Finite Element Analysis based Simulation of Friction Process

[1]Swapneel Rawool, [2]G. U. Tembhare, [3]Vinaay Patil

[1]Student, [2]Assistant Professor, [3]CEO
[1,2]Mechanical Engineering VJTI, Mumbai, India
[3]Vaftsy Cae, Pune, India
[1]swapneel.rawool@gmail.com, [2]gutembhare@vjti.org.in

Abstract: **Friction stir welding – FSW was a promising welding technology from the same moment of its existence because of its easy use, low energy costs, being ecology friendly process and with no need for filler metal. The aim of the project is to develop a F.E.A. based simulation to find heat generated during frictional process. This is done by first making a mathematical model for friction process and then comparing it with finite element analysis results. The aim of this paper is to create a simple, fast and accurate friction simulation model without the need of complex computational power or knowledge of precise process data. In this present work mathematical model is develop for angle of repose. Then a three dimensional non-linear simulations are conducted using Ansys. Similar three dimensional transient simulations are conducted. After running this simulation, it was observed that this model gives fairly close result and can be used to evaluate the frictional heating process.**

***Index Terms*—FSW, Angle of repose, transient analysis**

I. INTRODUCTION

Friction heat generation

Mechanical friction work is initiated when rotating tool surfaces are in contact with the immediate stationary surface of work material under a normal load. While the rotating tool is sliding, it introduces velocity difference between the dynamic rotating tool and the static work material surface and thus creates friction work and subsequently, heat.

Amonton's laws

This mechanical friction work is described based on the Amonton's laws [2] which firstly explain that the friction between two separate bodies is directly proportional to the normal load applied onto the bodies. In this law, coefficient of friction of static friction is a constant variable and temperature dependent but only to be considered as kinetic friction when the contact condition is non-sticking or sliding. Secondly, the friction force is independent on the apparent contact area.

Coulomb's dry friction

In general application, friction work is assumed based on Coulomb's dry friction model between solid bodies, which is also at the same time conforms the aforementioned Amonton's law. In details, the mechanical work and heat generation relationship in the presence of sliding friction is explained by contact conditions between hard and soft metallic material interaction. It involves very small scale asperities at the contact surfaces of hard and soft material. As normal force is acting on the rotating tool, it is being distributed onto smaller area asperities at the contact surfaces which resulted in a very high pressure per unit force. Due to relative velocity difference, the normal force causes ploughing of the soft material by the hard materials' asperities. The soft material gets agitated, deformed and finally broken, releasing the stored energy in the form of heat.

Local thermal energy

The released energy which is a very high local thermal energy causes the temperature to rise. The heat energy is eventually transferred and stored into the rotating tool and the lump work material. The heat causes the work material to soften, reduces its strength, broken and deforms into soft material layer in between the rotating tool and the work material. This soft layer is gradually displaced by the rotating tool pin revealing new surface contact condition for another cycle of ploughing action by the rotating tool. The process promotes another cycle of mechanical friction heat generation.

II. WHY DOES FRICTION CREATE HEAT?

This process is the translation of the kinetic energy of the object itself to heat energy which is the randomly distributed kinetic energy among atoms Fig. 1. Atoms are attached to one another via bonds that behave in some ways like springs. When one surface rubs along another, microscopically they are not smooth. So these rough surfaces of atoms bound together have high points and low points and as they are drawn along each other the high points are compressed as they meet other high points. This exerts a force in the opposite direction of their movement causing the collision with the other peak.

Once the two peaks have passed one another the pressure is no longer there and the bonds relax like a spring from which you have removed the weight. Thus what you have overall is a force felt by the object opposite it's direction of motion and an increase in the random jiggling of atoms on their bonds which is heat.

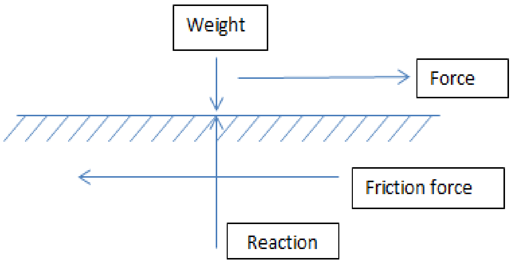

Figure No 01. Analysis of Friction

Friction Stir Welding

Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute)[1], England in the year 1991. Friction Stir Welding is a solid-state process, that the objects are joined below the melting point with the help of pressure, frictional heating by the rotation of a tool and mechanical deformation – extrusion and forging. The heat generated in the joint area is typically about 80-90% of the melting temperature. In FSW, a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between the two pieces of material to be joined. This process is suitable for joining of Al and alloys, Mg and alloys, Cu and alloys, Ti and alloys, steel and joining of metals and alloys.

Why FSW?

Normally metals and alloys are joined by fusion welding process. All fusion welding processes particularly for materials having low weldability such as copper are characterized by welding defects. Some Al, Cu and Mg alloy series are not at all fusion weldable. Welding of different materials and much different in thickness are impossible/very difficult with fusion welding process. The main defects noticed in fusion welding are porosity, hot cracking, HIC, NIC, residual stresses, distortion, grain growth, HAZ, composition changes at the weld nugget and HAZ. Other problems, such as environmental pollution due to welding fumes and slag, very high energy consumption, pre and post weld treatments, high initial investment.

Angle Of repose:

It is the minimum angle of inclination of a plane with the horizontal at which the body kept will just slide down on it without application of any external force (due to self weight).
Consider the block with weight W resting on an inclined plane, which makes an angle θ with horizontal as shown in figure 2. When θ is small the block will rest on the plane. If θ is increased gradually a slope is reached at which the block is about to start sliding. This angle θ is called as angle of repose.

Mathematical Model for Angle of Repose

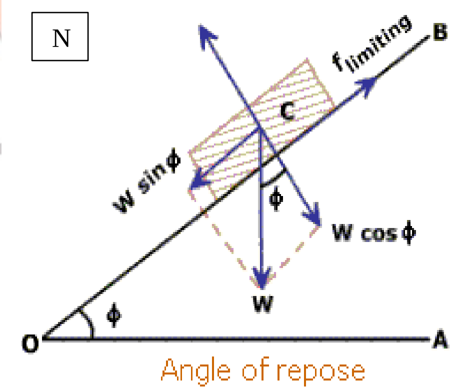

Figure No. 02 Angle of repose

€Fx=0
$-W \sin\theta + F_{limiting} = 0$
$W \sin\theta = F_{limiting}$
$F_{limiting} = \mu * N$
μ= Coefficient of friction between block and plane.
$W \sin\theta = \mu * N$ …………………..(1)
€Fy=0
$-W \cos\theta + N = 0$
$W \cos\theta = N$…………………..(2)
Dividing equation 1 by 2
$\tan\theta = \mu$

$\boldsymbol{\theta = \tan^{-1}(\mu)}$

Angle of repose depends on coefficient of friction and independent of block weight.

For μ=0.3 θ=16.6999°

III. FEA SIMULATION

1. Non-linear analysis: All physical processes are inherently nonlinear to a certain extent. For example, when you stretch a rubber band, it gets harder to pull as the deflection increases; or when you flex a paper clip, permanent deformation is achieved. Several common every day applications like these exhibit either large deformations and/or inelastic material behaviour. Failure to account for nonlinear behaviour can lead to product failures, safety issues, and unnecessary cost to product manufacturers. Nonlinear response could be caused by any of several characteristics of a system, like large deformations and strains, material behaviour or the effect of contact or other boundary condition nonlinearities. In reality many structures exhibit combinations of these various nonlinearities. MSC Software provides solutions to help you simulate accurately and efficiently systems with any or all of the nonlinearities, with applications encompassing multiple industries.

Considering contact type non linearity for frictional simulation.

In this approach, we use different model with different slopes. From Fig. 4, the angle for which, the impending motion start is: 16.9°

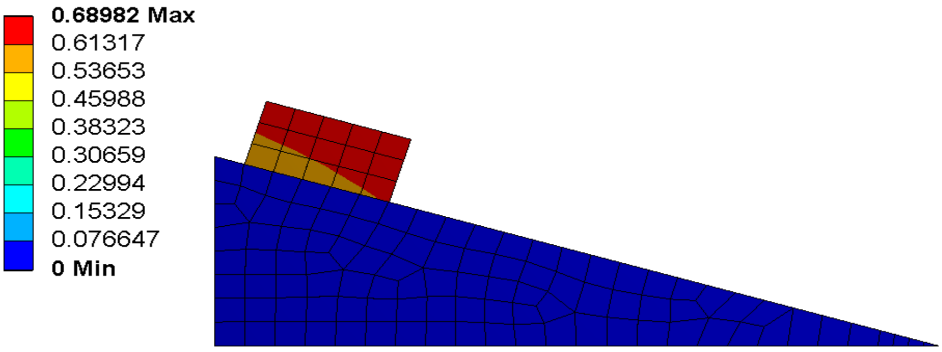

Figure No. 03 Non-Linear Static Structural Analysis for Angle16.7°

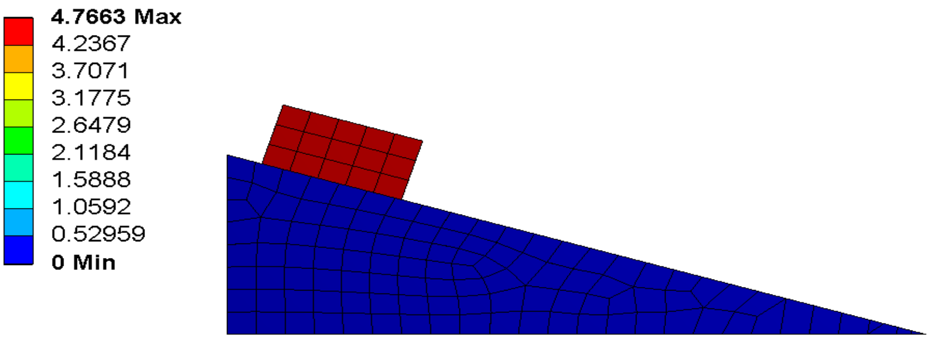

Figure No. 04 Non-Linear Static Structural Analysis for Angle16.9°

Transient Analysis(Acceleration):

We find the components of gravitational acceleration i.e. 9.81m/s^2. In x and y direction for 17 steps (1° to 17°). All the components of the gravitational acceleration are given in table no.1.

angle	X=9.81 Sin θ	Y=9.81 Cos θ
1	0.171208	9.8085
2	0.34236	9.80402
3	0.513416	9.796556
16	2.704	9.42997
17	2.86816	9.38134
18	3.031456	9.32986

Table No. 01 Table of transient Acceleration

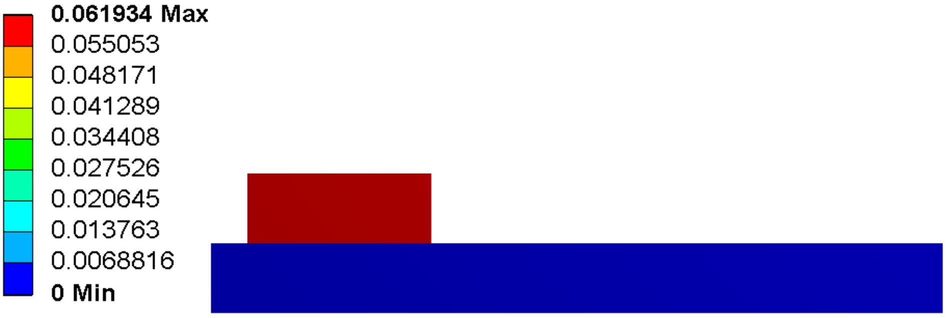

Figure No. 05 Non-Linear Transient Structural Analysis for Angle16.9°

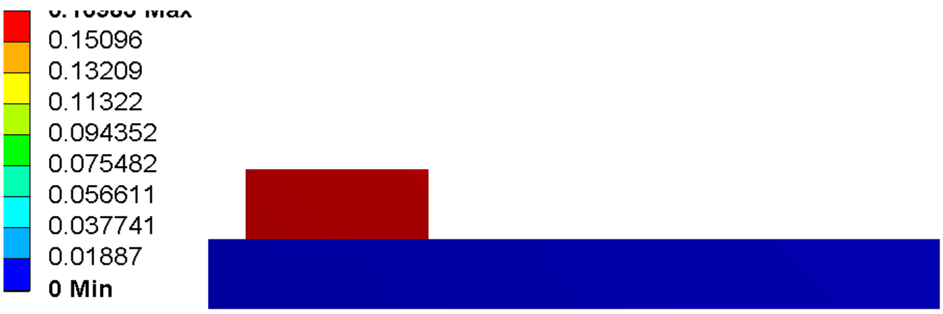

Figure No. 06 Non-Linear Transient Structural Analysis for Angle17°

Comparing Analysis Figure no. 5 and 6, It is clear that the angle of repose is 17°

Transient analysis (Remote displacement about Z):

Remote displacement is given for one face of the body. Then the face is rotated about z axis in 18 steps as per table no. 02.

Step	Time	Rz
1	0	0
2	1	-1
3	2	-2
4	3	-3
15	14	-14
16	15	-15
17	16	-16
18	17	-17

Table No. 02 Rotation angles about Z axis

Analysis results are shown in Figure no. 7 and 8.

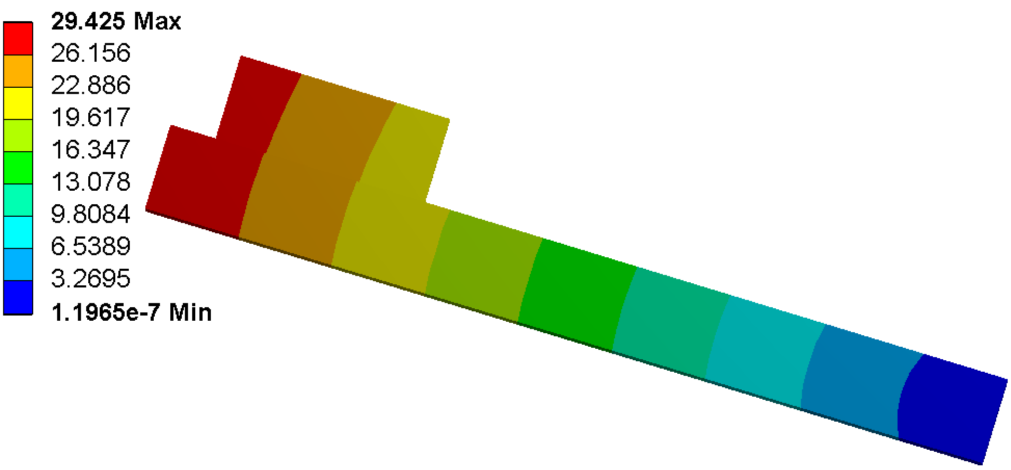

Figure No. 07 Non-Linear Transient Structural Analysis for Angle16.9°

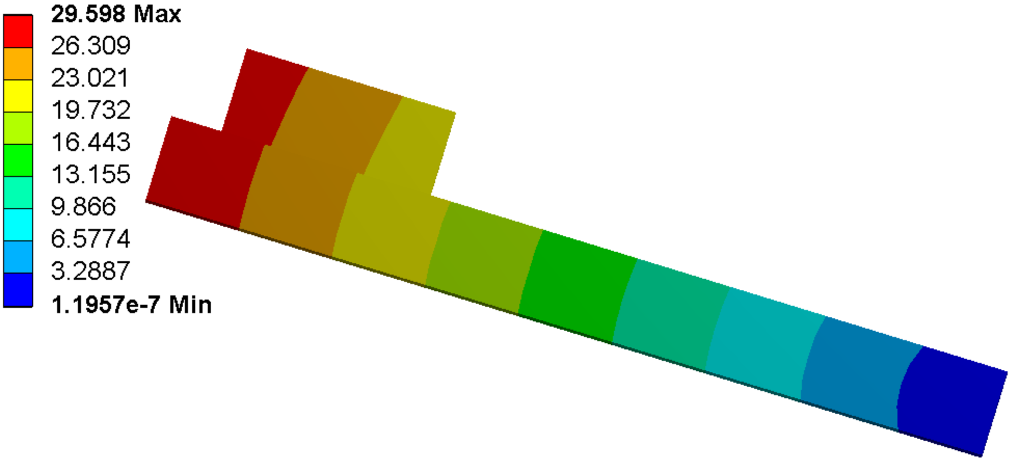

Figure No. 08 Non-Linear Transient Structural Analysis for Angle17°

The block starts sliding at 17° angle. From this analysis it is concluded that angle of repose is 17°

Conclusion:

The results of the model are compared with Ansys results. The comparison of the same is shown in Table 3.

Approach	Angle of Repose (°)	Error (%)
Mathematical Model	16.699	--
Non-linear Static	16.9	1.20
Transient Analysis (Acceleration)	17	1.80
Transient Analysis (Displacement)	17	1.80

Table No. 03 Result Table

The closeness of the values of output by this model gives suitability of the use of the model for Frictional heating process analysis at various conditions with sufficient accuracy.

References

[1] Friction Stir Link Inc, http://www.frictionstirlink.com/fslfswdescription.html.

[2] J. Gould, Z. Feng, Heat flow model for friction stir welding of aluminum alloys, J. Mater. Process. Manuf. Sci. 7 (1998) 185–194.

[3] Nandan, R., DebRoy, T., and Bhadeshia, H., *Recent advances in friction-stir welding - Process, weldment structure and properties.* Progress in Materials Science, 2008. **53**(6): p. 980-1023.

[4] Thomas, W.M., Nicholas, E.D., Needham, J.C., Murch, M.G., Temple-Smith, P., and Dawes, C.J., *Friction-stir butt welding*, GB Patent No. 9125978.8, International patent application No. PCT/GB92/02203, (1991).

[5] Thomas, W.M., Threadgill P.L., and Nicholas, E.D., *Friction stir welding of steel: Part one*, http://steel.keytometals.com/default.aspx?ID=CheckArticle&NM=219.

[6] W. Tang, X. Guo, J.C. McClure, L.E. Murr, A. Nunes, Heat input and temperature distribution in friction stir welding, J. Mater. Process. Manuf. Sci. 7 (1998) 163–172.

[7] Y.J. Chao, X. Qi, Thermal and thermo-mechanical modeling of friction stir welding of aluminum alloy 6061-T6, J. Mater. Process. Manuf. Sci. 7 (1998) 215–233.

[8] Y.J. Chao, X. Qi, Heat transfer and thermo-mechanical modeling of friction stir joining of AA6061-T6 plates, in: Proceedings of the First International Symposium on Friction Stir Welding, Thousand Oaks, CA, USA, 1999.