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Analysis of crucible performance for aluminum scrap casting at small and medium enterprises (SMEs) foundry

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Abstract. Performance analysis of crucible that used in aluminum casting at Small and Medium Enterprises (SMEs) Foundry have been done by non-destructive test (NDT). A non-destructive testing method is a felicitous method because it does not interfere with the production process. The crucible analysis includes the Chemical composition analysis use X-Olympus XRF to know the crucible material, fluids flow analysis and design using finite element method with Autodesk Inventor Software and Autodesk Simulation CFD. Based on the results showed that the crucible consists of 97.17% Fe, 1.68% Si, 0.6% S, 0.22% Mn, 0.26% P, and 0.08% Cr. From fluids flow simulation founded a critical point in crucible area that appropriates with the leaks occur. In this critical point, the air velocity about 8.89 m/s and the velocity in the inlet and outlet drooped 266.7 m/s, increasingly severe with fixed support the crucible only on upper hatrack while at the bottom there is no support that caused the maximum stress in this section. Finite element method divided the displacement area by a mesh average of 0.08 in four colour variations, red colour at 48.94 mm max displacement, yellow colour on 29.36 mm – 39.15 mm displacement area, green colour at 19.58 mm – 29.36 mm displacement area, and blue colour at 0 mm – 19.58 mm displacement. The crack of crucible located between red and yellow colour about 39.15 mm displacement.

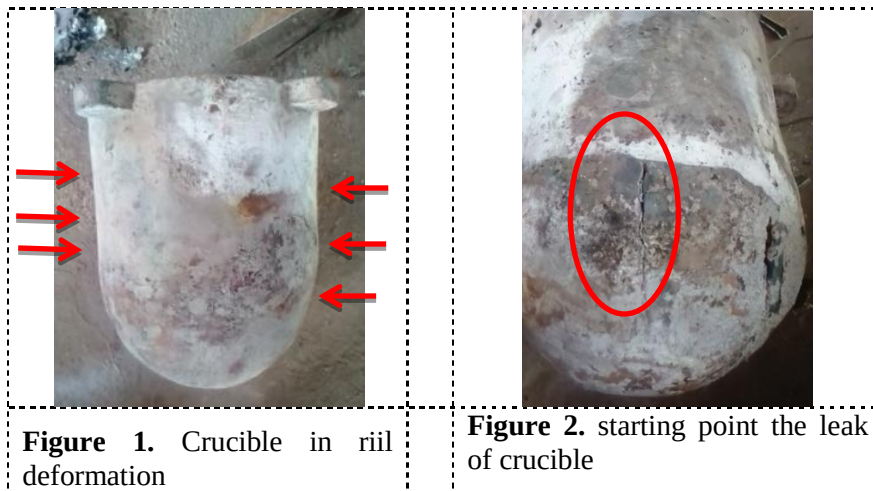
1. Introduction

A crucible is a container that has a melting point higher than the material want to melted. Crucible made of a variety of materials generally available are made of clay and graphite or silicon carbide [1], but now for non-ferrous smelting especially Small and Medium Enterprises (SMEs) commonly use of metal pots from iron casting because simple in production and inexpensive [2][3]. As the main utility of non-ferrous smelting, capacity greatly influences crucible usage. For example, for 60 Kg capacity of the crucible can be used in 3 to 5 batches per day for 3 to 4 hours to smelting time per batch. The crucible failure cannot avoid in continuous use. The failure can be divided into two types i.e. crack and deformation. The crack at crucible can cause the leak of smelting fluids so disturb the production processes i.e. shrinked the volume of smelting fluids; temperature droop that impacts the failure foundry like misrun or not fulfill the model of casting. The deformation of crucible caused by the material of crucible cannot hold the high temperature during the smelting process which happens repeatedly. Fig. 1 and Fig. 2 show the example of rill crucible failure in aluminum ornament SMEs. The leak is located at the bottom side of crucible while the deformation is located in the around of crucible. Based on Irwansyah *et.al* (2010), durability or lifetime the crucible depending on the quality of aggregate which not only must high temperature resistant, but also inert or not chemically react with fused solid materials and tangled gas [4]. While in Bertha (2008), crucible failure caused by hot



melt touch effect from melted material and caused penetration, corrosion and erosion melted material to crucible body [5]. The researchers explain if the deformation of crucible caused by temperature variations and over heating or the temperature operation is changed quickly and not continuous.

Crucible as a main tool in foundry, failure analysis, however without damaging the crucible so did not disturb the production, non destructive test can be used to analysis crucible (NDT) so software analysis is the best appropriate to analysis the failure of crucible.



Non destructive failure analysis uses stress analysis software can be used for predicting the workload of the design or objects like which conducted by Budimana *et.al.* (2016), analysis the safe-failed of the hydro Francis turbine blades [6]. Berkowski et al (2015), 3D modelling to examination and analysis the crack formation in a composite slab floor. Under examination, they find the cracks were caused by a reinforcement and deck plate thickness that were mismatch to the design [7]. Moreover, NASA R&D implements the same method to discovering load and forces in composite materials with the compare between simulation and experiment [8]. Furthermore, Engineering computational fluid dynamics (CFD) and Finite Element Method (FEM) can use to accurately analyze the design and safe-fail mechanically [9]–[11]. Han *et.al* (2010), used FLUENT to calculate the air force and boundary conditions the crane with 100 tons in capacity [12]. The stages of FEM are 3D models, then selecting material, and the next important step for an accurate FEM modelling is to mesh the model ineffective way so that critical regions are covered with an optimized number of elements [13].

2. Method

The method used non-destructive test (NDT) to analysis the crucible failure. The crucible failure in SMEs foundry analysis by Autodesk Inventor and Computed Fluid Dynamics (CFD) for free software, Autodesk provide two version i.e for student software & educator and free trial for 30 days. The primary data, i.e. dimensions and actual conditions obtained from UD Tami 15 located in Jl. Ir. Sutami Km. 15 Tanjung Bintang, South Lampung, Lampung Province. The measurement data such as the temperature of the burner room measuring by the Infrared Sanfix brand thermometer and air velocity measuring by anemometer type of Vane AM-4200. NDT analysis covers the chemical composition of crucible and encrustation used XRF portable merk X-Olympus, fluid flow analysis, and stress analysis. The stove and crucible drawn fit with actual dimension and assembly with real condition in UD Tami 15 workshop. The material input parameter, i.e. crucible material, furnace material used refractory brick SK 38, refractory shell used mill steel plate, air combustion from blower inputted in material data sheet of Autodesk Inventor software. The design in 3D model in the same direction as shown in Fig 3.

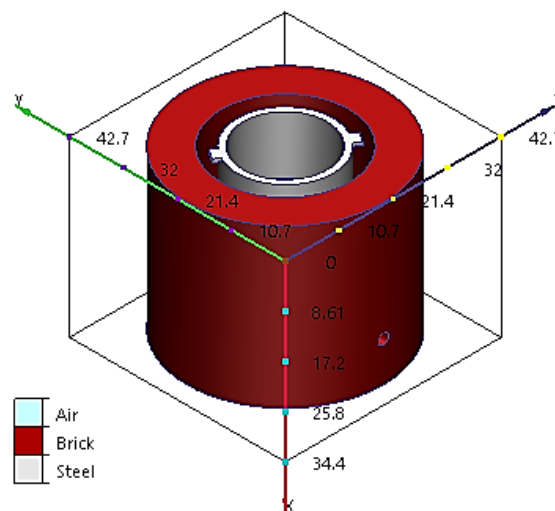


Figure 3. material selected of crucible furnace in the 3D autodesk inventor

After drawing the design, Computed fluid dynamics analysis with Autodesk Simulation CFD software. The parameter of crucible material, velocity, temperature, air pressure, inlet and outlet direction inputted as an initial parameters fluids analysis. The physical of mass, density, volume, and centre of gravity the crucible shown in Table 1.

Table 1. Physical of Crucible

Material	Iron, Cast
Density	7,25 g/cm ³
Mass	211,957 kg
Area	1731520 mm ²
Volume	29235500 mm ³
Center of Gravity	x=0 mm y=-246,809 mm z=117,886 mm

3. Result and Discussion

3.1. Chemical Composition

X-ray fluorescent (XRF) analysis the material of crucible result shown in Table 2.

Table 2. Crucible chemical composition

	Chemical Composition %								
	Fe	Si	S	Zn	Mn	P	Cu	Cr	Zr
Body	97.17	1.68	0.6		0.22	0.26		0.08	
Crust	94.22	1.68	2.84	0.62	0.25	0.20	0.14	0.04	0.015

The chemical analysis results shown the crucible made by 97.17% Fe and 1.68% Si. The crust of crucible bodies consists of 94.22% Fe, 1.68% Si and another element, such as 2.84% S, 0.62% Zn, 0.14% Cu, and 0.015% Zr. The chemical composition of Sulfur increase from 0.6 % in the body to 2.84% in the crust. The formation of 2.84% Sulfur formed from the combustion process in the outer wall of the crucible. The crucible working on high-temperature environment and this condition makes a possibility of corrosion. Sulfur (S) will react to binding Fe from the base material of crucible so will

reduce the layer of the wall crucible, penetration in the wall can cause the corrosion. furthermore, the wall of crucible getting thinner and easier to deformation because cannot resist the force.

3.2. CFD Simulation Analysis

The air flow from the blower inlet through a pipe with dia. 1 ¼ inch with velocity V_1 10.2 m/s and pressure P_1 1,2KPa. While the temperature obtained by burning the charcoal in combustion room. The crucible placed centre and supported by upper hatrack while at the bottom there is no support. The lines in Fig. 4 shows the fluid flow, the air from the blower entrance through the inlet pipe and formed the turbulent flow in the base of combustion room. Based on CFD analysis, show the air flow swirls two times in the base of the combustion room before up to the outlet, amongst the body of the crucible and the wall of the combustion furnace.

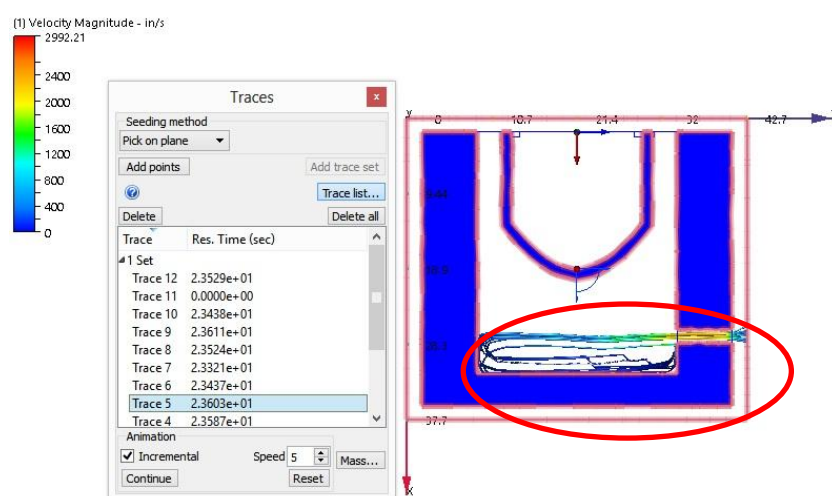


Figure 4. fluids flow in the combustion room

Fig. 5 represented the fluid flow between the crucible surface were hanged at the furnace. The first position of the air touched the outside of crucible surface and then out between the gap of the crucible wall and the wall of the furnace. The figure traces list showed the points of air forced the wall of the crucible and move leftward and eventually exit through the combustion room. This air has pressure and velocity and works continuously at high-temperature, which will be possible to stress the crucible.

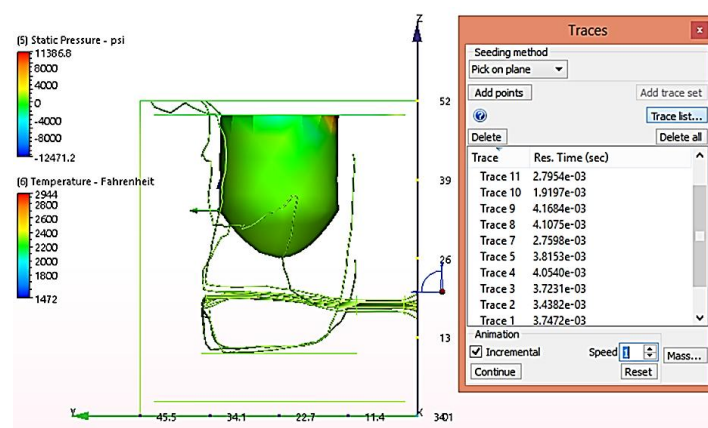


Figure 5. Traces of force air

The air velocity in the combustion room at certain points showed in Fig. 6 while the Fig. 7 showing the air velocity in 'z' direction (in 3D design, x y z coordinates).

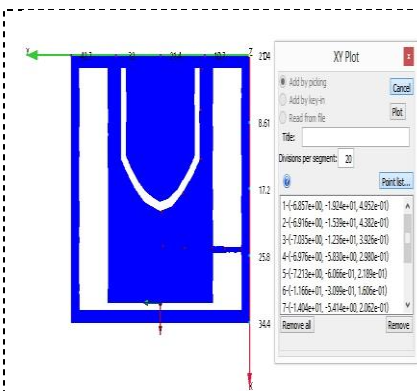


Figure 6. The air velocity at certain points

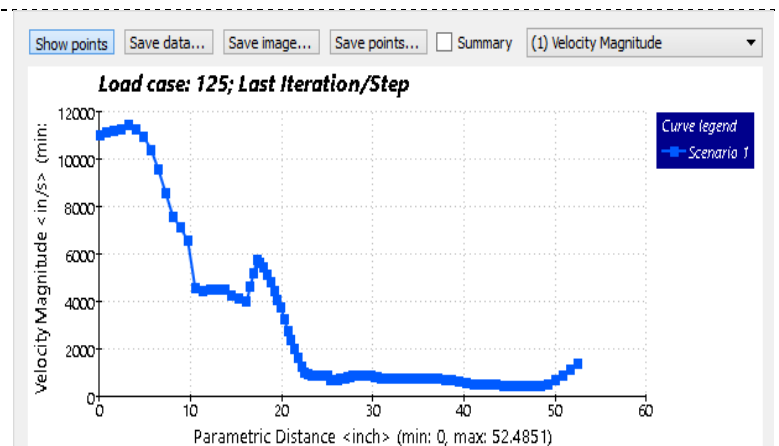


Figure 7. The air flow iteration at z coordinate

The air flow velocity at the combustion room in coordinate 0 to 10 Z direction 279.4 m/s - 114.3 m/s, or decreased velocity 165.1 m/s. This decreased happen because air vortex at the bottom of the combustion room detained by combustion wall and the fuel contact between the air flow. Whit the coordinate of 20 - 50, the air velocity 12.7 m/s. The velocity drop from inlet to outlet 266.7 m/s. The analysis of CFD finds that in coordinate 26 which is the velocity of air flow touched the outer convex body crucible is 8.89 m/s. The air continuously hit the body crucible during flow blower open in cold or hot conditions depend on the presence or absence of flame. This causes cracking point at crucible, this point is suitable with Fig. 2 where is the crack start happens in actual coditions..

3.3. Stress analysis

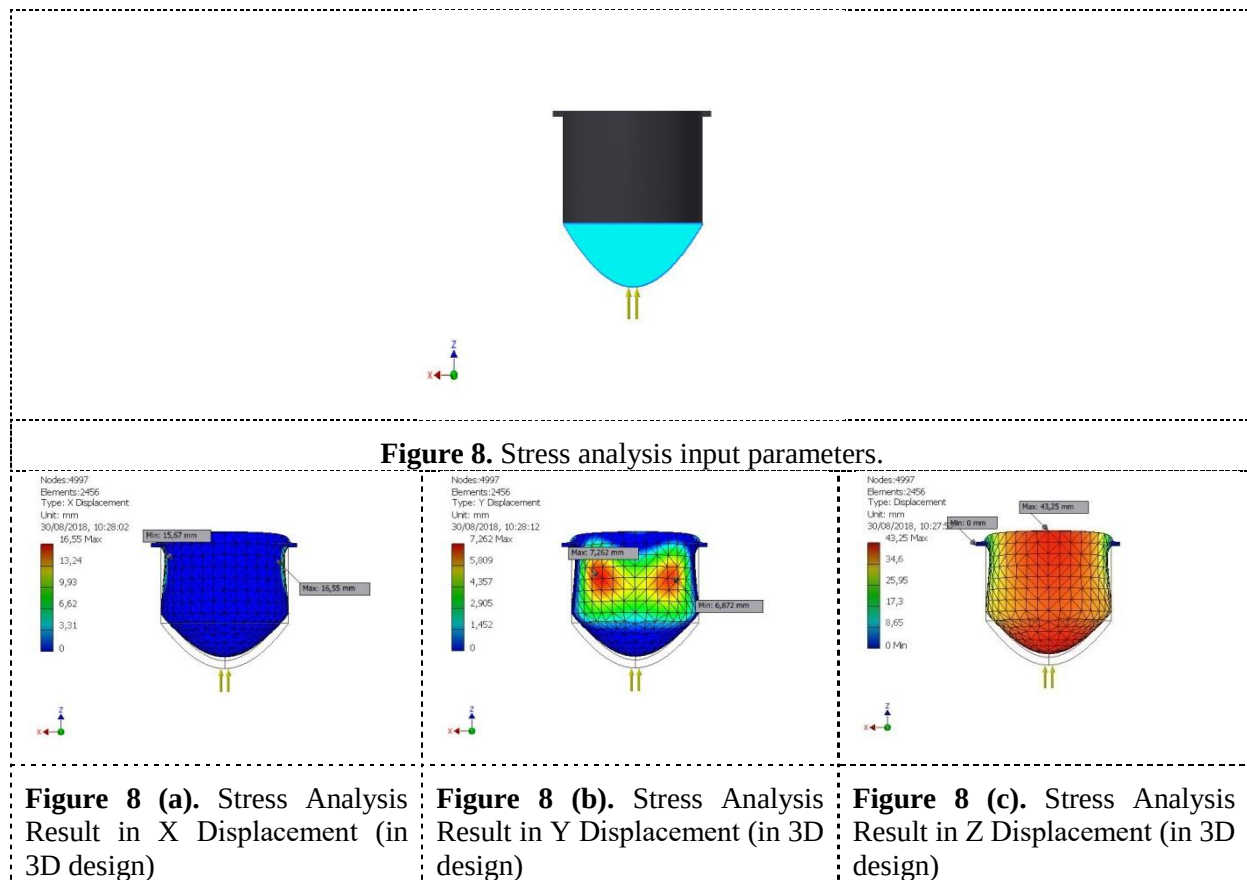
The stress analysis performed by input the parameter obtained from computational fluid dynamics analysis. The force that works in the crucible located at the bottom surface of the crucible as shown in Fig. 8. This force is the weight obtained from the crucible mass and the mass of the aluminum raw material shown in equation 1. The fixed points of the crucible located in upper hatrack. The meshing setting is shown in Table 3.

Table 3. Mesh settings

Avg. Element Size (fraction of model diameter)	0,08
Min. Element Size (fraction of avg. size)	0,2
Grading Factor	1,5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

$$W = (m_0 + m_1) \times g \quad (1)$$

where m_0 is mass crucible, m_1 is mass raw material, and g is gravity force (9.81 m/s^2).



The simulation of deformation crucible same with the real deformation crucible, the deformation crucible in z direction so crucible shown oval shaped. Similarly, on the side of crucible no longer straight, but curved in the x and y coordinates. This analysis is same with riil crucible that used in Small and Medium Enterprises UD Tami 15 shown in Fig. 1. The stress analysis result shows the high displacement in an area with the red colour shown in Fig. 8, maximum displacement 43.25 mm located inside of the outer concave crucible. The yellow area with displacement 25.95 mm – 34.6 mm, the green area with displacement 17.3 mm – 25.95 mm, and the dark blue and light blue with displacement 17.3 mm – 0 mm. The failure of the crucible is located in red colour and yellow with displacement about 34.6 mm. In the riil crucible deformation, the displacement about 10 – 30 mm located inside of the outer concave crucible, that can see in Fig. 1 in actual condition.

4. Conclusion

The analysis of crucible performance used Computed Fluid Dynamics and Stress Analysis Software shown the same phenomena to the defect of crucible in actual condition. Analysis software used more effective because non destructive the crucible and recommended to changes the crucible furnace design.

Acknowledgments

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