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Structural and Thermal Analysis of Bolted joint of Coiler Drum in Steckel Mill using Finite Element Method

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Abstract—FEM is the method of choice in all types of analysis in structural mechanics i.e. solving for deformation and stresses in solid bodies or dynamics of structures. The most attractive feature of the FEM is its ability to handle complicated geometries and boundaries with relative ease. This paper presents the insight of stress analysis in a bolted joint of Coiler Drum in Steckel Mill under load and high temperature. Present work includes finite element approach to study the results of failure of bolted joint of Coiler Drum. A three-dimensional finite element model of a bolted joint has been developed using Pro-E wildfire 4.0 and analysis has been done in ANSYS 11 commercial package. Modeling of Flange joint is done and then Structural and transient thermal analysis has been performed. Results obtained after analysis was then articulated which show good agreement. Finally, critical areas were identified and confirmed with the stress distribution results from simulation. The FEA outputs, such as stress and strain (Deformation), can be used with failure criteria to predict failure.

Keywords—Flange joint, Bolts failure, load, High Temperature, Modeling, Structural Analysis and Transient thermal Analysis.

I. INTRODUCTION

The coiler-drum is an essential component of steckel mill reversing hot strip rolling process. A steckel mill produces hot rolled strip steel from cast slab which are heated before being converted via roughing to the transfer bar of which the thickness is subsequently reduced to the desired gauge by means of a reverse rolling process performed by the steckel mill. Coiler drums are located inside two steckel furnaces which are positioned on the both sides of the mill stand. As the strip thickness is reduced during each pass, length increases. In order to obtain high rolling speed and retain temperature, the strip is successively coiled and uncoiled, under tension onto and from the heated coiler drum during process [12]. Due to high temperature and load, the stresses are induced per cycle inside the bolt via flanges causes shearing of bolt head. Moreover, a bolted joint is one of the joining techniques employed to hold two or more parts together by the help of nut and bolt to form an assembly in mechanical structures [1]. The flange joint consist of two flanges joined with 10 Nut-bolts as shown in fig.2. It is a joint between coiler drum flange and on-board bearing flange and fastened with nuts and bolts. In the joint, one of the flange and head of bolts are having direct exposure to the high temperature maintained at 950^0c inside the Steckel Mill. This causes thermal stress into the flange and bolts. As bolts and flange are subjected to load of 22 tons, resulting into cyclic fatigue and shearing of bolt head and sometimes at the interface. Fig.3 gives clear idea of cross section of Steckel Mill. Kovács et al. [2] carried out an experimental study on the behavior of bolted composite joints. The composite base columns were investigated under cyclic loading. Su and Siu [3] analyzed the nonlinear response of a bolt group under in-plane loading using the numerical method. In order to predict the physical behaviors of the structure with a bolted joint, simulation with three dimensional finite element models is desirable. With the recent increase in computing power, three dimensional finite element modeling of a bolted joint in bending has become feasible. T. N. Chakherlou, M. J. Razavi, A. B. Aghdam [4] carried out the study of variation of bending force and its concomitant effects on the performance of bolted double lap joints subjected to longitudinal loading. The results unanimously revealed a gradual initial reduction of bending force followed by a significant increase as the longitudinal load was increased. Also affected, was the load transfer mechanism in the joint resulting in variation of friction force between the flanges, but in a different trend compared to bending forc*e.*

Maggi et al. [11] also demonstrated using the same software how variations of geometric characteristics in bolted end flange could change the connection. Investigation on failure of threaded fasteners due to vibration spans nearly sixty years. Sparling [5] found that the fatigue life of the bolt could be amplified appreciably by tapering the nut thread form for the first few engaged threads measured from the loaded face of the nut. It also stated that truncating the threads improved fatigue life but reduced the static load capacity. Nevertheless, experimental studies in the late 1960s by Junker [6] demonstrated that loosening and failure both becomes more rigorous when the joint is subjected to dynamic loads perpendicular to the thread axis (shear loading). The most extensively used apparatus for experimental study of loosening under dynamic shear load is the transverse vibration test apparatus developed by Junker [6].

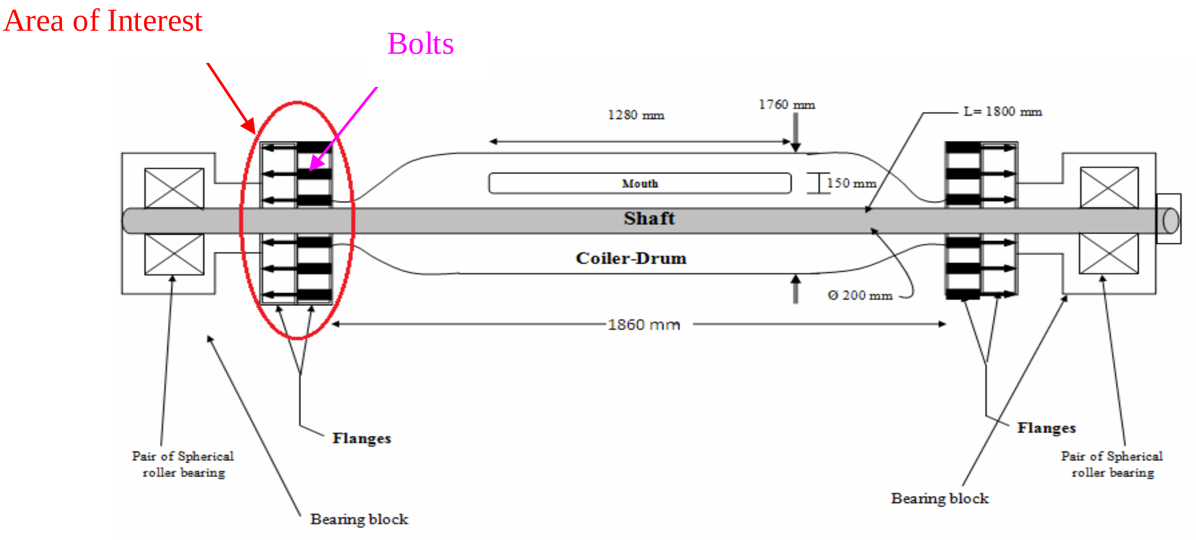

Fig.1. Coiler Drum and shaft assembly

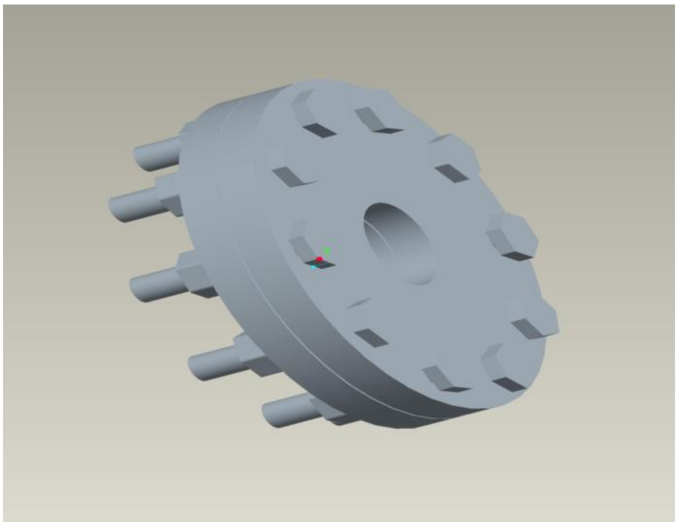

Fig.2. Bolted Flange joint

Bolts, apart from the load of preliminary tension (bending force) and torsion (if hydraulic or electric torque wrench is not applied), are subject to extra stretching or relieving, and Bending [7]. It was recently shown [8] that a fastener could turn loose under dynamic shear loading as a result of accumulation of localized slip in the form of strain at the fastener contacts surfaces. Krishnamurthy [9-10] was among the pioneers to perform analyses of extended and flush end-flange connections, which included elastic material behavior. Krishnamurthy et al. (1979) extended the earlier study to develop a two-dimensional plane stress FEM of bolted connection and conducted some physical tests to confirm the analyses. Gert J.M. Hamman [12] had experimentally investigated the Steckel Mill coiler drum failure mechanism (2006) in which the metallurgical properties of drum material had studied at different temperatures and loads.

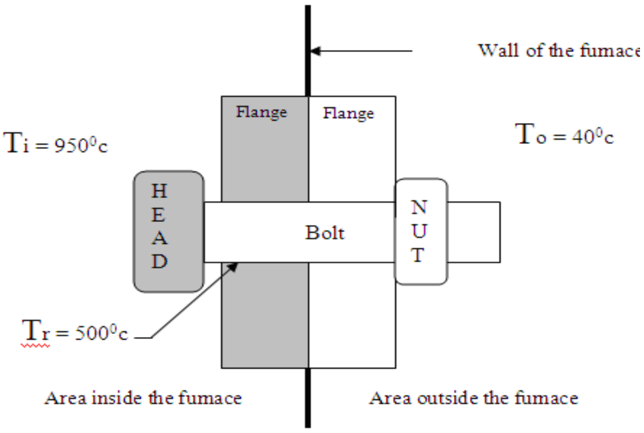

Fig.3. Cross section of Steckel furnace

II. GEOMETRIC MODELING

The front view of coiler drum and shaft assembly & specifications are shown in fig.1. The flange material properties used is based on SAE 6145 oil quenched and drawn 700^0c. The work for this study was carried out using the finite element method. In this work, Pro-E 4.0 modeling software is used for modeling of bolted joint as shown in fig.4. Finite element software program named ANSYS 11 was used for analysis of bolted flange joint. In simulation, the geometry scale factor is determined as 1,000 mm. The geometry of the model is based on two hollow circular flanges along with 10 bolts whose specifications are shown in table 1. The unit consisting of a bolt and a nut. The bolt hole of radius 36 mm is edited in the upper and lower flange.

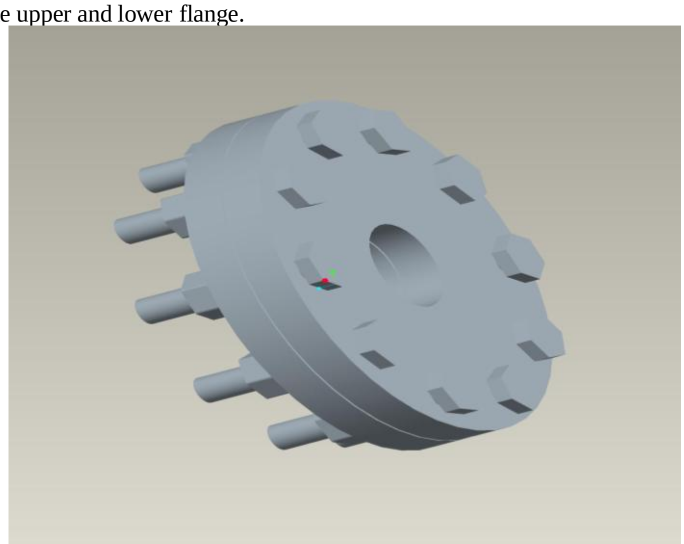

Fig.4. CAD Model of Flange joint

The diameter of the bolt shank is assumed to fully fit in the bolt hole. As illustrated, the position of origin is pointed by the arrow; direction represents the length of the flange, y direction represents the width of the flange, and z direction represents the thickness of the flange. The FE model of the test joint was developed using ANSYS 11, which is general-purpose finite element analysis software. A representative finite element mesh of the model used for the study is shown in Fig. 7. It consists of a Nut, which fastens the top flange through a threaded insert. The geometry is cut down to include only the key features of the structure. Since the base is assumed to be rigid, only a small region around the threaded insert is modeled, and the nodes on the external surface of this region are controlled.

Table No.1 Specification of Flange and bolt

Sr. No	Parameter	Value	Unit (SI)
1.	Thickness of Flange	50	mm
2.	Outer Diameter	600	mm
3.	Inner Diameter	150	mm
4.	No. of holes on flange	10	-
5.	Hole diameter	36	mm
6.	Type of Bolt	Hex. Headed	
7.	Size Of Bolt	M36	-
8.	Pitch	4	mm
9.	Length	200	mm
10.	Threaded length	125	Mm

III. MESH GENERATION

The complete assembly to be analyzed is divided into number of smaller parts or elements. The elements are non -overlapping and are connected with each other through nodes. The finite element mesh used in this study utilizes a mainly tetrahedral mesh, which provides good fallout within a levelheaded runtime. The element used on the bolt and flange is the same with SOLID 186 type Tetrahedral. The total elements in the model are 4521 and the numbers of nodes are 19,307. The mesh model & the position of origin shown in fig.7 is pointed by the arrow; direction represents the length of the flange, y direction represents the width of the flange, and z direction represents the thickness of the flange.

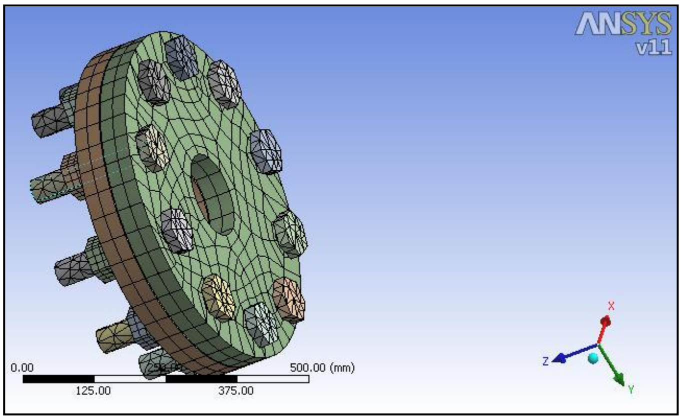

Fig.7. Mesh Model of Flange joint

IV. BOUNDRY CONDITION AND LOADING

The boundary conditions for the bolted joint are decided by selecting nodes as shown in Fig.8. The flange is in rotation about its own axis with the magnitude of 3.7 rad/s. Maximum load 22 tons is applied to the inner diameter where the load of shaft is transferred on the flanges (Pressure = 466 Mpa). The support is fixed at the bolts as shown in fig.8.These nodes are constrained by fixing the degrees of freedom; translations are in x, y, and z directions.

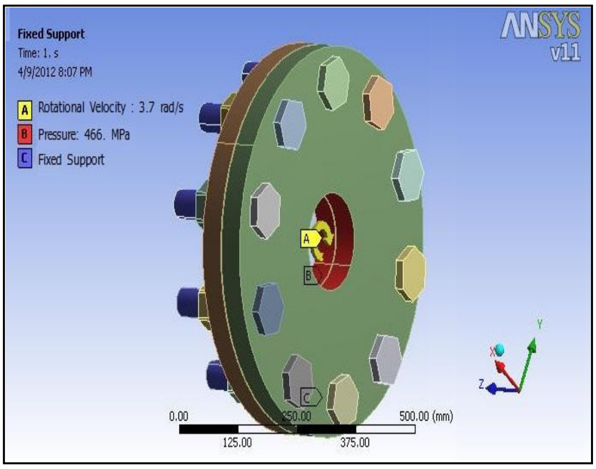

Fig.8. Boundary Conditions and loading

V. RESULT & DISCUSSION

A) STRUCTURAL ANALYSIS.

In order to find critical areas in the flange joint static structural analysis has been performed. Here, no temperature effect has been considered. Rotation is given with the magnitude of 3.7 radian/sec to the flange joint in a clockwise direction and load of 220 KN is applied at the inner diameter as the load of shaft is transferred to the flanges. From the analysis result, it is clearly seen from fig.8 that the maximum deformation is obtained at the point of loading and the area of deformation has spread over the bolt area where the effect of deformation is critical. The deformed shape of the finite element model is shown together with the actual deformation in Fig.8.The von mises (Equivalent stress) gives significant results about the stress distribution over the flange joint. The critical area is seen in fig.9.

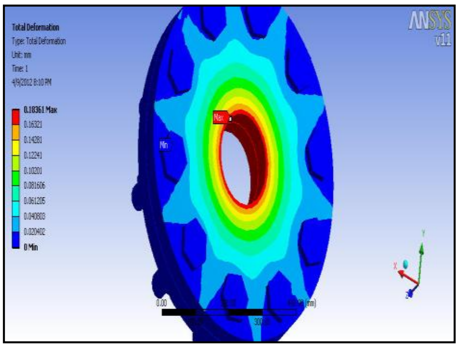

Fig. 8. Deformation

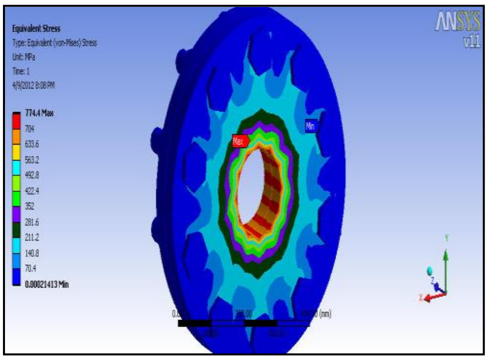

Fig.9. Von mises (Equivalent Stress)

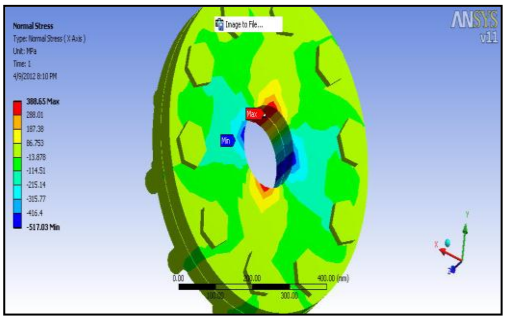

Fig.10. Normal Stress

This technique possesses accurate prediction of stress distribution. The normal stress is found maximum at the interface of the two flanges in fig.10 and at the same time the head portion of the bolts the stress concentration is about maximum (86.753 Mpa). Hence the critical area over the flange joint is examined. The fashion of stress along the path shows that the maximum stress occurs between the contact of the combination of contact stress and bending force. This

B) TRANSIENT THERMAL ANALYSIS.

Since one of the flange as well as head of the bolts are located inside the steckel furnace exposed to the temperature of 950^0c, Thermal stresses are developed in the critical area. Hence, Transient thermal analysis must be performed to examine the critical area. Internal heat is generation inside the bolt is calculated. From the above fig.11 it is clearly seen

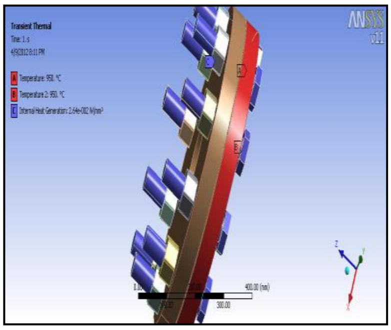

Fig.11. Bolted Flange joint

The total heat flux that is obtained after analysis is maximum at the interface of the two flanges. Thus it shows the thermal occurs when heavier contact stress between the bolt shank and bolt hole occurs due to bending. The stress changes non- the upper and lower flanges. This phenomenon is caused by uniformly along the path and increases sharply at the end of the bolt head Then again, higher stress at the edge of the bolt hole shows consistency with the bending force between the bolt nut and flanges. **Bending force increases the tension in the bolt head increases.**

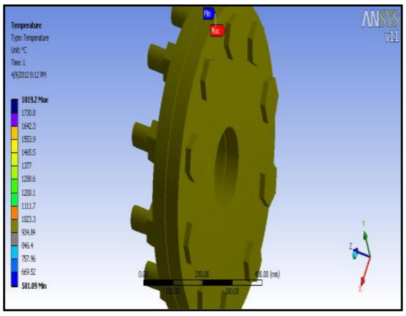

Fig.12. Temperature Effect

that one of the flange as well as head of the bolts are directly exposed to the atmosphere where the maximum ambient temperature is 950^0c (i.e. area inside the furnace). The internal heat generation is found 0.0264 W/mm^3. The effect of the temperature is clearly seen in fig.12. **The trend of the stress along the path shows that the maximum thermal stress occurs at the head of the bolts.** stress allocation is maximum from the bolt head to the interface of the two flanges obtained in fig 13.

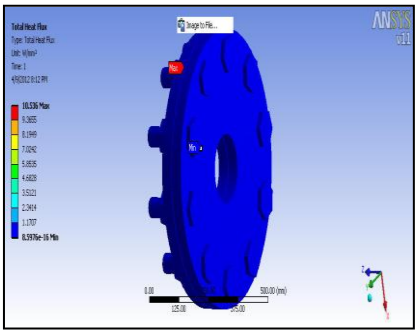

Fig.13. Total Heat Flux

VI. CONCLUSION

The FEM gives good control of experimental techniques, confirming, complementing and refining the specimen design before commencing experiment tests.

In case of structural analysis the critical area has been predicted from the simulation analysis inspite of the critical area occurring on the surface of upper flange of the bolted joint as predicted. It is motivating to examine the critical area of the bolt, since it was the main component in the joint. From the simulation result, it was observed that the critical areas in terms of stress developed in bolt and nut were between the bending surfaces of the bolt head. The flange will experience deformation due to the bolt penetration will load in bending. The joint strength of the bolted joint still relies on the strength of its bolts in both cases when the tension and bending load were applied.

In case of Transient thermal analysis, the maximum occurrence of thermal stress is identified in the head of the bolts. And the total heat flux is maximum at the interface of the two flanges. Thus critical areas in both the analysis are the same. So as load and temperature increases, that increases the tension in the bolt head and head is the most critical part of the flange joint.

REFERENCES

[1] Aidy Ali*, Ting Wei Yao, Nuraini Abdul Aziz, Muhammad Yunin Hassan and Barkawi Sahari, Simulation and Experimental Work of Single lap bolted joint tested in Bending, *Suranaree J. Science Technology*. Vol. 14 No. 4; October-December 2007

[2] Kovács, N., Calado, L., and Dunai, L. (2004).Behavior of bolted composite joints: experimental study. Construction Steel Research, 60(3-5):725-738.

[3] Ju, S.H., Fan, C.Y., and Wu, G.H. (2004). Three dimensional finite elements of steel bolted connections. Engineering Structures, 26(3):403-413.

[4] T. N. Chakherlou, M. J. Razavi and A. B. Aghdam (2011). On the Variation of Bending Force in Bolted Double Lap Joints Subjected to Longitudinal Loading: A Numerical and Experimental Investigation. *Journal for Experimental Mechanics*, 10.1111/j.1475-13. 05.2010.00795. X

[5] SPARLING, L. G. M., 'Improving the strength of Nut fasteners', *Chart. Mech. Engr,* April 1982, 58-59.

[6] JUNKER GH. New criteria for self-loosening of fasteners under vibration. *SAE Transactions* 1969; 78:314–35.

[7] D. Lehmann, Nonlinar axis force and bending moment distribution in bolt clamped L-flange, Stahlbau 9 (2003) 653-663 (in German).

[8] Gambrell SC. *Why bolts loosen* (Machine Design 1968; 40:163–7)

[9] Krishnamurthy N. Fresh look at bolted end-flange behavior and design. *Engineering Journal, American Institute of Steel Construction* 1978; 15(2):39–49 (second quarter).

[10] Krishnamurthy N, Krishna VR. Behavior of splice–flange connections with multiple bolt rows. Report submitted to the Metal Building Manufacturers Association; February 1981.

[11] Y.I. Maggi, R.M. Conclves, R.T. Leon, L.F.L. Ribeiro, Parametric analysis of steel bolted end flange connections using finite element modeling, J Construct. Steel Res. 61 (2005) 689–708.

[12] Gert J.M. Hamman, An investigation of Steckel mill coiler drum failure mechanisms, University of Johansburg, Nov 2006.