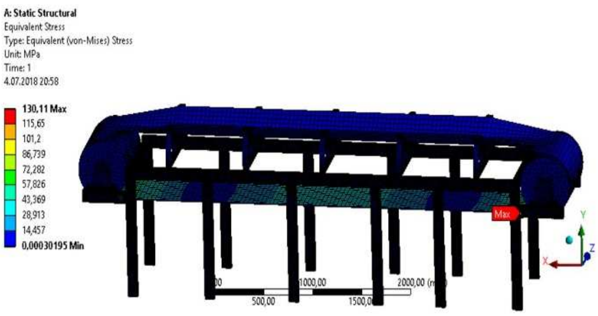


Fig. 8. Structural analysis

3. RESULTS AND DISCUSSION

3.1. DEM Analysis

The obtained DEM analysis results are given in Figure 9 and Table 3.

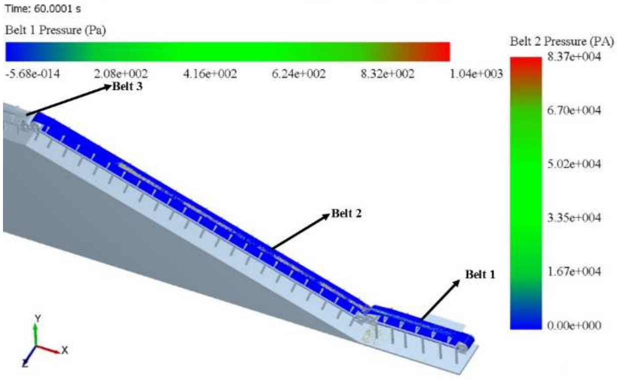


Fig. 9. DEM analysis results

Table 3.
Obtained force results for different operation speeds

Operation Speed (m/s)	Belt No	Compressive Force (N)
4	1	6,484
	2	4,904
	3	7,086
2	1	6,097
	2	4,468
	3	6,513
1	1	5,804
	2	4,159
	3	6,292

It was observed from the DEM analysis that operation speed had an important effect on the compressive forces. The maximum values were found as 7,086, 6,513 and 6,292N, respectively for the 4m/s operation speed.

3.2. Structural Analysis

The structural analysis results are presented in Figure 10 and Table 4.

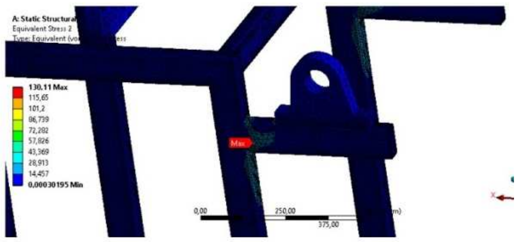


Fig. 10. Critical region

Table 4.
Results from structural analysis

Operation Speed (m/s)	Stress (MPa)	Strain (%)	Safety Factor

4	118	0.083	1.9
2	96	0.072	2.5
1	72	0.057	3.3

As given in the Table 4, maximum stresses and strains were obtained from 4m/s operation speed. The critical region was observed as pulley holder leg for each operation speed values. It was understood from the structural analysis that operation speed had a significant effect on the forces, stress, strain and factor of safety. Although the occurred stress on the critical region was found as 118MPa, the designed conveyor system was mechanically safe enough with the value of 1.9.

4. CONCLUSION

In this research, the relationship between the operation speed and occurred compressive forces, stress and strain values has been researched through applied DEM and FEA analyses. Findings from the results showed that:

1) The maximum value of compressive force was observed for 4m/s operation velocity.

2) The critical region was found as the pulley holder leg as it was expected. There were 4 connection places and dimension changes at this zone that caused to stress concentration.

3) The occurred maximum stresses on the structure were calculated as about 72, 96 and 118 MPa for 1, 2 and 4m/s velocities, respectively. These results showed that the operation speed had a significant effect on the loads that act on the system and structure.

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ANALIZA ELEMENTELOR STRUCTURALE ŞI DISCRETE ALE SISTEMULUI DE CONVEIERE A UNEI MINEI DE CĂRBUNI

Rezumat: Scopul acestui studiu este de a determina relațiile dintre viteza de operare și tensiunile apărute la sistemul de conveiere a minei de cărbune proiectate. Sistemul de mine de cărbune a fost proiectat folosind modelare solidă în software-ul CAD (Computer Aided Design). Sarcina produsă din materialul granular (cărbune) a fost calculată prin analiza DEM (Discrete Element Method). Analiza structurală a fost aplicată sistemului cu metoda de analiză a elementelor finite (FEA) în mediul structural Ansys Workbench Static, prin rezultatele analizei DEM. Vitezele de funcționare ale sistemului pentru analiză au fost definite ca 1, 2 și 4 m / s. Încărcările au fost obținute ca forțe de compresiune de la DEM în funcție de viteza benzii transportoare și aceste sarcini au fost aplicate pe transportor în analiza structurală. Tensiunile apărute pe structură au fost calculate ca aproximativ 72, 96 și 118MPa pentru viteze de 1, 2 și respectiv 4 m / s. Aceste rezultate au arătat că viteza de operare a avut un efect semnificativ asupra sarcinilor care acționează asupra sistemului și structurii.

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