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Heat Transfer Transient Analysis on the Fire Proofing Coating Applications for Structural Steel

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Abstract. In the development of building construction, the use of Structural Steels is now widely used due to itsadvantages in terms of mechanical strength, elasticity, standardization of sizes, ease of fabrication and economic considerations. However, structures made of steel are susceptible to temperature increases during a fire. Currently, there are several typesof fireproofingcoating forStructural Steels such as intumescent coatings, cementitiouscoating products and etc. This paper will discuss the resistance of Structural Steel in the event of a fire between protected and unprotected Structural Steel in Pamitra Workshop. This research is simulated using Ansys heat transfer analysis software. Based on the simulation results, the unprotected Structural Steel reaches a critical temperature (550^{0}C) within 5-6 minutes and has a risk of collapse, then the protected Structural Steel with intumescent coating reaches a critical temperature up to 3 hours and 4 hours with cementitious coating product. Furthermore, the isotropic thermal conductivity decreases significantly from unprotected Structural Steel to protected Structural Steel up to 200^{0}C.

Keywords:- *Structural Steels, Fireproofing Coating, Ansys.*

I. INTRODUCTION

The use of steel as a structural element in buildings is increasingly being used today because steel has several advantages compared to other construction materials in terms of mechanical strength, elasticity, standardization of sizes, ease of fabrication and economic considerations [1]. However, the material properties of steel significantly reduce at high temperatures. This can have a detrimental effect on the stability of a structure as experienced during the catastrophic collapse of the World Trade Centre towers in New York City[2] For this reason, a passive fire protection system is needed in addition to active fire protection, this is to provide additional time for building occupants and rescue teams to evacuate before the building collapses and also protect the Structural Steels defect caused by burning. Fire losses are one of the major preventable tragedies in modern civilization[3].

Therefore, structural steel protection is required to preserve the stability of the building in the event of a fire[4].In order to guarantee safe clearing of inhabitants in unintentional fire occasion, the framed structures must have stability for a specific period. Many fire protection methods are used to prevent Structural Steel failure in buildings. Most countries have their own fire resistance construction methods that meet building safety regulations [5].

Fig. 1: Deflection of Structural Steel after a fire andStructural Steel has collapsed after a fire

A. Pamitra Workshop

Pamitra Workshop is a building with dimensions of 13 m wide and 42 m long, with an area of546 m^{2}owned by PT. PamitraJaya Konstruksias a national private company engaged in Engineering, Procurement, Construction and Commissioning (EPCC) in Sidoarjo, East Java – Indonesia[6].This workshop will be erected using various steel structure made of SS400. SS400 is a material grade and designation defined in JIS G 3101 standard. JIS G 3101 is a Japanese material standard for hot rolled steel plates, sheets, strips for general structural usage[7].

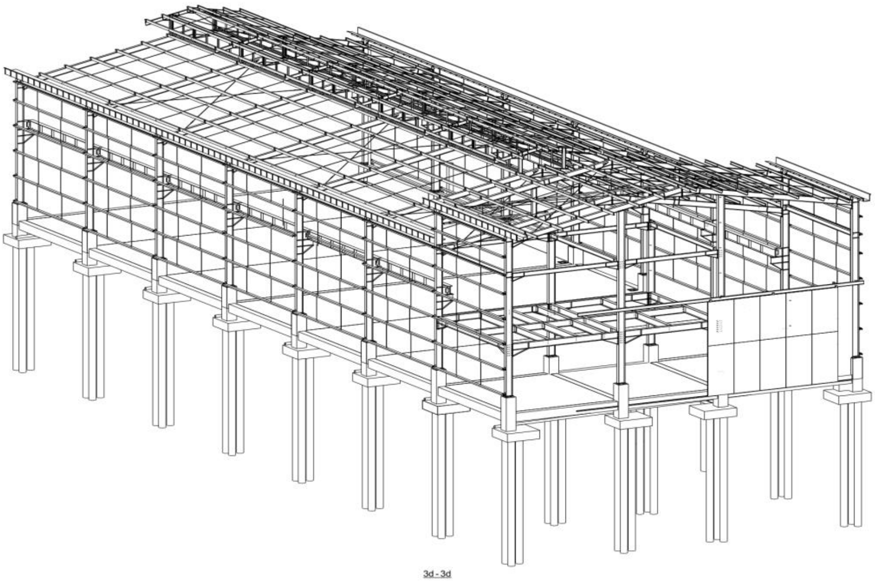

Fig. 2: Pamitra Workshop Building (3D View)

According to the hazard identification and risk assessment document for workshop activities set by Pamitra[8], there are two fire risks that can occur in the workshop. The first is the risk of SMAW welding activities and the second is the risks of grinding activities. Both of risks are included in the extreme category, which means that immediate action is needed.

In this study, the risk matrix reference standard used is the risk matrix standard from AS/NZS 4360:1999[9].

Probability	Consequence				
	1	2	3	4	5
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H

Fig. 3: Risk Matrix based on AS/NZS 4360:1999

Remark:

E :Extreme Risk (immediate action is needed)

H :High Risk (requires senior management attention)

M : Moderate Risk (management responsibilities must be determined)

L : Low Risk (need control with routine procedures)

B. Heat Transfer Theory

Based on the science of thermodynamics, we know that energy can be transferred due to the interaction between the system and the environment. This interaction is called work and heat[10]. However, only thermodynamics deals with the final state of the process in which the interaction occurs and does not provide information indication the nature of the interaction or the time rate at which interaction occurs. The interaction of the system and environment that is the focus of this report is heat transfer.

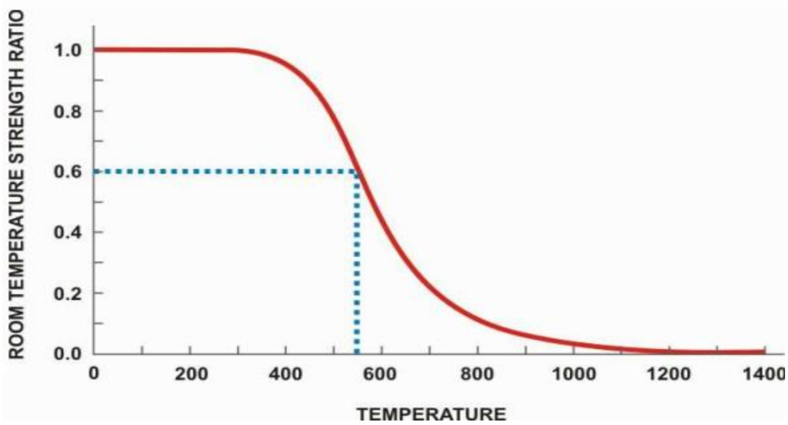

Fig. 4: Material temperature growth time

Based on the chart above, Steel loses its loadbearing capacity at a temperature in excess of 550^{0}C during a fire, risk of collapse of building structure is greatly increased. Maraveas[11] steel will lose its structural strength at temperatures in excess of 550^{0}C during fire events, in this condition, the risk of the structure collapsing is very high.

Heat transfer itself is heat energy that moves from one system to another due to differences in spatial temperature[10]. When there is a temperature difference that occurs in a medium, heat transfer will occur. Judging from the media and the process, heat transfer is divided into 3, namely:

a) Conduction Heat Transfer
Conduction is the process of heat transfer when a temperature gradient occurs in a static medium, either solid or liquid. The mechanism of heat transfer occurs due to the random movement of molecules. In general, conduction heat transfer refers to the general equation of the conduction rate equation (Fourier's law) as follows[12]:

$$q" = -k\nabla T = -k(i\frac{\partial T}{\partial x} + j\frac{\partial T}{\partial y} + k\frac{\partial T}{\partial z}) \quad (1)$$

b) Convection Heat Transfer
Convection is a heat transfer process that occurs between a surface and a fluid moving at different temperatures. The heat transfer mechanism occurs due to the random motion of molecules and the transfer of energy from the mass motion. In general, the equation for determining the rate of heat transfer refers to Newton's Law of Cooling[13]. The equation for the rate of convection heat transfer is:

$$q" = h(T_S - T_\infty) \quad (2)$$

c) Radiation Heat Transfer
All surfaces with a limited temperature will radiate energy in the form of electromagnetic waves, even in the absence of an intermediate medium. The transfer of heat due to the difference in temperature between these two surfaces is called radiant heat transfer[14]. The equation used in radiant heat transfer refers to the Stefan-Botlzmann law, the equation is:

$$q" = \varepsilon\sigma(T_S^4 - T_{Surr}^4) \quad (3)$$

C. Finite Element Analysis Software (Ansys)

Ansys is software that is used to solve various engineering problem numerally using the finite element method (Muhammad, Ali, &Shanono, 2019)[15]. In Ansys, the created model will be broken down into smaller parts and united with nodes (Racmawaty, Dewi, Djakfar, &Wisnumurti, 2015)[16]. In engineering (and other disciplines), Ansys is useful in simulation work in structural engineering, heat transfer, and fluid flow[17].

D. Fireproofing Coating

Fire protection can be divided into two types, namely non-reactive or the most common types, namely boards and sprays, and reactive types, namely a thin intumescent film layer that will expand to form charcoal as a heat insulator[1, 18].This water-based protection material consists of polyvinyl acetate resin and filler for fire protection in steel structures. This material can expand and form an insulating layer that prevents the temperature rise of the steel structure[19, 20].

Fig. 5: Intumescent coating spraying procedure

The spray is applied without air to speed up the quality of the finish, however brush and roller applications are also possible. Applied directly to the contours of the main substrate, flame retardant up to 2 hours and above (BS 476 part 21), flame retardant up to 3 hours and up (ASTM E119/NFPA 251), resistant to decorative coatings, ideal for visible steelwork[21].

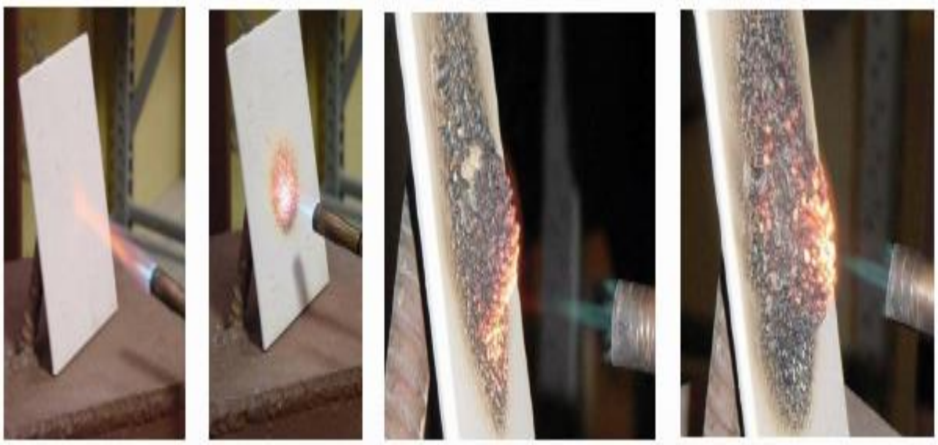

Fig. 6: Intumescent coating reaction when burned

Then the next alternative is a cement-based protective material with a light density, or it can be called wet spray vermiculate cementitious. This material is applied by spraying on the surface to be protected. Can provide fire resistance up to 240 minutes or 4 hours according to ASTM E119 (UL 263) standard[22].

Fig. 7: Illustration of the procedure for spraying wet spray vermiculate cementitious and the results

II. METHODS

Solving this problem is done by simulation using Ansys heat transfer analysis software on building structures, steel material on I-Beam and I-Beam materials with stiffeners, then each structure is varied with intumescent coating and cementitious refractory materials vermiculate with a certain thickness, this is to assess the distribution of temperature and heat flux during the fire process in the steel structure of the building and its parts, that are not protected by fire resistant materials and protected by fire-resistant materials.

A. Geometry

The geometry used in this simulation is divided into 3, namely:

- A building with a frame structure that is simplified into a box shape for simulation purposes
- The structure of the building is in the form of I-Beam
- The structure of the building is I-Beam with Stiffener

The frame is used is the I-Beam category with standard SS 212750 I-Shape with HE size 100 A

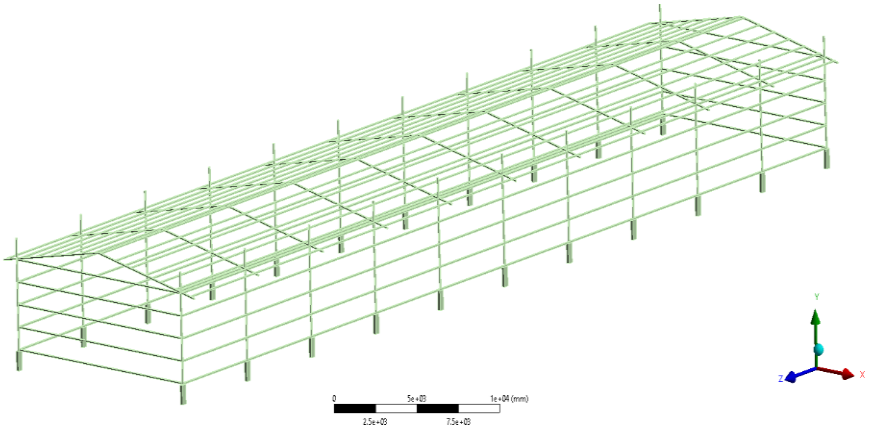

Fig. 8: Geometry of the building structure model

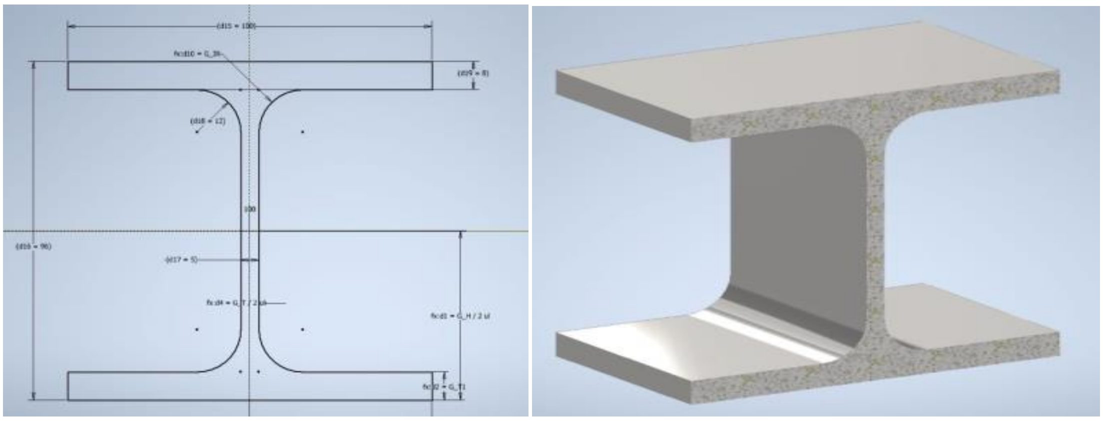

Fig. 9: Geometry model I-Beams SS 212750 I-Shape

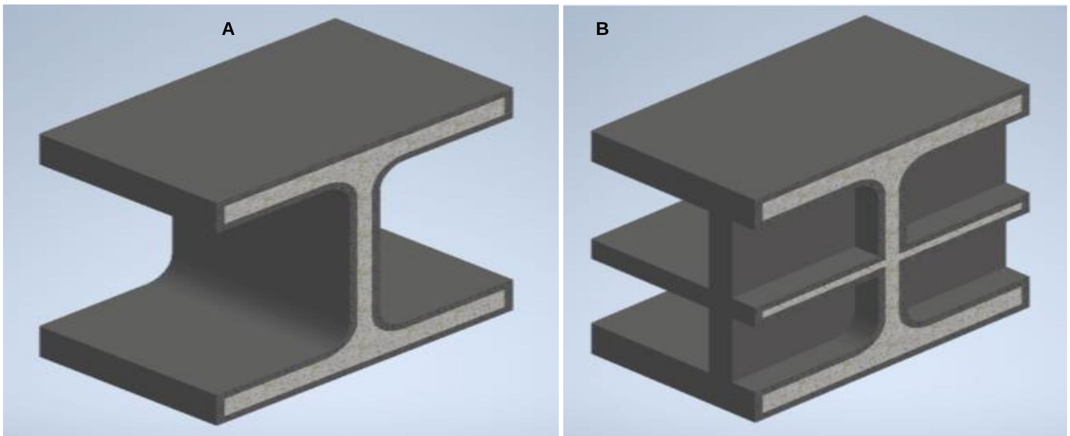

Fig. 10: Geometric model I-Beam with fire protection type intumescent coating (A) without stiffener, and (B) with Stiffener

Then the three geometries above are also developed with a protective layer that will be compared into 3 variations, namely:

- Geometry without fire protection coating application
- Geometry with fire protection layer type intumescent Cafco spray film WB3
- Geometry with fire protection type wet spray vermiculate cementitious Promaspray P400

B. Meshing

Discretization meshing or FEA is the process of converting a continuous solid domain into a discrete computational domain with a finite number of elements so that structural equations can be solved using the FEA numerical method[23]. Then meshing is made using tetrahedral in complex areas such as indentations and details because of the advantages of tetrahedral mesh which is able to form complex geometries. In all building structure geometries, the dimensions are the same, i.e. 100 mm for each element.

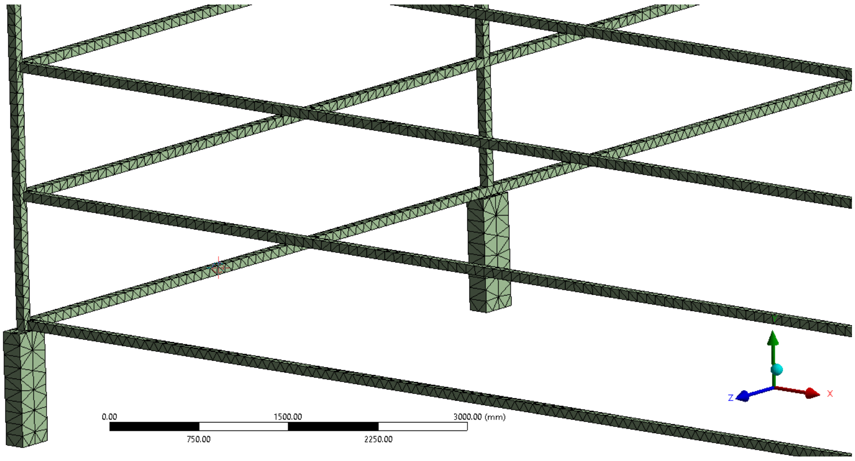

Fig. 11: Meshing on building structures

Statistics	
Nodes	363534
Elements	128703

Table 1: Number of nodes and element mesh on the building structure

While the meshing for the I-Beams model uses a hexa-dominant because of its superiority which is able to form a mesh that does not contain too many elements but has accurate results. In all geometries, the sizes are made the same, i.e. 3 mm for each element.

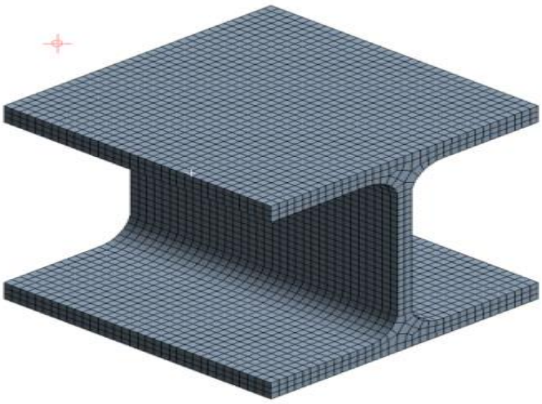

Fig. 12: Meshing on sample frame (I-Beam) without coating

C. Section Factor and Protection Thickness

Thin sections heat up faster than thick sections of equivalent size. Heat transfer is defined as transfer of energy which is caused by temperature difference. When there is temperature difference between two locations in a solid, heat flows by conduction (Forsberg, 2020)[24].

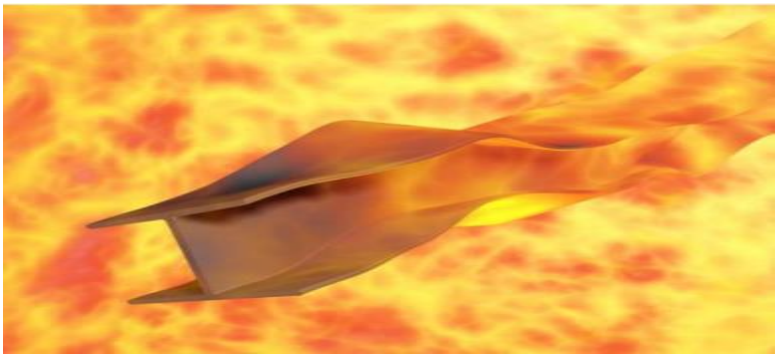

Fig. 13: Deflection on thin section

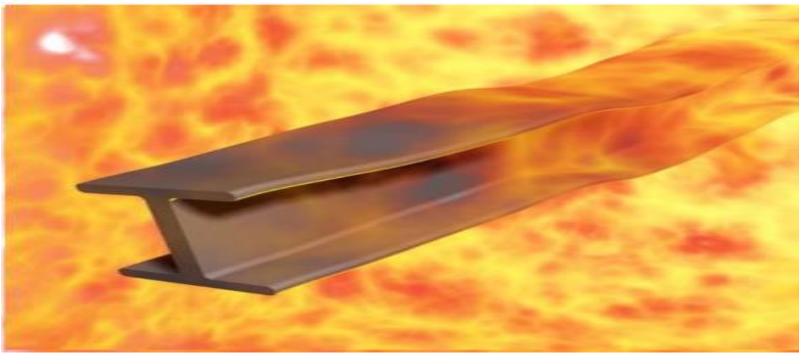

Fig. 14: Deflection on thick section

In the exposure scenario which is considered in performed heat transfer analyses for column models, all exterior sides of the columns uniformly exposed to fire. Accordingly, there were no temperature difference between the nodes which are positioned on axes parallel to height of the column and heat conduction has been acted in two dimensions. Therefore, heat has been flowing across the cross-sections which are perpendicular to the column height. Consequently, all cross-sections along height of each column experience same temperature distributions[25].

Section Factor (Hp/A), is the ratio of the heated perimeter of the steel section to gross cross sectional area of the section which has units of m-1[25].

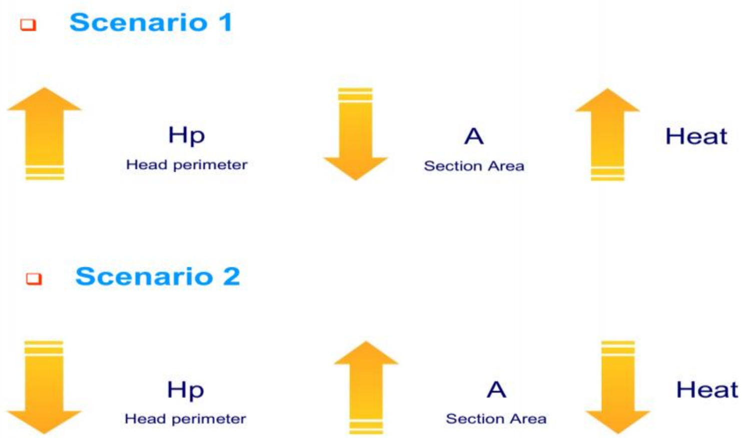

Fig. 15: Deflection on thin section

Then fire rated requirement of Structural Steel (FRL) divides on to 60 min, 120 min, 180 min and 240 min. and then determine the thickness base on table product thickness, the thickness base on section factor (Hp/A) and fire resistance requirement[26].

Section factor (Hp/A), for intumescent coating & cementitious product protection configuration with values of perimeter Hp for use in the calculation of section factor Hp/A (A/V)

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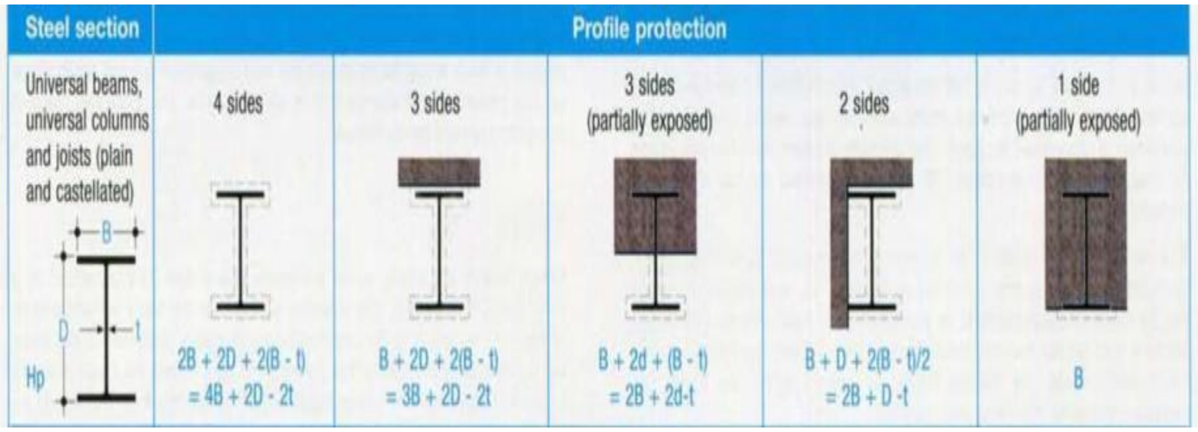

Steel section	Profile protection				
Universal beams, universal columns and joists (plain and castellated)	4 sides	3 sides	3 sides (partially exposed)	2 sides	1 side (partially exposed)
B, D, t, Hp	2B + 2D + 2(B - t) = 4B + 2D - 2t	B + 2D + 2(B - t) = 3B + 2D - 2t	B + 2d + (B - t) = 2B + 2d-t	B + D + 2(B - t)/2 = 2B + D - t	B

Table 2: Hp/A Section factor profile

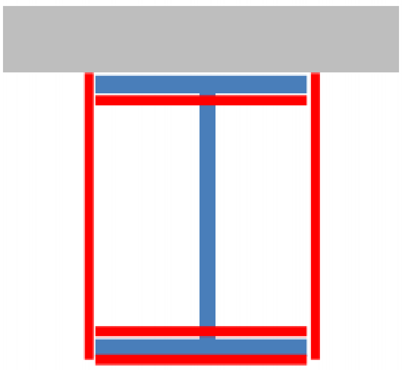

Fig. 16: I-Beam

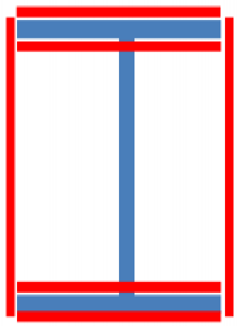

Fig. 17: Column

I-Beam (Wide Flange) with dimension 250 x 125 x 6 x 19, A = 29,6 kg/m

$$Hp = (3\ xB) + (2\ xD) - (2\ xt)$$
$$Hp = (3\ x\ 125) + (2\ x\ 250) - (2\ x\ 6)$$
$$Hp = 863\ mm$$
$$Hp = 0.863\ m$$

Section factor (Hp/A)

$$Hp/A = \frac{0.863 \text{ m x } 7850 \text{ kg/m3}}{29{,}6 \text{ kg/m}}$$
$$Hp/A = 228.8\ m - 1$$

Column (Wide Flange) with dimension 250 x 125 x 6 x 19, A = 29,6 kg/m

$$Hp = (4\ xB) + (2\ xD) - (2\ xt)$$
$$Hp = (4\ x\ 125) + (2\ x\ 250) - (2\ x\ 6)$$
$$Hp = 988\ mm$$
$$Hp = 0.988\ m$$

Section factor (Hp/A)

$$Hp/A = \frac{0.988 \text{ m x } 7850 \text{ kg/m3}}{29{,}6 \text{ kg/m}}$$
$$Hp/A = 262.0\ m - 1$$

Fire rated requirement of Structural Steel (FRL): 1 hour

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- **Protection thickness:**

No.	System	Product	FRL	I-Beam (HP/A = 228,8 m-1)	Column (HP/A = 262,0 m-1)
1.	Intumescent Coating	PromatCafcoSprayfilm WB3	1 hr	0,99 mm	1,14 mm
2.	Wet Spray Vermiculite Cementitious	Promaspray P400	1 hr	17,28 mm	19,14 mm

Table 3: Minimum thickness requirement for coating material on FRL 1 hour

D. Computing settings

In this simulation, the thermal transient mechanical APDL solver is used. The main boundary conditions used are initial temperature, convection, heat flux. Then the material used is Stainless Steel with innate properties and for initial temperature input is 26^0 C (default ambient temperature).

a) Heat Transfer – Convection

To determine that the building structure is in free air, a simplified air approximation is used as the input rather than convection heat transfer. For the frame used, the gas temperature is 1000^0 C.

b) Heat Transfer – Heat Flux

The magnitude of the heat flux is applied to all the various surfaces of the inner building structure. According to (Peter & James. 2013)[27] the total surface heat flux can reach 200 kW/m^2 during a fire. So this value becomes the main benchmark in this simulation.

E. Data retrieval

In this simulation, the results to be studied are the distribution of temperature and total heat flux as follows:

a) Variation 1.A building with a frame structure without fire protection coating application.

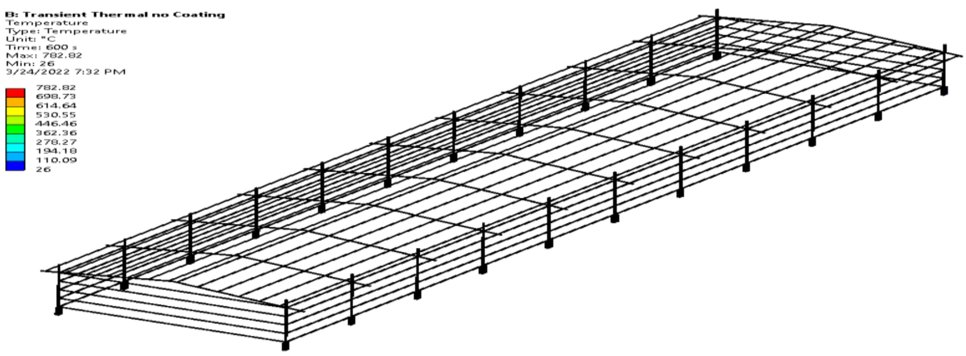

Fig. 18: Temperature distribution in variation 1.A

Figure 18 above shows an increase in temperature during a fire in the steel structure of the Pamitra workshop by convection from the initial temperature of 26^0 C (ambient temperature) at Ansys, shown in blue until it reaches a temperature of $782{,}82^0$ C, shown in red, which is achieved within 600 seconds or 10 minutes.

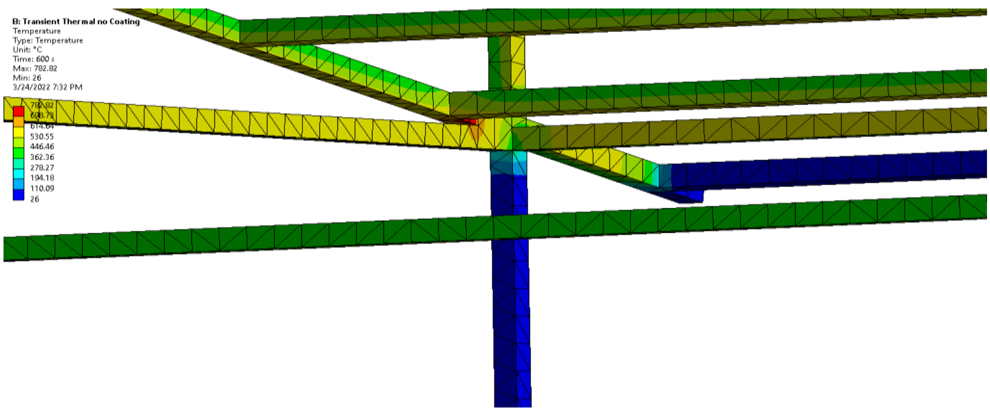

Fig. 19: Detail display of temperature distribution in one part of the building in variation 1.A

Figure 19 above shows a detailed image of the angle of the steel structure workshop building which shows that the beams, rafters and roof of the steel structure experienced a higher temperature rise (above $278{,}27^0$ C) than the column structure of the building during a fire, in Ansys it was indicated by green, yellow and orange areas.

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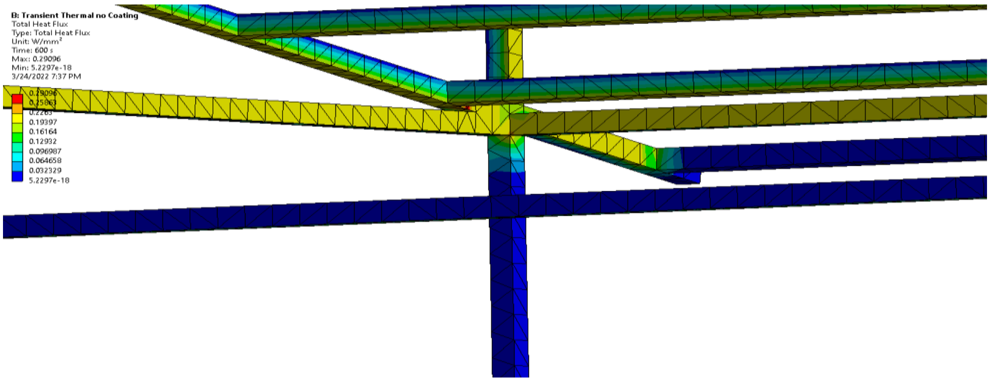

Fig. 20: Detail display of total heat flux in one part of the building in variation 1.A

Figure 20 above shows a detailed image of the angle of the steel structure workshop building which shows that the beam, rafters and roof of the steel structure experienced a higher heat flux increase (above 0,12932) than the column section of the building structure during a fire, in Ansys it is shown with coloured areas, green, yellow and orange.

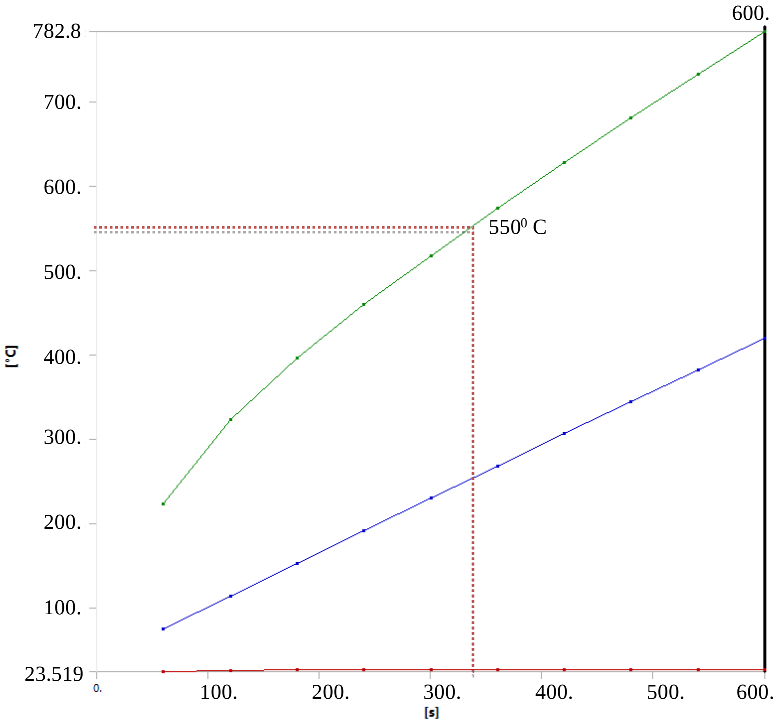

Fig. 21: Comparison of temperature and time at variation 1.A

The picture above shows a significant increase in temperature within 600 seconds or 10 minutes in variation 1.A (steel structure of the workshop building without fireproofing coating protection) from ambient temperature to peak temperature (782,82^0 Celsius). At 340 seconds or at 5.6 minutes the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	60.	23.519	222.35	73.766
2	120.	25.094	322.74	113.
3	180.	25.777	395.79	151.86
4	240.	26.	458.73	190.55
5	300.	26.	517.11	229.09
6	360.	26.	572.97	267.49
7	420.	26.	627.13	305.74
8	480.	26.	680.02	343.85
9	540.	26.	731.87	381.81
10	600.	26.	782.82	419.64

Table 4: Temperature data at variation 1.A

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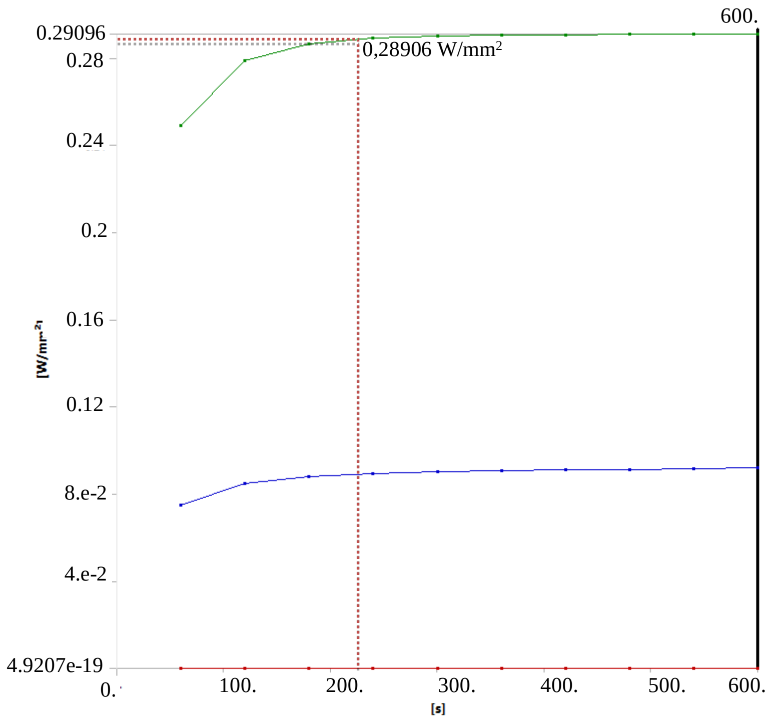

Fig. 22: Total heat flux with time at variation 1.A

The picture above shows a significant increase in heat flux in the first 240 seconds or 4 minutes in variation 1.A (steel structure of the workshop building without fireproofing coating protection) the heat flux has reached 0,28906 W/mm^2.

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	60.	4.2257e-018	0.24893	7.5017e-002
2	120.	4.209e-018	0.27872	8.471e-002
3	180.	4.9549e-018	0.28653	8.8049e-002
4	240.	3.3763e-018	0.28906	8.9513e-002
5	300.	4.4024e-018	0.28999	9.028e-002
6	360.	2.6854e-018	0.29039	9.0747e-002
7	420.	2.9331e-018	0.29061	9.1065e-002
8	480.	4.9207e-019	0.29075	9.1328e-002
9	540.	3.6113e-018	0.29086	9.1572e-002
10	600.	5.2297e-018	0.29096	9.1808e-002

Table 5: Total heat flux at variation 1.A

b) Variation 1.B building with a frame structure with fire protection layer type intumescent Cafco spray film WB3

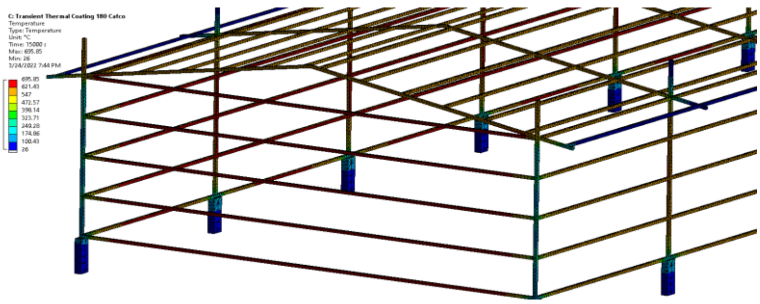

Fig. 23: Temperature distribution at variation 1.B

Figure 23 above shows an increase in temperature during a fire in the steel structure of the Pamitra workshop building which is protected by a fireproofing intumescent coating by convection from an initial temperature of 26^0 Celsius (ambient temperature) at Ansys, shown in blue until it reaches a temperature of $695{,}85^0$ Celsius, shown in red, which was achieved in time 15000 seconds or 250 minutes or 4,1 hours.

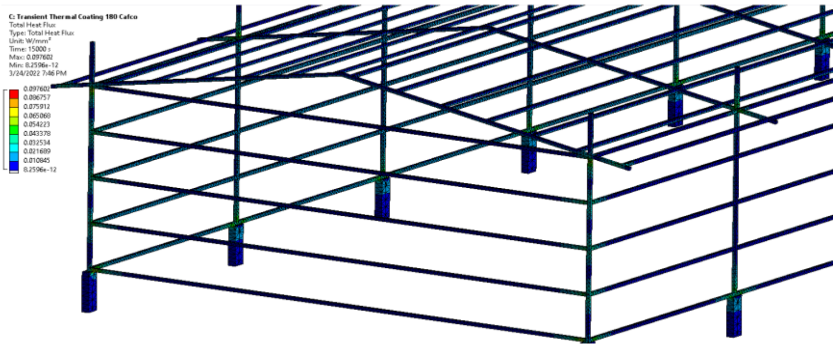

Fig. 24: Total heat flux at variation 1.B

Figure 24 above shows an increase in heat flux during a fire in the steel structure of the Pamitra workshop building which is protected by a convective fireproofing intumescent coating from 8,2596e-12 to 0,097602 W/mm^2 within 15000 seconds or 250 minutes or 4.1 hours.

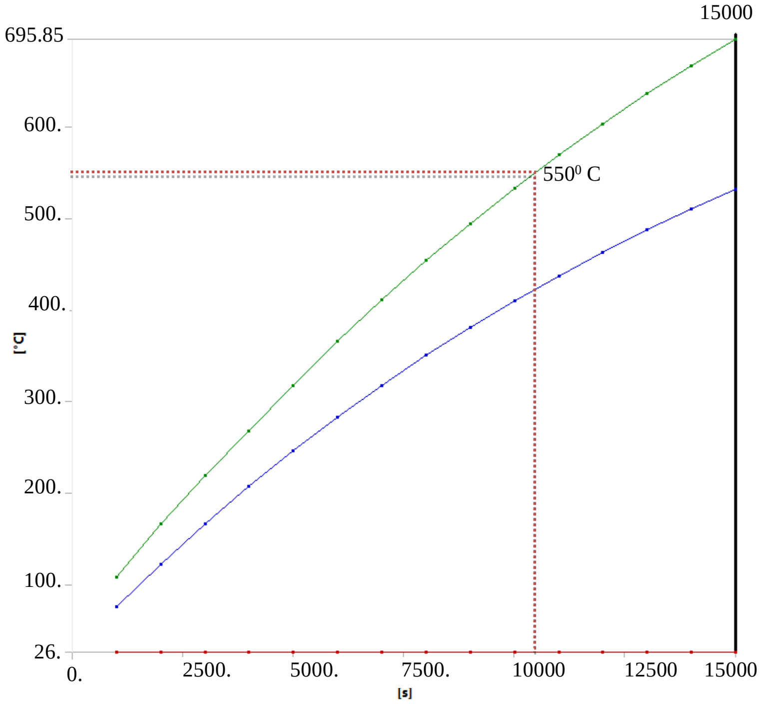

Fig. 25: Comparison of temperature and time at variation 1.B

In the picture above, it can be seen that the temperature increase is quite long in a period of 15000 seconds or 4.1 hours in variation 1.B (steel structure of the workshop building protected by a fireproofing intumescent coating) from ambient temperature to peak temperature (695,85^0 Celsius). At 10500 seconds or at 175 minutes or 2.9 hours the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	1000.	26.	108.01	76.01
2	2000.	26.	166.24	122.45
3	3000.	26.	218.66	166.21
4	4000.	26.	267.09	207.45
5	5000.	26.	317.35	246.34
6	6000.	26.	365.42	282.99
7	7000.	26.	410.88	317.56
8	8000.	26.	453.85	350.15
9	9000.	26.	494.49	380.89
10	10000	26.	532.92	409.88
11	11000	26.	569.25	437.23
12	12000	26.	603.61	463.02
13	13000	26.	636.09	487.35
14	14000	26.	666.81	510.3
15	15000	26.	695.85	531.95

Table 6: Temperature data at variation 1.B

15000
9.7602e-2

8.75e-2

7.5e-2

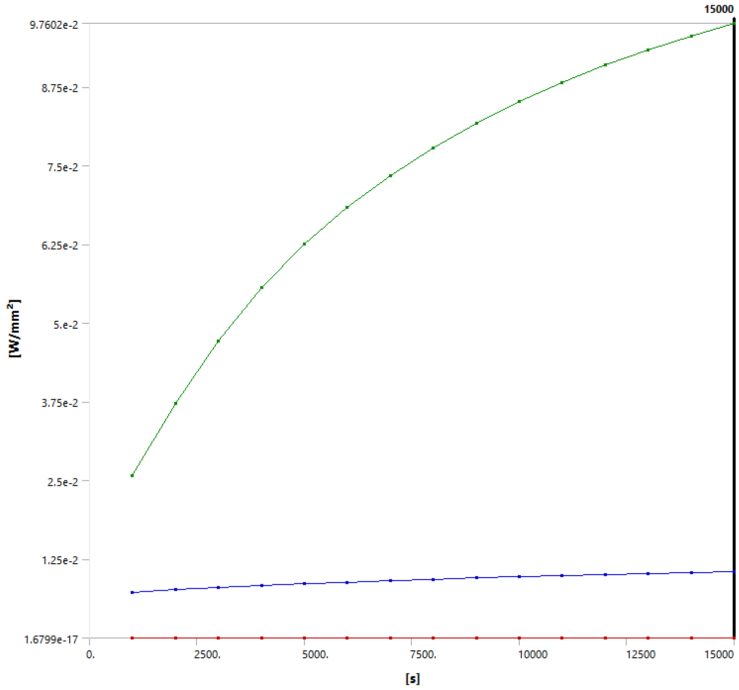

Fig. 26: Total heat flux with time at variation 1.B

In the picture above, it can be seen that the increase in heat flux is quite long in a period of 15000 seconds or 4.1 hours in variation 1.B (the steel structure of the workshop building protected by a fireproofing intumescent coating). The heat flux reaches 9,7602e-002 W/mm^2.

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	1000.	1.6799e-017	2.5717e-002	7.2761e-003
2	2000.	4.7567e-017	3.7273e-002	7.7396e-003
3	3000.	2.2298e-016	4.7176e-002	8.0336e-003
4	4000.	9.4522e-016	5.5596e-002	8.3111e-003
5	5000.	3.3535e-015	6.253e-002	8.5758e-003
6	6000.	1.1368e-014	6.8397e-002	8.8277e-003
7	7000.	3.1163e-014	7.3449e-002	9.067e-003
8	8000.	8.1851e-014	7.7854e-002	9.294e-003
9	9000.	1.6315e-013	8.173e-002	9.5092e-003
10	10000	3.3321e-013	8.5164e-002	9.713e-003
11	11000	7.0561e-013	8.8221e-002	9.9059e-003
12	12000	1.4834e-012	9.0956e-002	1.0088e-002
13	13000	2.9824e-012	9.3408e-002	1.0261e-002
14	14000	5.5016e-012	9.5614e-002	1.0424e-002
15	15000	8.2596e-012	9.7602e-002	1.0579e-002

Table 7: Total heat flux at variation 1.B

c) Variation 1.C building with a frame structure with fire protection type wet spray vermiculate cementitious Promaspray P400

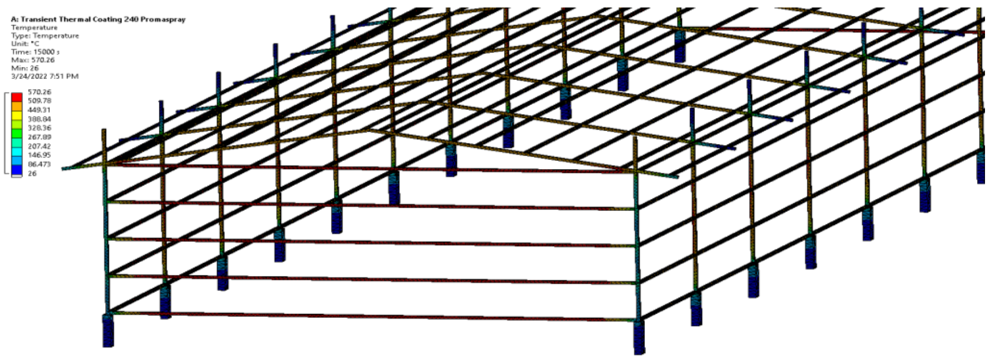

Fig. 27: Temperature distribution at variation 1.C

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In Figure 27 above, it can be seen that the temperature increase during a fire in the steel structure of the Pamitra workshop building which is protected by a fireproofing Promaspray coating by convection from an initial temperature of 26^0 Celsius (ambient temperature) at Ansys is shown in blue until it reaches a temperature of $570{,}26^0$ Celsius, which is shown in red which was achieved in time 15000 seconds or 250 minutes or 4.1 hours.

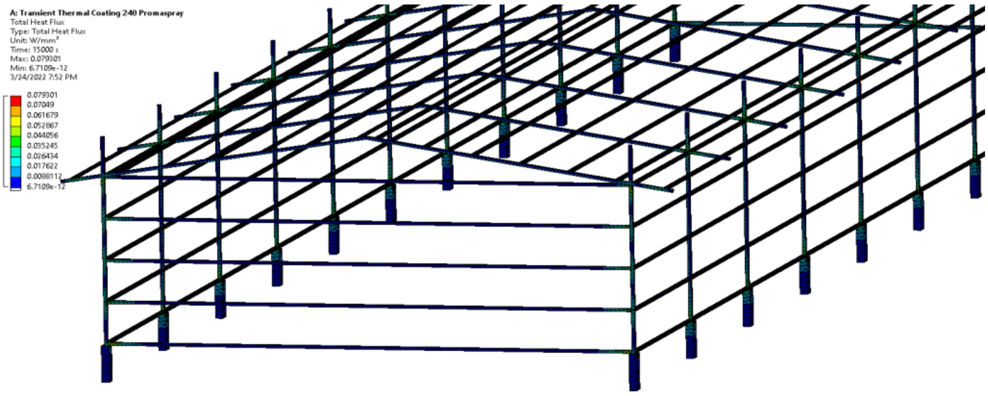

Fig. 28: Total heat flux at variation 1.C

Figure 28 above shows an increase in heat flux during a fire in the steel structure of the Pamitra workshop building which is protected by a fireproofing Promaspray coating by convection from 2,0895e-002 to 7,9301e-002 W/mm^2 within 15000 seconds or 250 minutes or 4,1 hours.

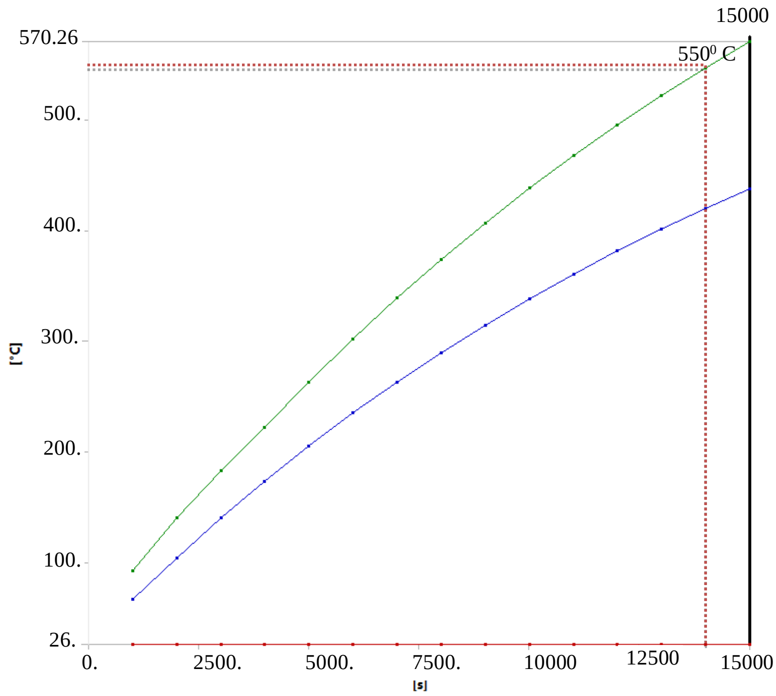

Fig. 29: Comparison of temperature and time at variation 1.C

In the picture above, it can be seen that the temperature increase is quite long in a period of 15000 seconds or 4.1 hours in variation 1.C (the steel structure of the workshop building protected by a fireproofing Promaspray coating) from ambient temperature to peak temperature ($570{,}26^0$ Celsius). At 13250 seconds or at 220 minutes or 3.6 hours the temperature reaches 550^0 C or the critical temperature.

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	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	1000.	26.	92.632	66.633
2	2000.	26.	139.94	104.37
3	3000.	26.	182.54	139.92
4	4000.	26.	221.89	173.43
5	5000.	26.	262.72	205.02
6	6000.	26.	301.78	234.81
7	7000.	26.	338.71	262.89
8	8000.	26.	373.63	289.37
9	9000.	26.	406.65	314.35
10	10000	26.	437.87	337.9
11	11000	26.	467.39	360.12
12	12000	26.	495.31	381.08
13	13000	26.	521.7	400.85
14	14000	26.	546.66	419.49
15	15000	26.	570.26	437.09

Table 8: Temperature data at variation 1.C

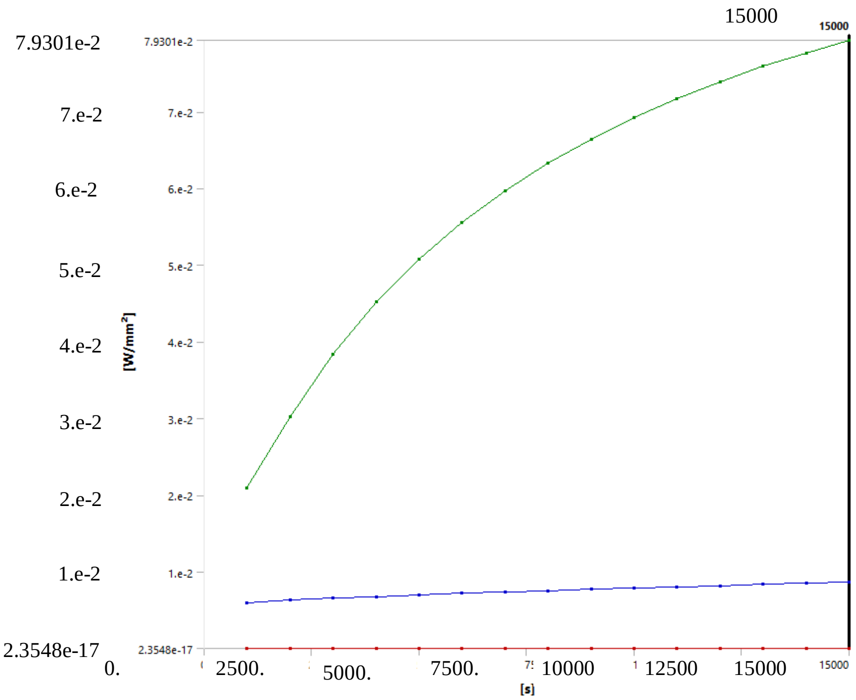

Fig. 30: Total heat flux with time at variation 1.C

In the picture above, it can be seen that the increase in heat flux is quite long in a period of 15000 seconds or 4.1 hours in variation 1.C (steel structure of the workshop building protected by a fireproofing Promaspray coating) heat flux reaching 7,9301e-002 W/mm^2.

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	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	1000.	2.3548e-017	2.0895e-002	5.9118e-003
2	2000.	3.7206e-017	3.0285e-002	6.2884e-003
3	3000.	1.6819e-016	3.833e-002	6.5273e-003
4	4000.	7.76e-016	4.5171e-002	6.7527e-003
5	5000.	2.743e-015	5.0806e-002	6.9678e-003
6	6000.	9.2733e-015	5.5573e-002	7.1725e-003
7	7000.	2.5322e-014	5.9678e-002	7.367e-003
8	8000.	6.648e-014	6.3257e-002	7.5514e-003
9	9000.	1.3255e-013	6.6406e-002	7.7262e-003
10	10000	2.7075e-013	6.9196e-002	7.8918e-003
11	11000	5.733e-013	7.168e-002	8.0485e-003
12	12000	1.2052e-012	7.3901e-002	8.1969e-003
13	13000	2.4232e-012	7.5894e-002	8.3372e-003
14	14000	4.4701e-012	7.7686e-002	8.4699e-003
15	15000	6.7109e-012	7.9301e-002	8.5954e-003

Table 9: Total heat flux at variation 1.C

d) Variation 2.A The structure of the building is in the form of I-Beam without fire protection coating application

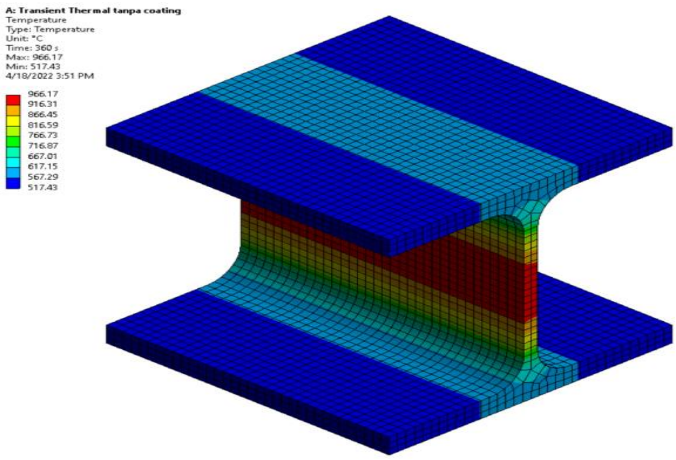


Fig. 31: Temperature distribution at variation 2.A

Figure 31 above shows an increase in temperature during a fire in the I Beam structure of the Pamitra workshop building which is not protected by a convective fireproofing layer from an initial temperature of 517^0 Celsius at Ansys, shown in blue until it reaches a temperature of $966,17^0$ Celsius, shown in red which is achieved within 360 seconds or 6 minute.

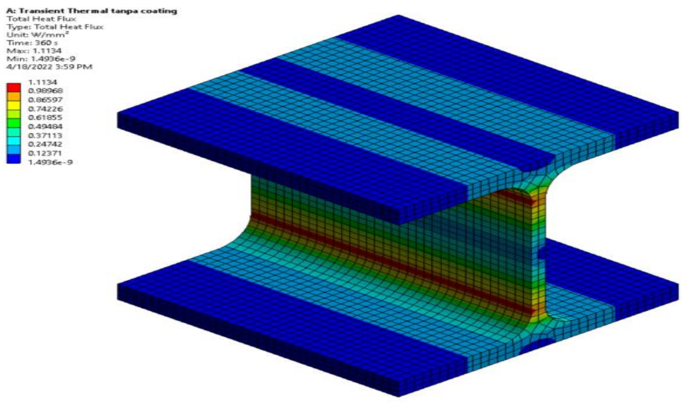


Fig. 32: Total heat flux at variation 2.A

Figure 32 above shows an increase in heat flux during a fire in the I Beam structure of the Pamitra workshop building which is not protected by a convection fireproofing layer from 1,4936e-9 to 1,1134 W/mm^2 in 360 seconds or 6 minutes.

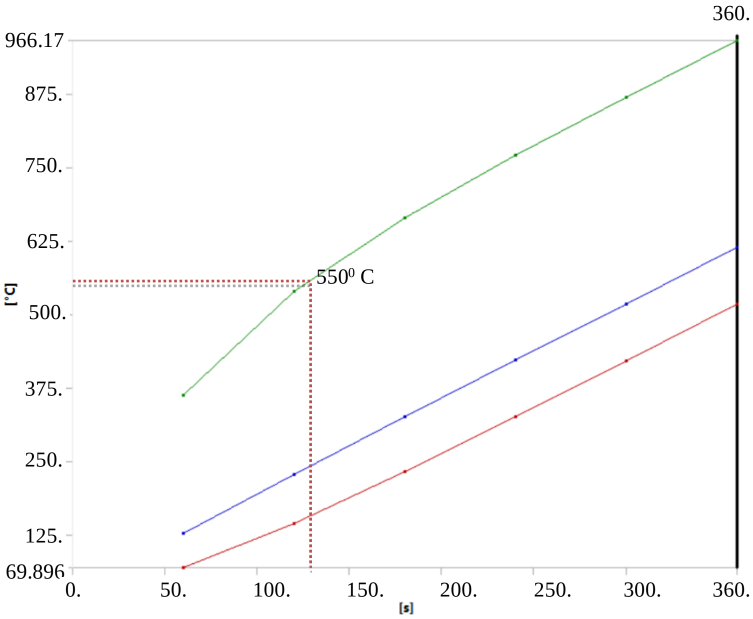


Fig. 33: Comparison of temperature and time at variation 2.A

In the picture above, it can be seen that the temperature increase is quite short within 360 seconds or 6 minutes in variation 2.A (I Beam Pamitra workshop building structure which is not protected by a fireproofing layer) from the initial temperature of 517^0 Celsius to the peak temperature (966,17^0 Celsius). At 130 seconds or at 2.1 minutes the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	60.	69.896	362.77	128.88
2	120.	144.26	540.33	228.01
3	180.	232.66	665.05	325.76
4	240.	326.42	771.08	422.61
5	300.	421.83	870.1	518.7
6	360.	517.43	966.17	614.07

Table 10: Comparison of temperature and time at variation 2.A

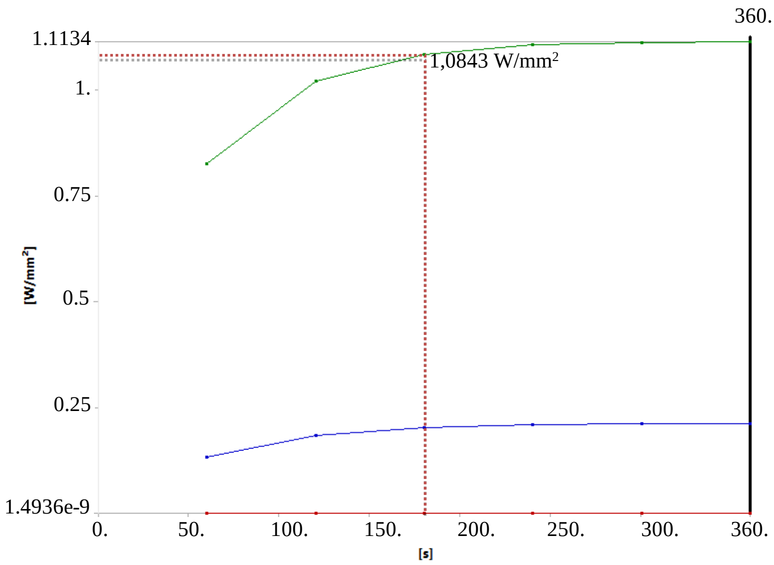


Fig. 34: Total heat flux with time at variation 2.A

The picture above shows a significant increase in heat flux in the first 180 seconds or 3 minutes in variation 2.A (I Beam Pamitra workshop building structure which is not protected by a fireproofing layer) heat flux has reached 1,0843 W/mm^2.

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	60.	1.9783e-006	0.82411	0.13321
2	120.	4.1101e-007	1.0199	0.18332
3	180.	4.9541e-007	1.0843	0.20217
4	240.	2.296e-007	1.1056	0.20896
5	300.	6.1977e-008	1.1121	0.21128
6	360.	1.4936e-009	1.1134	0.21195

Table 11: Total heat flux at variation 2.A

e) Variation 2.B The structure of the building is in the form of I-Beam with fire protection layer type intumescent Cafco spray film WB3

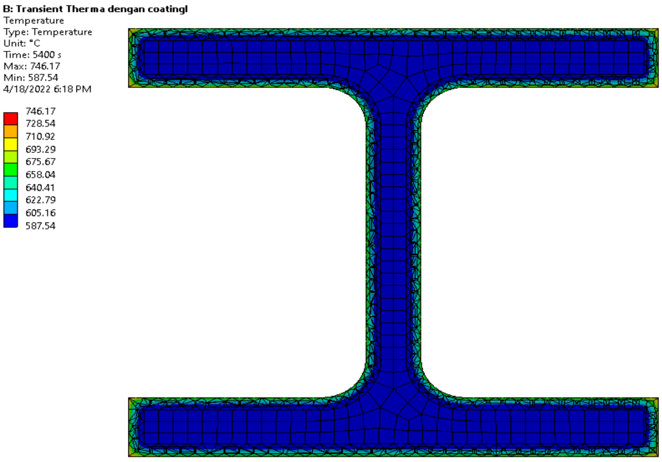


Fig. 35: Temperature distribution at variation 2.B

Figure 35 above shows an increase in temperature during a fire in the I Beam structure of the Pamitra workshop building which is protected by a fireproofing intumescent coating by convection from an initial temperature of 587,54^0 Celsius at Ansys, shown in blue until it reaches a temperature of 746,17^0 Celsius, shown in red which is achieved in 5400 seconds or 90 minutes or 1.5 hours.

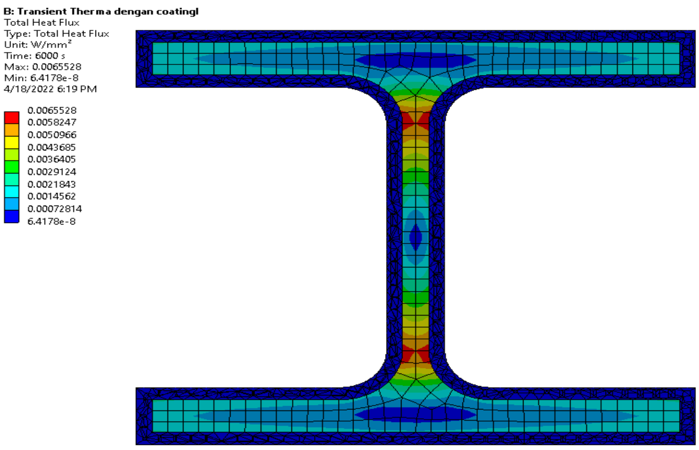
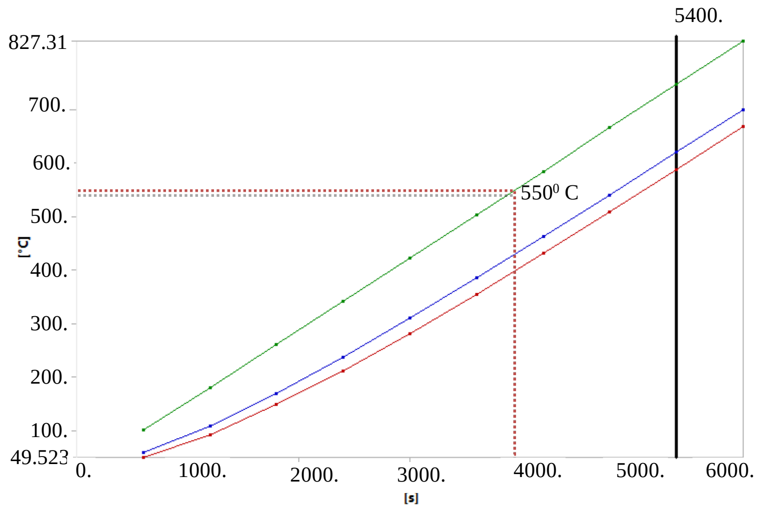


Fig. 36: Total heat flux at variation 2.B

Figure 36 above shows an increase in heat flux during a fire in the I Beam structure of the Pamitra workshop building which is protected by a convective fireproofing intumescent coating from 6,4178e-8 to 0,0065528 W/mm^2 in 5400 seconds or 90 minutes or 1, 5 hours.


5400.
827.31
700.
600.
550⁰ C
500.
[°C]
400.
300.
200.
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49.523
0.
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2000.
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5000.
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Fig. 37: Comparison of temperature and time at variation 2.B

In the picture above, it can be seen that the temperature increase is quite long in a period of 6000 seconds or 100 minutes or 1.6 hours at variation 2.B (I Beam Pamitra workshop building structure which is protected by a fireproofing intumescent coating) from the initial temperature to the peak temperature (827,31^0 Celsius). At 3950 seconds or at 65 minutes or 1,1 hours the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	600.	49.523	100.75	58.504
2	1200.	92.199	180.	108.53
3	1800.	147.69	260.31	169.33
4	2400.	211.71	341.02	237.02
5	3000.	281.41	421.91	309.22
6	3600.	354.9	502.9	384.4
7	4200.	430.94	583.96	461.57
8	4800.	508.67	665.05	540.06
9	5400.	587.54	746.17	619.43
10	6000.	667.16	827.31	699.4

Table 12: Temperature data at variation 2.B

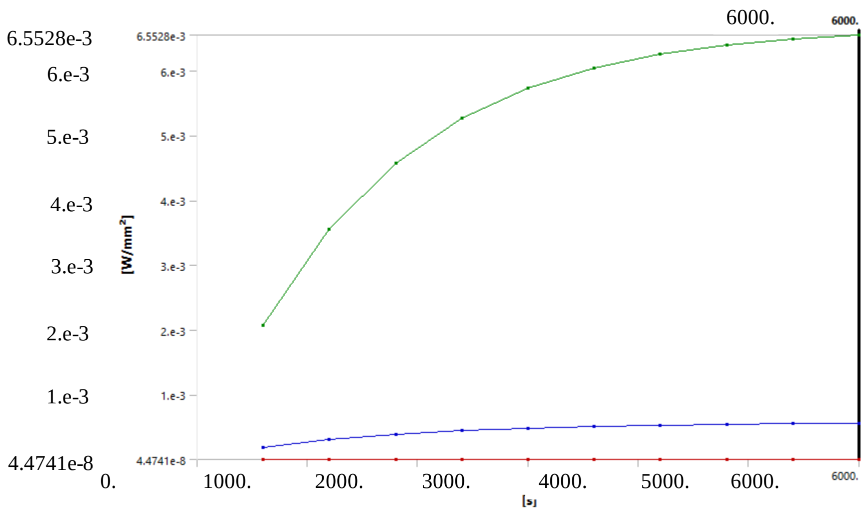

Fig. 38: Total heat flux with time at variation 2.B

In the picture above, it can be seen that the increase in heat flux is quite long in a period of 6000 seconds or 100 minutes or 1.6 hours in variation 2.B (I Beam Pamitra workshop building structure which is protected by a fireproofing intumescent coating) heat flux reaches 6,5528e-003 W /mm^2.

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	600.	1.2266e-007	2.067e-003	1.7912e-004
2	1200.	8.7103e-008	3.5512e-003	3.0448e-004
3	1800.	9.1567e-008	4.5713e-003	3.897e-004
4	2400.	1.0214e-007	5.2637e-003	4.4749e-004
5	3000.	8.9128e-008	5.7304e-003	4.8645e-004
6	3600.	7.9645e-008	6.044e-003	5.1263e-004
7	4200.	4.4741e-008	6.2543e-003	5.3019e-004
8	4800.	6.8856e-008	6.3952e-003	5.4196e-004
9	5400.	6.6032e-008	6.4896e-003	5.4984e-004
10	6000.	6.4178e-008	6.5528e-003	5.5512e-004

Table 13: Total heat flux at variation 2.B

f) Variation 2.C The structure of the building is in the form of I-Beam with fire protection type wet spray vermiculate cementitious Promaspray P400

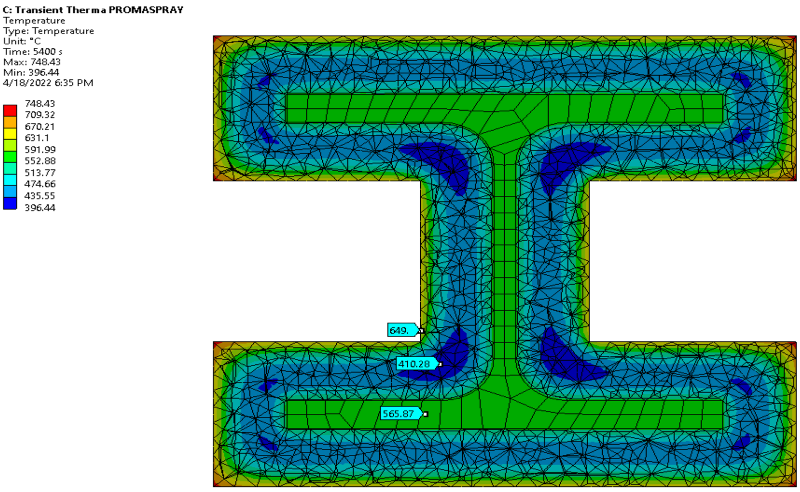

Fig. 39: Temperature distribution at variation 2.C

Figure 39 above shows an increase in temperature during a fire in the I Beam structure of the Pamitra workshop building which is protected by a fireproofing Promaspray coating by convection from an initial temperature of 396,44^0 Celsius at Ansys, shown in blue until it reaches a temperature of 748,43^0 Celsius, shown in red which is achieved within 5400 seconds or 90 minutes or 1.5 hours. The picture shows that the inside is protected by Promaspray (565,87^0 C) compared to the outside (649^0 C).

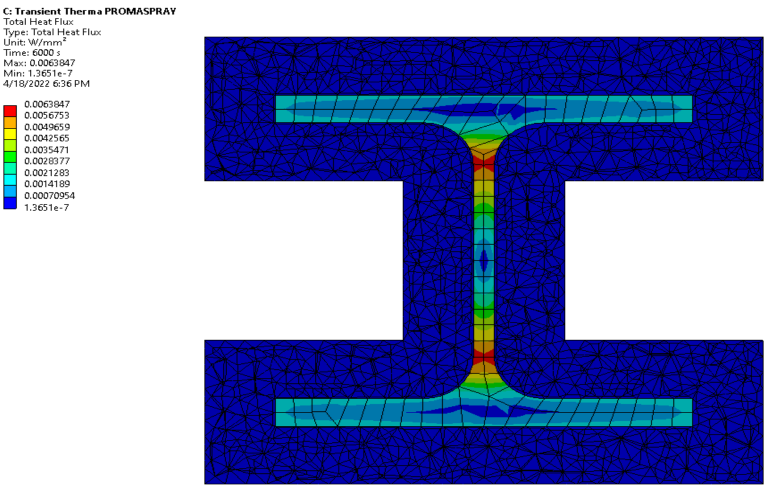

Fig. 40: Total heat flux at variation 2.C

Figure 40 above shows an increase in heat flux during a fire in the I Beam structure of the Pamitra workshop building which is protected by a fireproofing Promaspray coating by convection from 1,3651e-7 to 0,0063847 W/mm^2 in 6000 seconds or 100 minutes or 1, 6 hours.

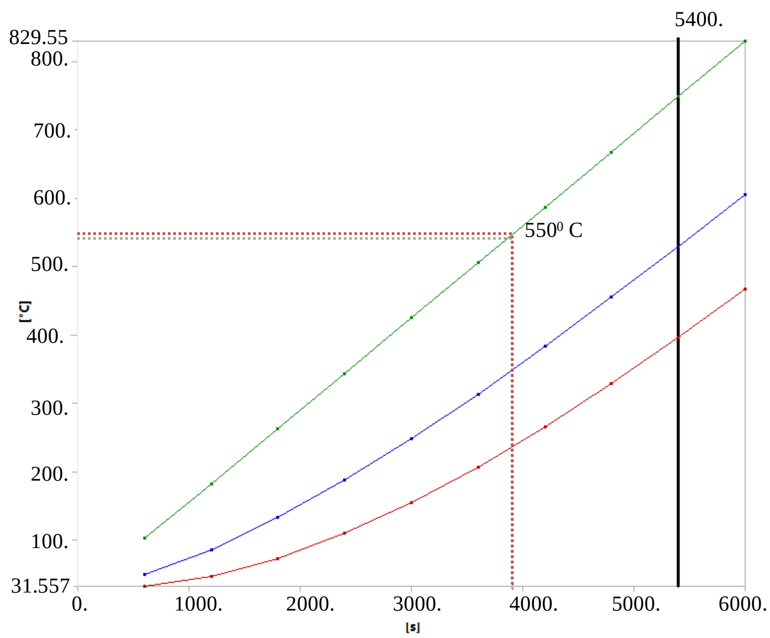

Fig. 41: Comparison of temperature and time at variation 2.C

In the picture above, it can be seen that the temperature increase is quite long in a period of 6000 seconds or 100 minutes or 1.6 hours at variation 2.C (I Beam Pamitra workshop building structure which is protected by a fireproofing Promaspray coating) from the initial temperature to the peak temperature (829,55^{0} Celsius). At 3950 seconds or at 65 minutes or 1.1 hours the temperature reaches 550^{0} C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	600.	31.557	102.14	48.549
2	1200.	46.664	181.94	85.056
3	1800.	72.556	262.48	131.91
4	2400.	108.71	343.28	186.68
5	3000.	153.84	424.21	247.56
6	3600.	206.49	505.21	313.16
7	4200.	265.24	586.26	382.38
8	4800.	328.9	667.33	454.4
9	5400.	396.44	748.43	528.57
10	6000.	467.01	829.55	604.39

Table 14: Temperature data at variation 2.C

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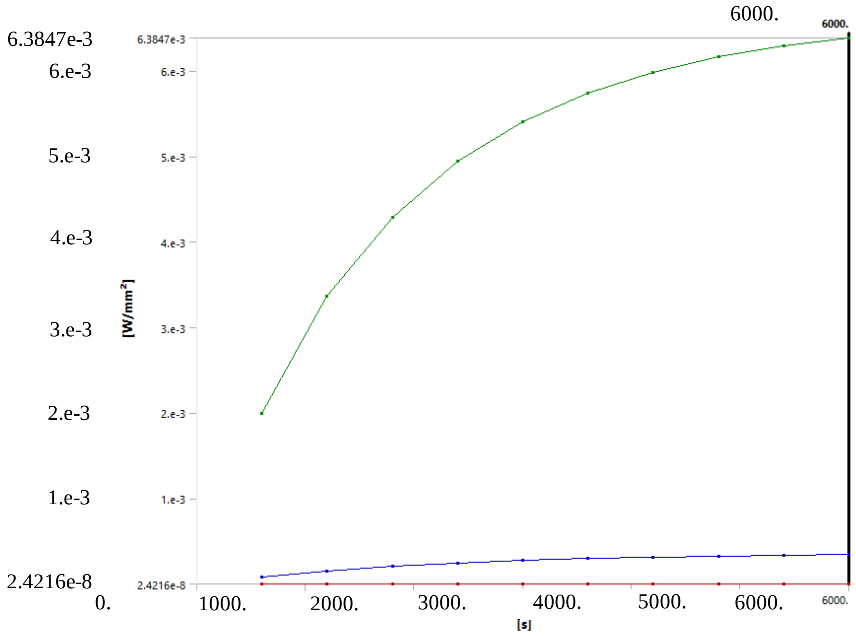

Fig. 42: Total heat flux with time at variation 2.C

In the picture above, it can be seen that the increase in heat flux is quite long in a period of 6000 seconds or 100 minutes or 1.6 hours in variation 2.C (I Beam Pamitra workshop building structure which is protected by a fireproofing Promaspray coating) heat flux reaches 6,3847e-003 W /mm^2.

	Time [s]	Minimum $[W/mm^2]$	Maximum $[W/mm^2]$	Average $[W/mm^2]$
1	600.	2.4216e-008	1.9923e-003	8.3473e-005
2	1200.	6.1257e-008	3.3606e-003	1.5041e-004
3	1800.	7.0778e-008	4.2896e-003	2.0194e-004
4	2400.	2.6822e-008	4.9443e-003	2.413e-004
5	3000.	4.224e-008	5.4099e-003	2.713e-004
6	3600.	9.2667e-008	5.7433e-003	2.9415e-004
7	4200.	7.6586e-008	5.9844e-003	3.1154e-004
8	4800.	1.9997e-007	6.1604e-003	3.2479e-004
9	5400.	1.098e-007	6.2895e-003	3.3487e-004
10	6000.	1.3651e-007	6.3847e-003	3.4254e-004

Table 15: Total heat flux at variation 2.C

g) Variation 3.A The structure of the building is I-Beam with Stiffener without fire protection coating application

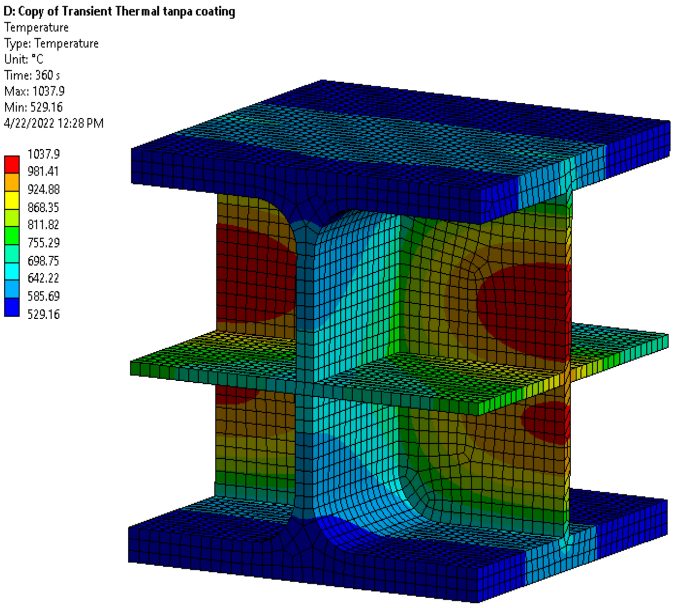

Fig. 43: Temperature distribution at variation 3.A

In Figure 43 above, it can be seen that the temperature increase during a fire on the I Beam with a stiffener of the Pamitra workshop building structure which is not protected by a convection fireproofing layer from an initial temperature of $529{,}16^0$ Celsius at Ansys is shown in blue until it reaches a temperature of $1037{,}9^0$ Celsius, which is shown in red. 360 seconds or 6 minutes.

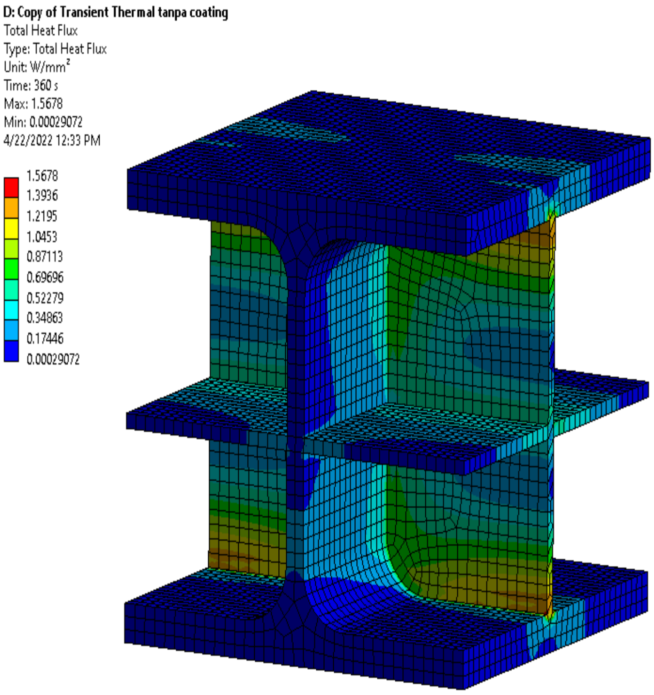

Fig. 44: Total heat flux at variation 3.A

Figure 44 above shows an increase in heat flux during a fire in the I Beam with a stiffener for the Pamitra workshop building structure that is not protected by a convection fireproofing layer from 0,00029072 to 1,5678 W/mm^2 in 360 seconds or 6 minutes.

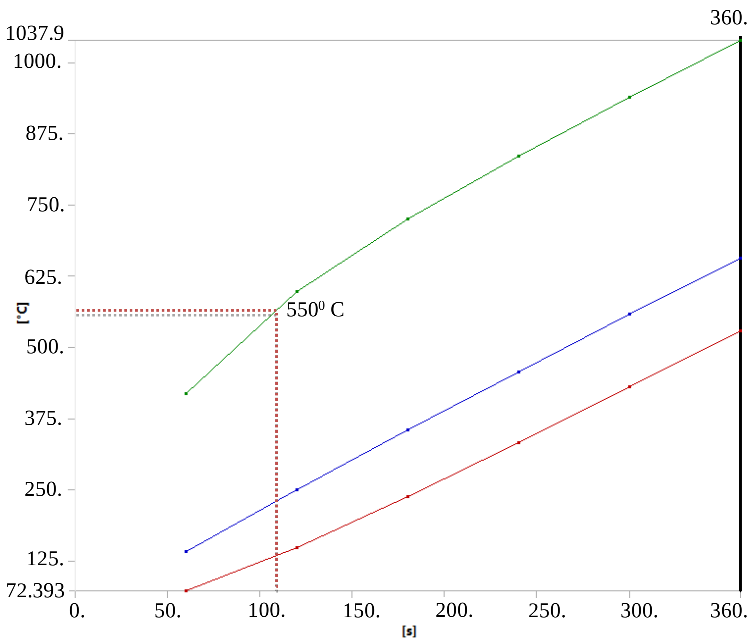

Fig. 45: Comparison of temperature and time at variation 3.A

In the picture above, it can be seen that the temperature increase is quite short in a period of 360 seconds or 6 minutes in variation 3.A (I Beam with stiffener Pamitra workshop building structure which is not protected by a fireproofing layer) from the initial temperature of $72{,}393^0$ Celsius to the peak temperature ($1037{,}9^0$celcius). At 110 seconds or at 1.8 minutes the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	60.	72.393	417.48	141.84
2	120.	147.95	597.92	249.81
3	180.	237.23	724.47	354.23
4	240.	332.6	834.53	456.51
5	300.	430.49	937.9	557.24
6	360.	529.16	1037.9	656.7

Table 16: Temperature data at variation 3.A

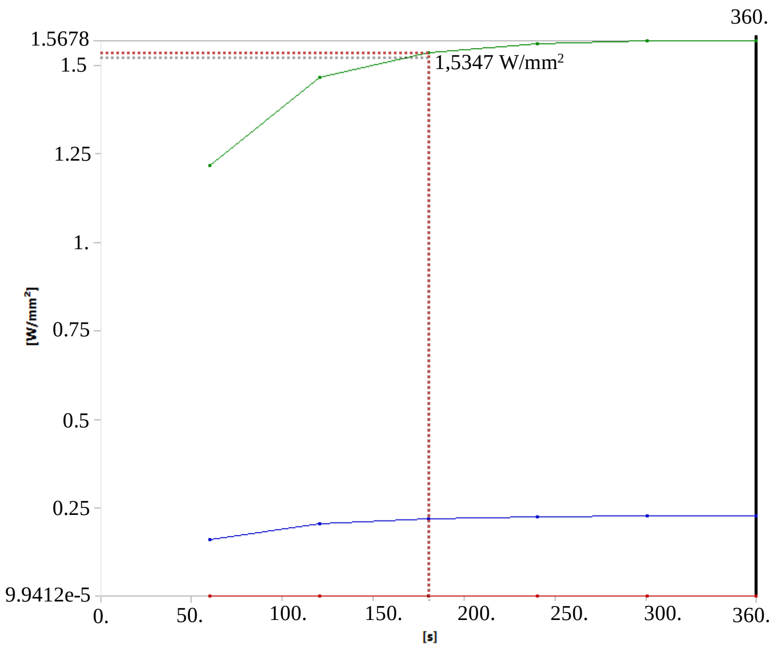

Fig. 46: Total heat flux against time at variation 3.A

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The picture above shows a significant increase in heat flux in the first 180 seconds or 3 minutes in variation 3.A (I Beam with stiffener for Pamitra's workshop building structure which is not protected by a fireproofing layer). The heat flux has reached 1,5347 W/mm^2.

	Time [s]	Minimum [W/mm^2]	Maximum [W/mm^2]	Average [W/mm^2]
1	60.	9.9412e-005	1.2167	0.1583
2	120.	2.2777e-004	1.4631	0.20342
3	180.	1.9387e-004	1.5347	0.21848
4	240.	2.3531e-004	1.5589	0.22397
5	300.	2.4083e-004	1.5667	0.22594
6	360.	2.9072e-004	1.5678	0.22644

Table 17: Total heat flux at variation 3.A

h) Variation 3.B The structure of the building is I-Beam with Stiffener Beam with fire protection layer type intumescent Cafco spray film WB3

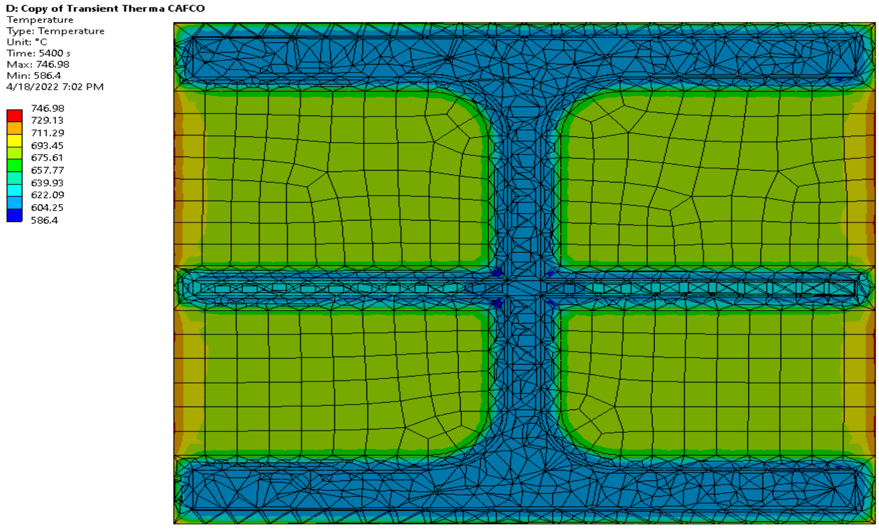

Fig. 47: Temperature distribution at variation 3.B

Figure 47 above shows an increase in temperature during a fire in the I Beam with a stiffener for the Pamitra workshop building structure which is protected by a convection fireproofing intumescent coating from an initial temperature of 586,4^0 Celsius at Ansys shown in blue until it reaches a temperature of 746,98^0 Celsius, which is shown in red 5400 seconds or 90 minutes or 1.5 hours.

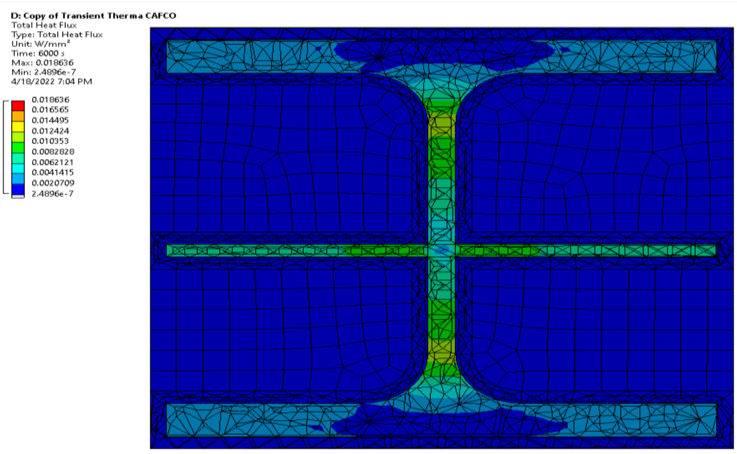

Fig. 48: Total heat flux at variation 3.B

Figure 48 above shows an increase in heat flux during a fire in the I Beam with the Pamitra workshop building structure stiffener protected by a convection fireproofing intumescent coating from 2,4896e-7 to 0,018636 W/mm^2 in 6000 seconds or 100 minutes or 1.6 hours.

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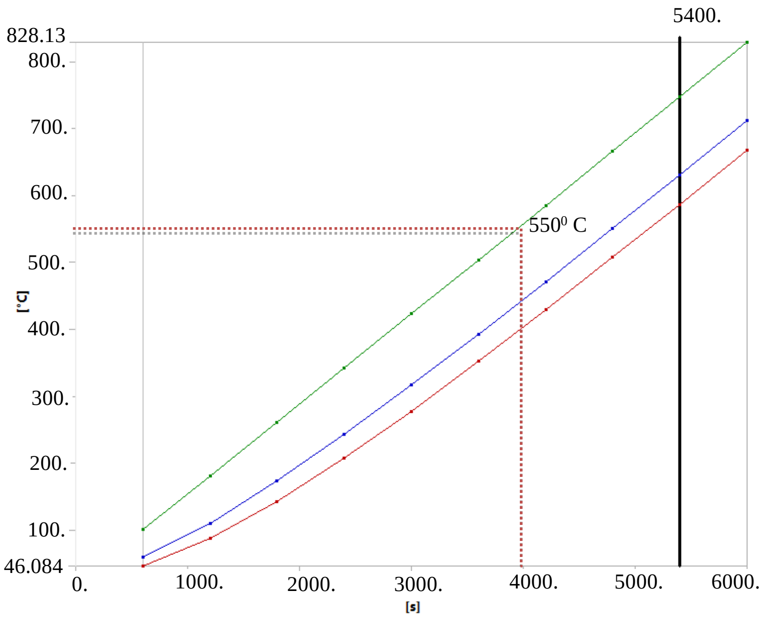

Fig. 49: Comparison of temperature and time at variation 3.B

In the picture above, it can be seen that the temperature increase is quite long in a period of 6000 seconds or 100 minutes or 1.6 hours at variation 3.B (I Beam structure with stiffener Pamitra workshop building protected by a fireproofing intumescent coating) from the initial temperature to the peak temperature (828,13^{0}celcius). At 4000 seconds or at 66 minutes or 1,1 hours the temperature reaches 550^0 C or the critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	600.	46.084	100.82	58.909
2	1200.	87.154	180.3	110.25
3	1800.	142.13	260.79	172.82
4	2400.	206.54	341.6	242.32
5	3000.	277.08	422.57	316.15
6	3600.	351.52	503.62	392.7
7	4200.	428.45	584.71	470.95
8	4800.	506.93	665.84	550.28
9	5400.	586.4	746.98	630.29
10	6000.	666.5	828.13	710.72

Table 18: Temperature data at variation 3.B

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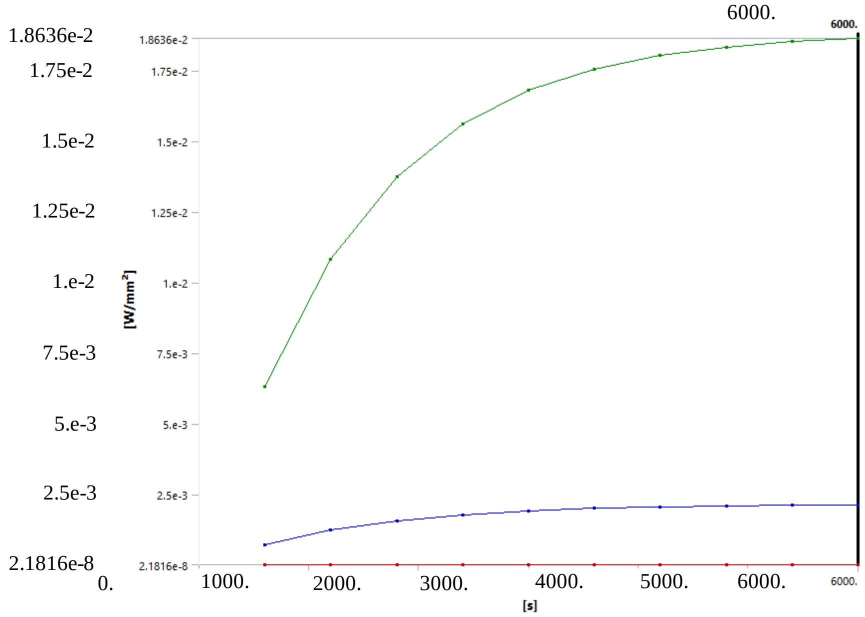

Fig. 50: Total heat flux with time at variation 3.B

In the picture above, it can be seen that the increase in heat flux is quite long in a period of 6000 seconds or 100 minutes or 1,6 hours in variation 3.B (I Beam with stiffener Pamitra workshop building structure protected by a fireproofing intumescent coating) heat flux reaches 1,8636e-002 W/mm^2.

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	600.	3.1812e-008	6.3179e-003	7.1398e-004
2	1200.	2.1816e-008	1.0799e-002	1.2268e-003
3	1800.	9.2939e-008	1.3724e-002	1.5616e-003
4	2400.	1.8373e-007	1.5598e-002	1.776e-003
5	3000.	4.4267e-008	1.679e-002	1.9124e-003
6	3600.	2.2075e-007	1.7545e-002	1.9988e-003
7	4200.	2.1341e-007	1.8023e-002	2.0535e-003
8	4800.	9.6163e-008	1.8325e-002	2.088e-003
9	5400.	2.0833e-007	1.8516e-002	2.1098e-003
10	6000.	2.4896e-007	1.8636e-002	2.1236e-003

Table 19: Total heat flux at variation 3.B

Variation 3.C The structure of the building is I-Beam with Stiffener with fire protection type wet spray vermiculate cementitious Promaspray P400

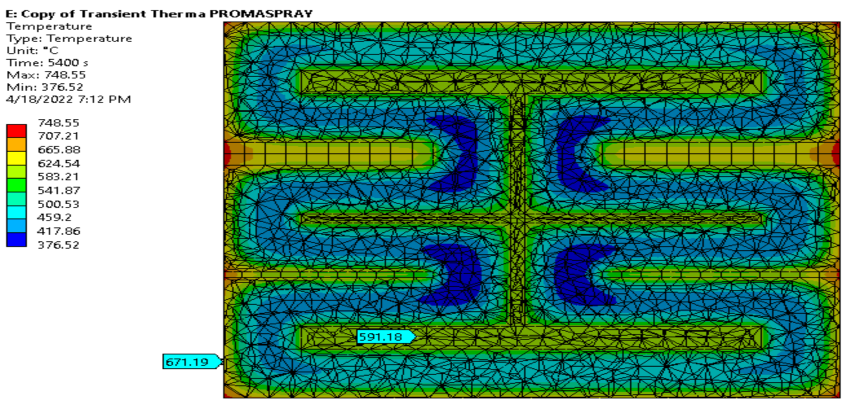

Fig. 51: Temperature distribution at variation 3.C

In Figure 51 above, it can be seen that the temperature increase during a fire in the I Beam structure with the Pamitra workshop building stiffener protected by a fireproofing Promaspray coating by convection from an initial temperature of 376.52^0 Celsius at Ansys is shown in blue until it reaches a temperature of 748,55^0 Celsius, which is shown in red which is achieved within 5400 seconds or 90 minutes or 1.5 hours. The picture shows that the inside is protected by Promaspray (591,18^0 C) compared to the outside (671,19^0 C).

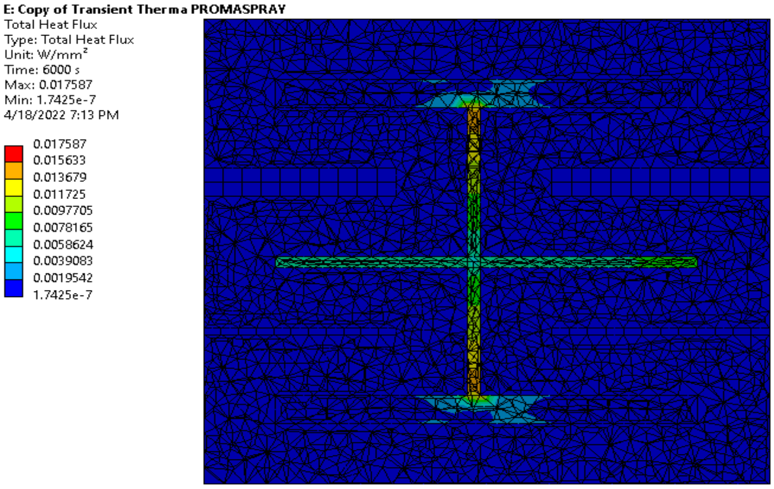

Fig. 52: Total heat flux at variation 3.C

Figure 52 above shows an increase in heat flux during a fire in the I Beam structure with a stiffener in the Pamitra workshop building which is protected by a fireproofing Promaspray coating by convection from 1,7425e-7 to 0,017587 W/mm^2 in 6000 seconds or 100 minutes or 1,6 hours.

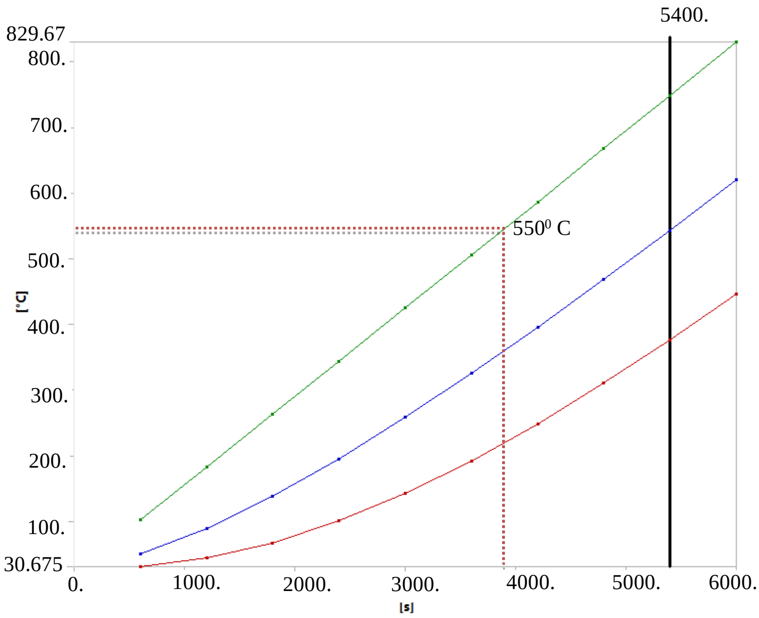

Fig. 53: Comparison of temperature and time at variation 3.C

In the picture above, it can be seen that the temperature increase is quite long in a period of 6000 seconds or 100 minutes or 1,6 hours at variation 3.C (I Beam structure with stiffener Pamitra workshop building protected by a fireproofing Promaspray coating) from the initial temperature to the peak temperature (829,67^{0}celcius). At 3950 seconds or at 65 minutes or 1,1 hours the temperature reaches 550^0 C or critical temperature.

	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	600.	30.675	102.3	50.21
2	1200.	43.804	182.1	88.966
3	1800.	67.01	262.63	138.11
4	2400.	100.	343.42	194.98
5	3000.	142.09	424.34	257.67
6	3600.	192.07	505.33	324.76
7	4200.	248.55	586.38	395.21
8	4800.	310.39	667.45	468.2
9	5400.	376.52	748.55	543.14
10	6000.	446.06	829.67	619.56

Table 20: Temperature data at variation 3.C

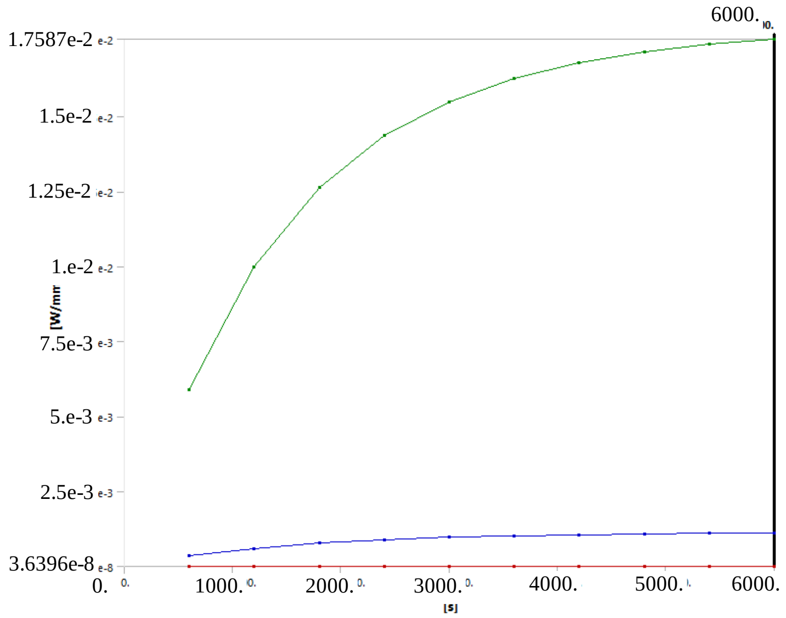

Fig. 54: Total heat flux with time at variation 3.C

In the picture above, it can be seen that the heat flux increase which is quite long in a period of 6000 seconds or 100 minutes or 1,6 hours in variation 3.C (I Beam with stiffener Pamitra workshop building structure protected by a fireproofing Promaspray coating) heat flux reached 1,7587e-002 W/mm².

	Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1	600.	3.6396e-008	5.9098e-003	3.5016e-004
2	1200.	6.031e-008	9.9918e-003	6.0269e-004
3	1800.	9.6367e-008	1.2636e-002	7.7269e-004
4	2400.	9.0393e-008	1.4363e-002	8.8827e-004
5	3000.	9.2054e-008	1.5507e-002	9.6819e-004
6	3600.	1.2153e-007	1.6275e-002	1.0243e-003
7	4200.	1.1838e-007	1.6799e-002	1.0642e-003
8	4800.	1.1604e-007	1.716e-002	1.0929e-003
9	5400.	5.8392e-008	1.7411e-002	1.1137e-003
10	6000.	1.7425e-007	1.7587e-002	1.1289e-003

Table 21:Total heat flux at variation 3.C

III. RESULT

It can be seen that based on (Peter & James.2013) [27]in the title of their research "Convective heat transfer coefficient in compartment fires" Total surface heat flux can reach 200kW/m² during a fire. So this value becomes the main benchmark in this simulation. Based on the literature, stainless steel can be said to be damaged by heat when the temperature exceeds 550 degrees Celsius.

After doing the Transient Thermal simulation. Visible fire can damage the structure of the building because the temperature exceeds 550 degrees Celsius. As for the building structure that is not covered with a coating, meaning that the building structure is directly exposed to fire, the time it takes for fire to damage the building structure is about 300-360 seconds, meaning it only takes 5-6 minutes.

When the building structure is given a coating layer, there are 2 variations of the coating used, namely Promaspray and Cafco. In the Cafco type coating, the building structure is much more durable than without the coating. Cafco is able to withstand the heat of the fire for 10000 to 11000 seconds or approximately 180 minutes. In the Promaspray type, it takes longer by holding the heat from the fire for 14000 to 15000 seconds or about 240 minutes.

It is also characterized by the heat-flux can be retained or reduced by each coating.

No.	Coating Type	Heat-Flux Average (kW/m²)
1	Without Coating	200
2	Cafco SPRAYFILM WB3	1.6
3	Promaspray P400	1.3

Table 22: Heat flux average for each coating

Coating is able to reduce heat transfer by about 10 times compared to without coating when the building structure is exposed to fire continuously.

To measure the strength of 2 coatings of different types, the same setting is used between variations including the section factor of the building structure.

For coating type CafcoSprayfilm WB3, with this section factor, it takes about 3 mm of coating thickness which can last for 90 minutes. As for the Promaspray P400 coating type with unrestrained protection type using the interpolation principle, with a coating that can last for 90 minutes, the thickness was found to be 16,85 mm.

The isotropic thermal conductivity data of each coating is not attached to the product specifications and only attaches the density. With the results of this simulation, obtained isotropic thermal conductivity from the results of computer calculations by considering the critical temperature of stainless steel, which is around 550 degrees Celsius.

No.	Coating Type	Isotropic Thermal Conductivity (W/m.K)	Density (kg/m^3)
1	Without Coating	60.5	7850
2	Cafco SPRAYFILM WB3	0.005	1330
3	Promaspray P400	0.01	437

Table 23: Isotropic thermal conductivity for each coating

In the case of a very thick coating, for example here 16,85 mm, the coating temperature at some points has a lower temperature than the building structure. This is because the building structure conducts heat faster due to certain parts, especially in the corners than the building structure, heat will increase and reach the structure faster than from the coating to the inside of the coating itself.

It can be seen from the addition of stiffener, the temperature obtained by the frame is higher than without stiffener. This is due to the increase in cross-sectional area which is potentially exposed to heat from the fire.

IV. CONCLUSIONS

From the results of processing and analysing data related to the formulation of the problem and objectives in this study, the following conclusions can be drawn:

- The building structure used is I-Beams type with a Section Factor of 267 m-1
- The time it takes for fire to damage the building structure is around 300-360 seconds, meaning that it takes only 5-6 minutes when the building structure is not coated with a coating.
- Cafco is able to withstand heat from fire for 5400 seconds or about 90 minutes with a thickness of 3 mm.
- Promaspray is actually longer by holding heat from the fire for 90 minutes with a thicker thickness of 16.85 mm.
- Coating is able to reduce heat transfer by about 10 times compared to without coating when the building structure is continuously exposed to fire.
- Both coatings are able to withstand heat from fire with temperature differences that can reach almost 200 degrees Celsius.
- The thicker the coating, the longer the building structure will withstand the heat of the fire.
- The use of stiffener will accelerate the building structure reaches its critical temperature due to the larger surface area so that the heat energy absorbed by the building structure is greater.

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