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FIre and Seismic performances of Hybrid fire WALLs in case of single-storey industrial and commercial steel buildings (FISHWALL)

EXPERIMENTAL ANALYSIS OF MECHANICAL BEHAVIOUR OF ALUMINIUM BOLTS AT AMBIENT AND ELEVATED TEMPERATURE

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ABSTRACT

It is well known that the intrinsic fire resistance of single-storey unprotected steel-framed buildings is largely sufficient to guarantee the evacuation of occupants in the event of fire. In consequence, for this type of building, the main concern of national fire regulations in Europe is how to prevent the spread of fire to the whole building. To achieve this objective, two performances shall be usually satisfied, namely, the appropriateness of constructive systems to ensure that there is no progressive collapse between fire compartments, and the efficiency of fire walls to stop the fire inside the initial compartment regardless of the state of structures exposed to fire. In practice, many constructional solutions can be implemented in order to preserve the integrity of the fire walls, while accepting that the fire exposed part of the structure may collapse. One of the most common solutions is to place a non-load bearing wall between two independent steel structures and to connect it to them by means of "fusible" links. In fire situation, these fusible links have to allow the wall to be disconnected from the structure affected by fire without endangering the separating function of the wall, which shall remain fixed to the steel structure on the other side of the wall and therefore not exposed to fire. However, due to the lack of corresponding scientific evidence, questions are being very often raised about the real efficiency of such systems in fire situation, which, in certain cases, have also to provide an adequate seismic resistance, if they are used in seismic areas.

Today, concrete or masonry wall solutions are frequently used for the compartmentation of buildings, predominately for low-rise commercial and industrial steel buildings. However, as an alternative, lightweight sandwich panels (comprising two thin flat metal faces and an insulated core) could become an appropriate steel fire wall solution, offering numerous benefits in comparison to other solutions, including fire resistance, durability, flexibility, easy dismounting and fast construction times. But, there is an evident lack of technical information about the adequate fire performance of such type of wall solutions when they are implemented in single-storey buildings with unprotected steel structure, which constitutes a major obstacle for their large use.

In this context, the overall goal of the FISWHALL project is to develop a design guidance and recommendations for an innovative hybrid fire wall solution based on lightweight steel-faced sandwich panels associated with unprotected steel structure under both fire and seismic actions, but considered individually. This will be achieved through the following specific tasks: i) Establishing of a full range of experimental evidence about the fire and seismic behaviour of the investigated hybrid fire wall solution by carrying out a number of tests; ii) Investigating intensively the fire and seismic performances of the above hybrid fire wall solution in combination with unprotected single-storey steel structures through a variety of parametric numerical studies by means of validated FE numerical models; iii) Developing both cost-effective and innovative "fusible" connection systems for fire walls to be used in combination with unprotected steel structures of single-storey buildings; and iv) Developing a design guidance and practical recommendations for the studied hybrid fire wall and fusible links solutions, on the basis of above studies, from which engineers can carry out very efficient design.

The present report aims at summing up the results of material tests performed on Aluminum Bolts at the Laboratory of the Czech Technical University in Prague (CVUT) in the scope of the FISWHALL project. A set of 36 tests were performed on bolts in tension and 36 in shear. The results were generalized in both force-deformation and stress-strain diagrams at both ambient and elevated temperatures. The standard values of material degradation in EN 1999-1-2:2005 were compared against the experimental results. Good agreement was observed.

1 INTRODUCTION

When a fire breaks out in a specific area of a single-story building, the occupants can usually be extricated from the building within minutes. The deployment of internal partition fire walls to prevent the spread of fire to subsequent fire compartments, as well as the use of appropriate structural systems to ensure that there is no progressive collapse between compartments, are the most effective protection measures in this situation.

For this research, it is vital that data on the mechanical properties of aluminium bolts at elevated temperatures be gathered through tension and shear fire tests, together with mathematical models that account for those results appropriately, building a strong experimental foundation in this sector by investigating the fire behaviour of a hybrid fire wall solution connected with unprotected steel structures. Due to the investigation of "fusible" links, it is required to obtain data on the mechanical properties of aluminium bolts at elevated temperatures. Steel structures connected with this fire wall solution are studied extensively for their mechanical reaction to actual fire conditions using advanced calculation models validated against the experimental data. Due to the investigation of "fusible" linkages, it is required to obtain data on the mechanical properties of aluminium bolts at elevated temperatures. Isothermal tests were conducted at 9 different temperatures ranging from ambient temperature to 500°C, putting the bolt assemblies in tension and shear.

2 EXPERIMENTAL PROCESS

Several isothermal uniaxial tensile tests on bolting assemblies (bolt with nut) were conducted to investigate the performance of bolt solutions that can be used to create "fusible" links at elevated temperatures. The bolting assemblies were used to make "fusible" links. Additional tensile tests were carried out at ambient temperature to determine their basic strength and stiffness**.**

2.1 Materials and Properties

A total of four different types of aluminium alloy bolts were tested, including the following: AA7075, AA6061, AA6063, and AA6082. 36 tension tests and 36 shear tests were carried out at both ambient and elevated temperatures. All tests were carried out at the Laboratory of the Czech Technical University in Prague (CVUT).

Table 1: Nominal Mechanical properties of Aluminium Alloy

S. No	Type of Alloy	Process Type	Ultimate Strength	Shear Strength
1	AA7075	Rolled	530	331
2	AA6061	Cut	310	207
3	AA6063	Cut	245	152
4	AA6082	Cut	310	210

Table 2: Geometrical properties of tested aluminium bolts

S. No	Type of Alloy	Type of Grade	Length in mm	Diameter in mm
1	AA7075	M12 & M16	60	12 & 16
2	AA6061	M12 & M16	80	12 & 16
3	AA6063	M12 & M16	80	12 & 16
4	AA6082	M12 & M16	80	12 & 16

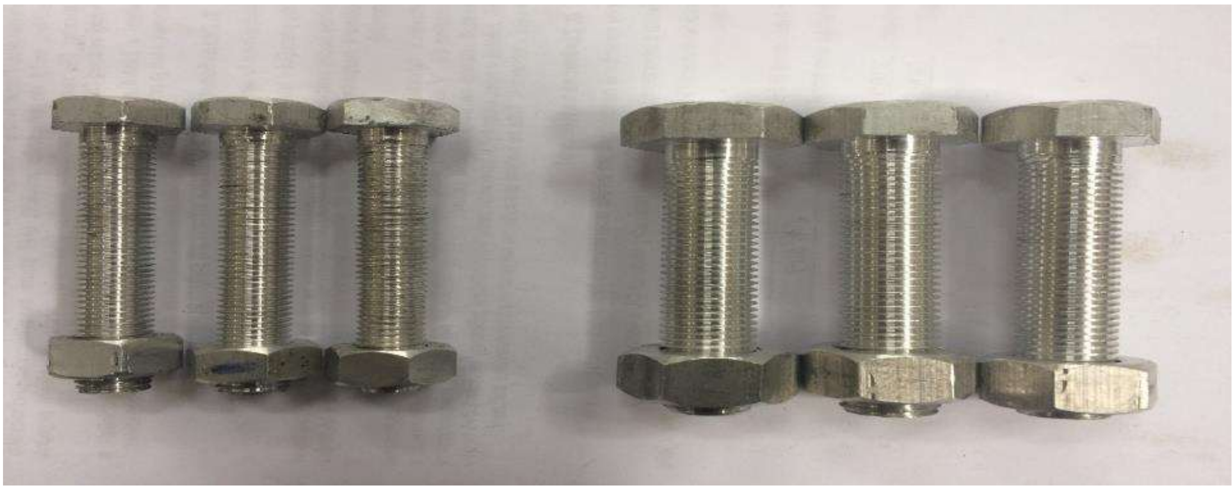

Figure 1: Tested Aluminium Bolts

2.2 Experimental setup

Every test carried out in the Czech Republic was carried out at the Laboratory of the Czech Technical University (CVUT), which is in Prague. The tests were carried out on a SHIMADZU testing machine with a load capacity of 300 KN, and they were carried out in either tension or compression modes. Due to the obvious high temperature involved, the tests were carried out around the bolt's setup stable. The experiments were carried out at both ambient and elevated temperatures using the traditional test setup. The test device and its associated setup are depicted in the following figures.

Figure 2: SHIMADZU testing device

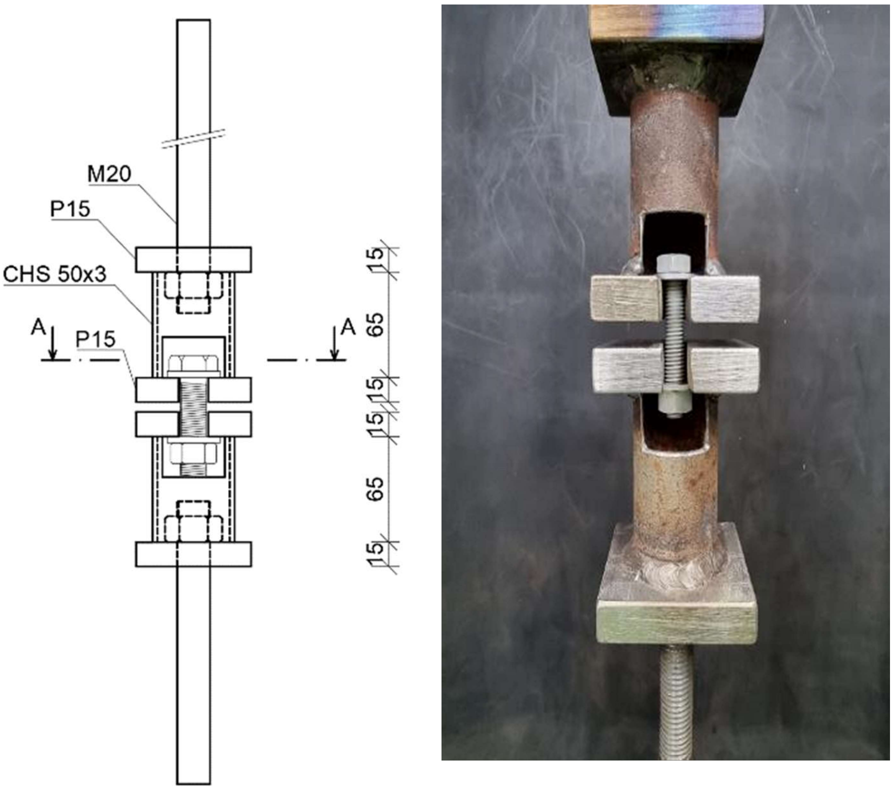

Figure 3: Test setup in tension

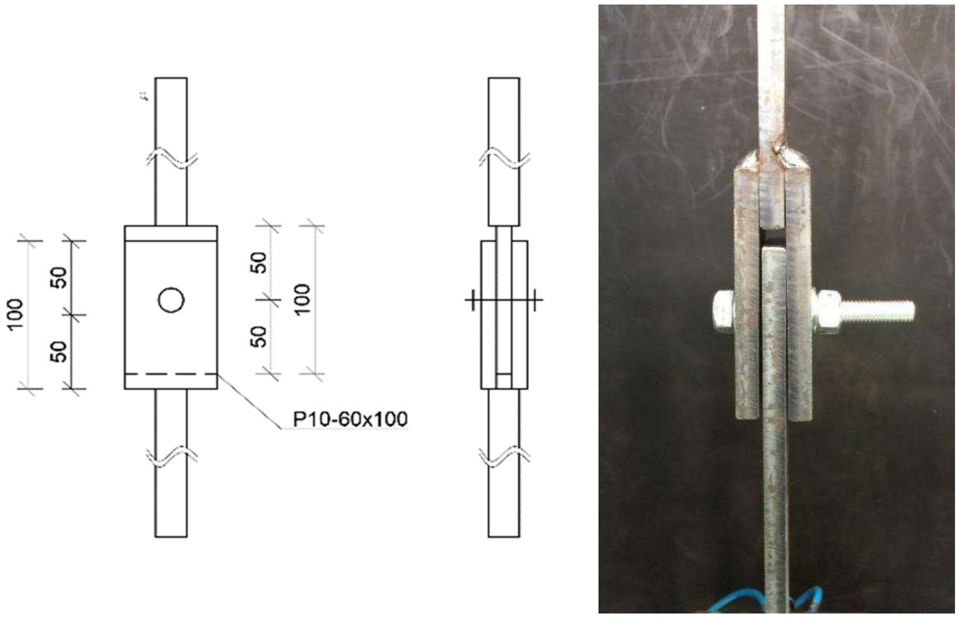

Figure 4: Test setup in shear

2.3 Experimental procedure

For the first 30 to 45 mins, the θ_{max} target temperature of each tested bolt solution was steadily raised, depending on the type of bolt solution. The temperature in the bolt's setup portion was then maintained at a constant temperature until the desired temperature was reached. To achieve a uniform temperature throughout the bolt, the temperature stabilization process was carried out for approximately 30 to 35 mins. While the test specimen was allowed to expand at its leisure, its thermal elongation was automatically measured during this period. Once the temperature in the bolt had stabilized, on average after 45 mins, a displacement was gradually imposed until failure was reached. The loading speed was 0.2 mm/min while the temperature was maintained at a constant temperature. External heating equipment, such as thermo-cables and ceramic pads, as well as temperature measuring equipment were employed during the elevated temperature test. The formal process for conducting ambient temperature experiments has been completed. In total, 72 tests were performed in both tension and shear; experiments were carried out at 9-10 distinct temperatures, which were as follows: 20°C, 100°C, 150°C, 200°C, 250°C, 280°C, 300°C, 320°C, 350°C, and 400°C.

2.4 Measured data

Since the force measurements associated with the imposed displacements, load-displacement curves for all the tests were constructed for each one. These curves are shown in the following section. The following ISO 898-1-defined properties of aluminium bolts were discovered through the examination of each load-displacement curve: The plastic elongation, denoted $\Delta L_{p.}$

The ultimate tensile load, denoted F_m, F_{max} Maximum load occurred during the test.

From this equation, the tensile strength, R_m, of the tested bolts can be determined:

$R_m = F_m / A_{s\ nom}$

With respect to the thread of the bolt, where $A_{s,nom}$ is the nominal cross-sectional area and F_m is the ultimate tensile load obtained during the test. Since aluminium bolts have dimensional characteristics in principle as steel bolts, a nominal cross-section area of 157 mm^2 and 84.3 mm^2 has been assumed by default for all aluminium bolts in accordance with the values specified in ISO 898-1 [1], which specifies the mechanical and physical characteristics of screws, studs, and threaded rods made of carbon or alloy steel.

The following equation has been used to compute the elongation after fracture:

$A_f = \Delta L_p / L_e$

ΔL_p is the plastic elongation of the bolts determined from the experimental load-displacement curve and L_e is the free length of the bolts under load.

3 EXPERIMENTAL RESULTS

3.1 Tension

An overall total of 36 aluminium bolts with four distinct alloys (AA7075, AA6061, AA6063, and AA6082) were tested in tension at temperatures ranging from 20°C to 400°C. These tests were conducted on bolting assemblies, bolt + nut, throughout the process. Table 3 and Table 4 summarize the most important findings from the experiments. The load-displacement curves as a function of temperature are shown in the following Figures. The Figure 7 depicts the distorted shape of aluminium bolts after being tested at temperatures from 20°C to 400°C.

Table 3: Results of Tested AA7075 bolts in tension

Designation			Measured data			Calculated
Alloy-dia-temp-threat-no	Diameter	θ (°C)	Failure	F_{max} (kN)	A_f	$R_{\theta,m,exp}$
7075-12-20-1	M12	20	Shaft	42.63	0.24	505.7
7075-12-20-2	M12	20	Shaft	42.63	0.24	504.51
7075-12-20-3	M12	20	Shaft	37.59	0.22	445.95
7075-16-20-4	M16	20	Shaft	73.44	0.25	467.8
7075-16-20-5	M16	20	Shaft	76.2	0.3	485.36
7075-12-100-1	M12	100	Shaft	33.49	0.11	397.27
7075-12-200-2	M12	200	Shaft	16.64	0.12	197.39
7075-12-300-3	M12	300	Shaft	6.28	0.14	74.49
7075-16-100-4	M12	100	Shaft	64.00	0.12	407.64
7075-16-200-5	M12	200	Shaft	34.84	0.14	221.91
7075-16-300-6	M12	300	Shaft	10.51	0.15	66.94
7075-12-400-7	M12	400	Thread	2.64	-	31.31

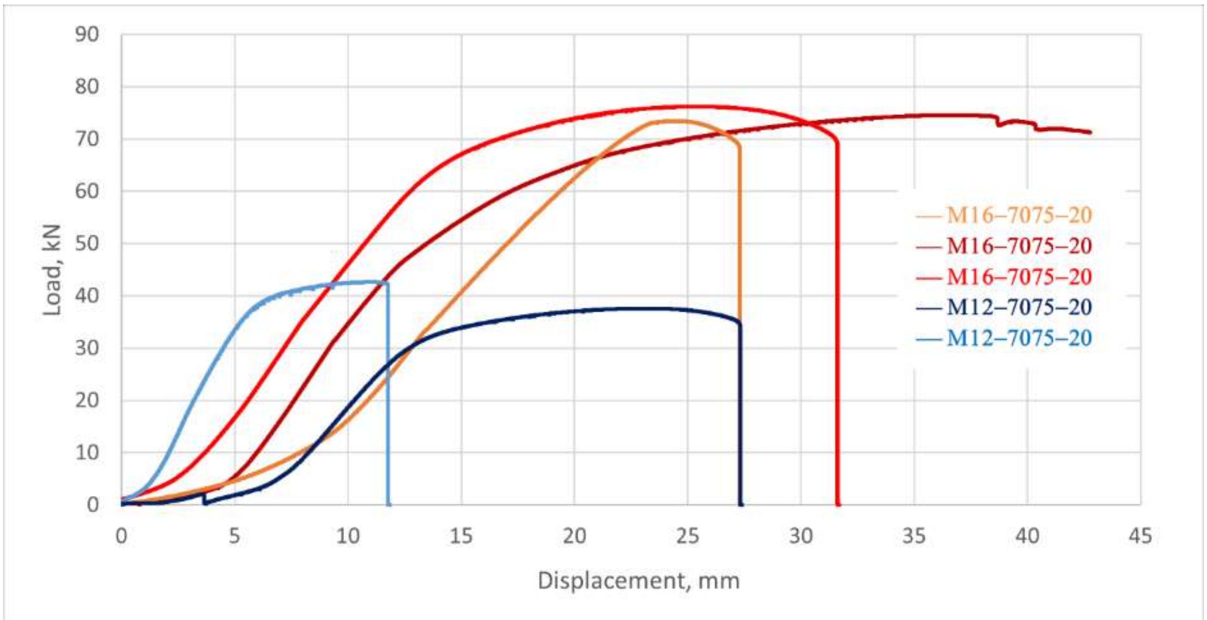

Figure 5: Measured Load-Displacement curves of AA7075 at 20°C in tension

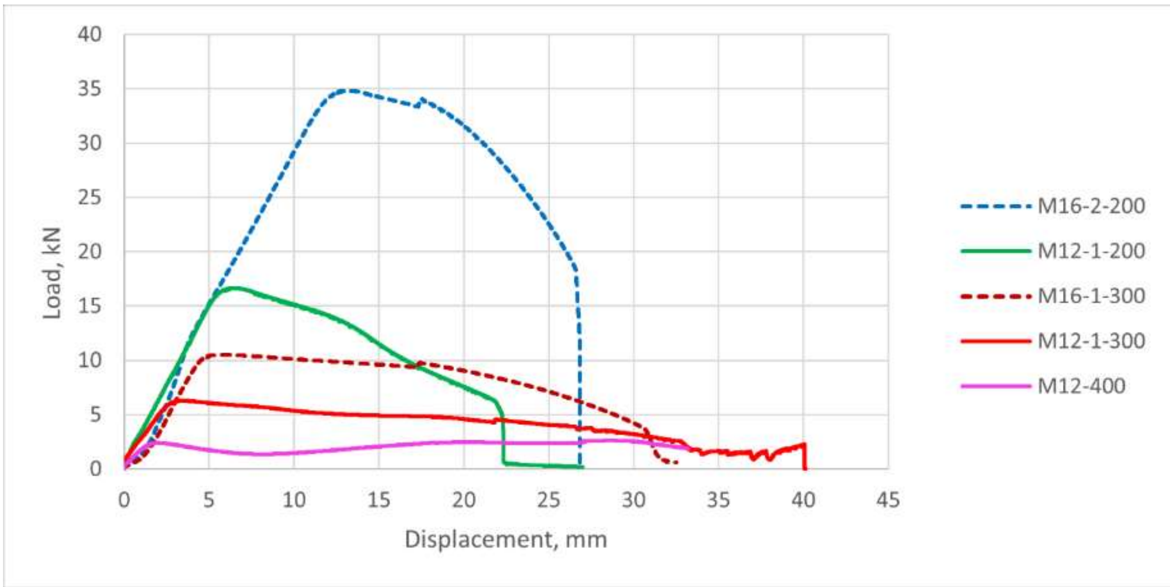

Figure 6: Measured Load-Displacement curves of AA7075 at 200◦C - 400◦C in tension

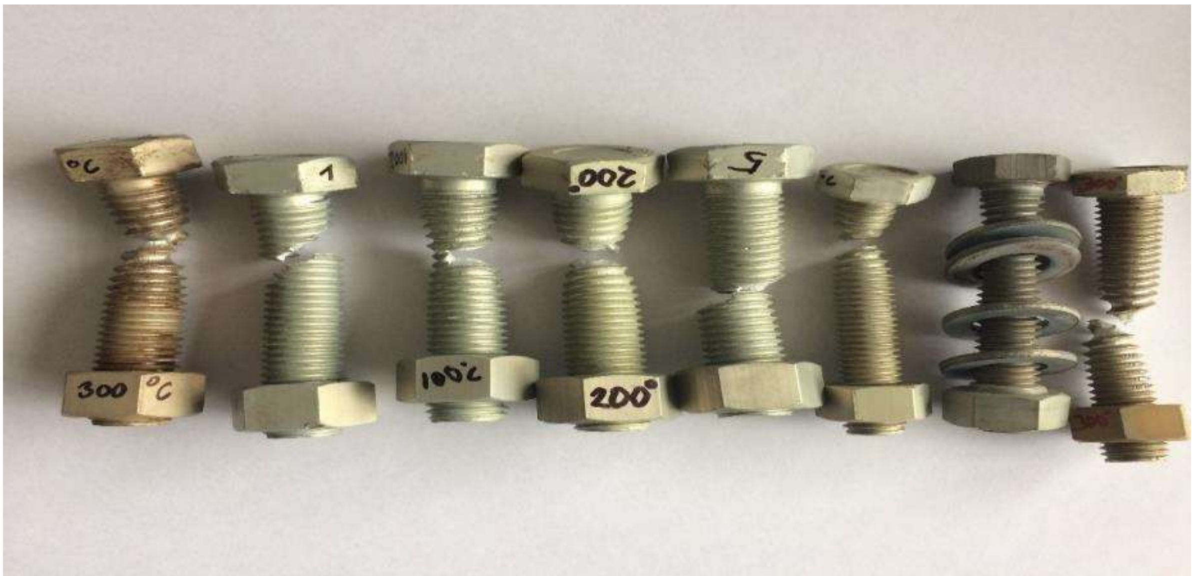

Figure 7: Failure of AA7075 bolts at different temperatures, 20°C - 400°C, in tension

Table 4: Results of Tested AA6061, AA6063, AA6082 bolts in tension

Designation			Measured data			Calculated
Alloy-dia-temp-threat-no	Diameter	θ (°C)	Failure	F_{max} (kN)	A_f	$R_{\theta,m,exp}$
6082-12-20-C-1	M12	20	Shaft	30.46	0.14	361.32
6082-12-20-C-2	M12	20	Shaft	30.67	0.16	363.81
6061-12-20-C-1	M12	20	Thread	28.04	-	332.62
6061-12-20-C-2	M12	20	Thread	24.34	-	288.73
6061-12-20-C-3	M12	20	Thread	12.79	-	151.72
6063-12-20-C-1	M12	20	Shaft	18.01	0.19	213.64
6063-12-20-C-2	M12	20	Shaft	17.64	0.17	209.25
6082-16-20-C-1	M16	20	Shaft	27.44	0.04	174.77
6082-16-20-2	M16	20	Shaft	21.87	0.04	139.29
6061-16-20-C-2nuts-1	M16	20	Thread	51.22	-	326.24
6061-16-20-C-2nuts-2	M16	20	Thread	51.12	-	325.6
6063-16-20-C-2nuts-1	M16	20	Thread	36.08	-	229.8
6063-16-20-C-2nuts-2	M16	20	Thread	36.29	-	231.14
6082-16-20-C-2nuts-1	M16	20	Shaft	50.76	0.25	323.31
6061-12-20-C-1	M12	20	Shaft	30.47	0.18	361.44
6063-12-20-C-1	M12	20	Thread	17.95	-	212.93
6082-12-20-C-1	M12	20	Thread	30.43	-	360.97
6061-16-20-C-1	M16	20	Thread	27.04	-	172.23
6063-16-20-C-1	M16	20	Thread	22.23	-	141.59
6082-16-20-C-1	M16	20	Thread	18.60	-	118.47
6061-12-300-C-1	M12	300	Thread	5.06	-	60.02
6063-12-200-C-1	M12	200	Thread	12.05	-	142.94
6061-16-300-C-1	M16	300	Thread	7.48	-	47.64
6063-16-280-C-1	M16	280	Thread	9.38	-	59.75
6082-16-320-C-1	M16	320	Thread	6.27	-	39.94

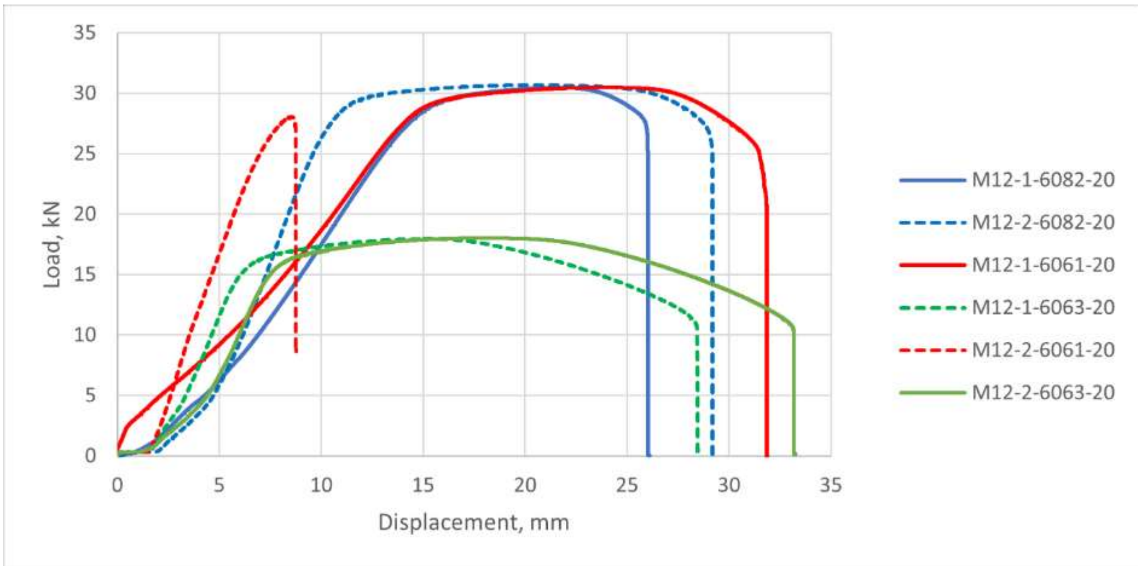

Figure 8: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 20°C in tension

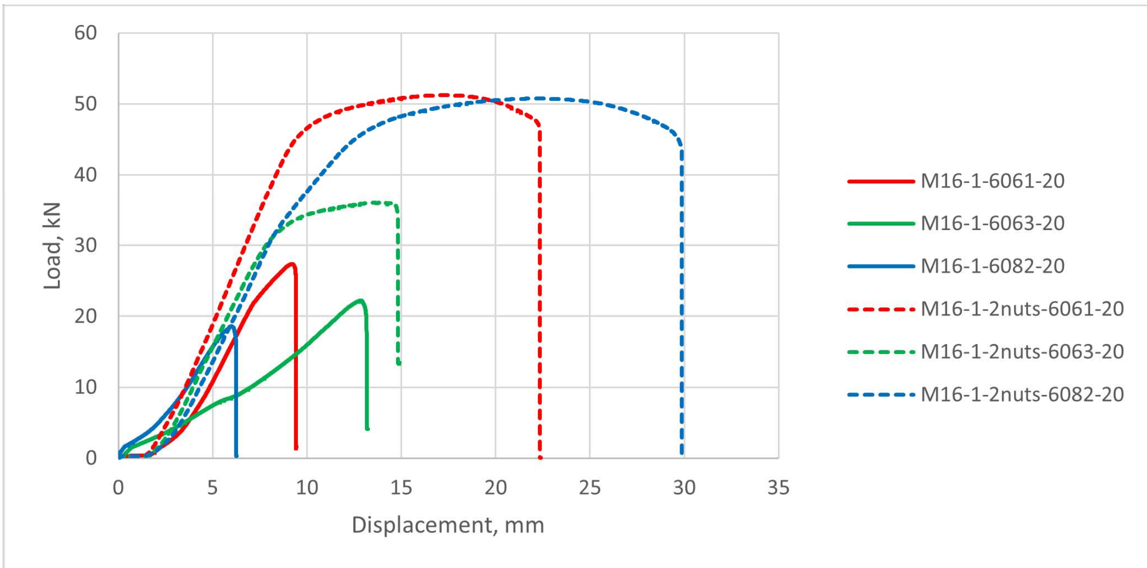

Figure 9: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 20°C in tension

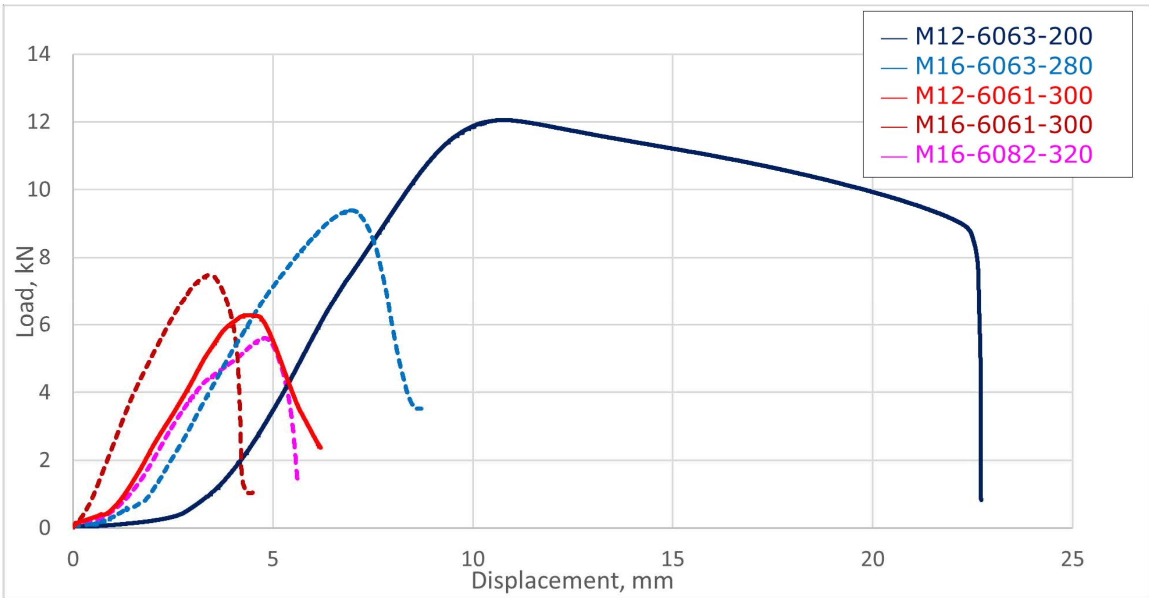

Figure 10: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 200°C-320°C in tension

Figure 11: Failure thread destruction of AA6XXX series bolts in tension

3.2 Shear

An overall total of 36 aluminium bolts with four distinct alloys (AA7075, AA6061, AA6063, and AA6082) were tested in tension at temperatures ranging from 20°C to 350°C. These tests were conducted on bolting assemblies (bolt + nut) throughout the process. Table 5 and Table 6 summarizes the most important findings from the experiments. The load-displacement curves as a function of temperature are shown in the following Figures. The Figure 15 depicts the distorted shape of aluminium bolts after being tested at temperatures from 20°C to 350°C.

Table 5: Results of Tested AA7075 bolts in shear

Designation			Measured data			Calculated
Alloy-dia-temp-threat-no	Diameter	θ (°C)	Failure	F_{max}, (kN)	A_f	$R_{\theta, m,exp}$
7075-12-20-1	M12	20	Shaft	35.79	0.11	424.56
7075-12-20-2	M12	20	Shaft	36.97	0.07	438.55
7075-12-20-3	M12	20	Shaft	37.01	0.08	439.03
7075-16-20-4	M16	20	Shaft	78.73	0.13	501.46
7075-16-20-5	M16	20	Shaft	79.63	0.12	507.20
7075-16-20-6	M16	20	Shaft	79.57	0.12	506.82
7075-12-100-1	M12	100	Shaft	35.55	0.12	421.71
7075-12-150-1	M12	150	Shaft	32.56	0.13	386.24
7075-12-200-1	M12	200	Shaft	23.06	0.13	273.55
7075-12-250-1	M12	250	Shaft	11.71	0.16	138.91
7075-12-300-1	M12	300	Shaft	9.09	0.17	107.83
7075-12-350-1	M12	350	Shaft	3.18	0.06	37.72
7075-16-100-1	M16	100	Shaft	68.18	0.15	434.27
7075-16-150-1	M16	150	Shaft	62.52	0.13	398.22
7075-16-200-1	M16	200	Shaft	44.00	0.15	280.25
7075-16-250-1	M16	250	Shaft	25.93	0.14	165.16
7075-16-300-1	M16	300	Shaft	13.95	0.22	88.85
7075-16-350-1	M16	350	Shaft	9.55	-	60.83

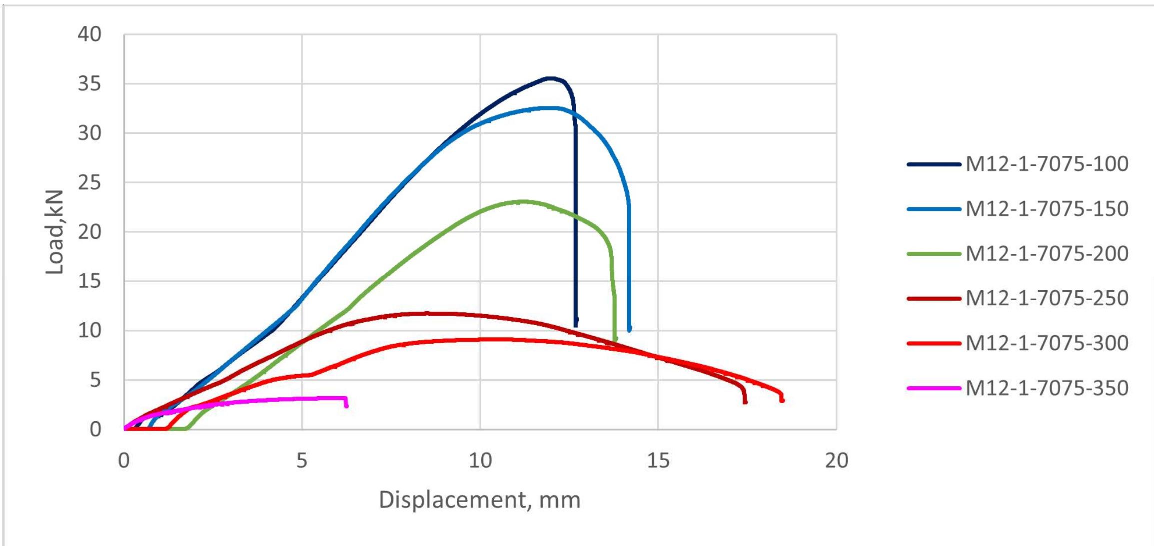

Figure 12: Measured Load-Displacement curves of AA7075 at 100°C-350°C in shear

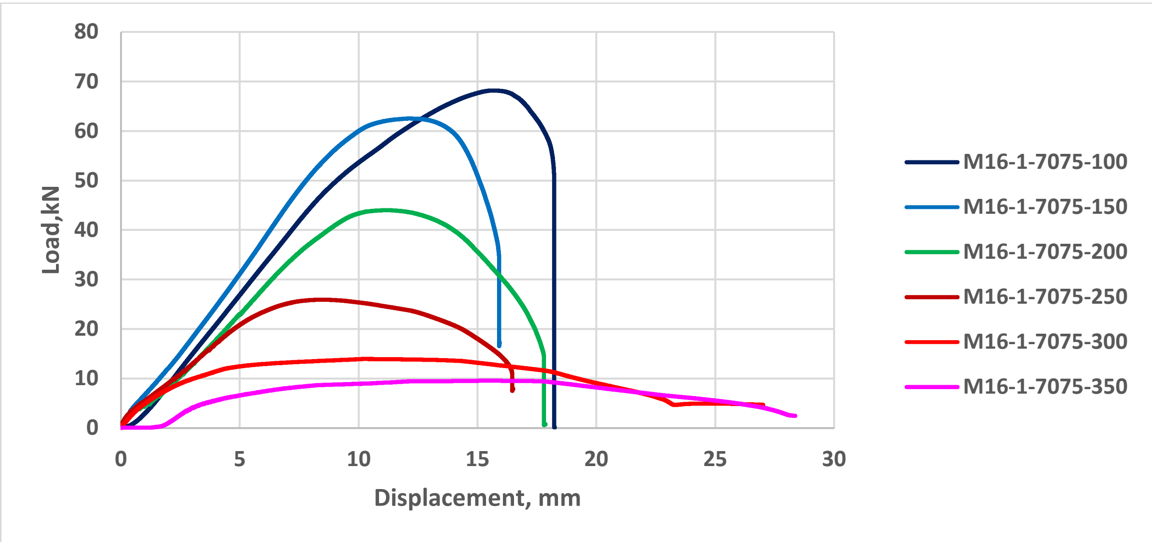

Figure 13: Measured Load-Displacement curves of AA7075 at 100°C-350°C in shear

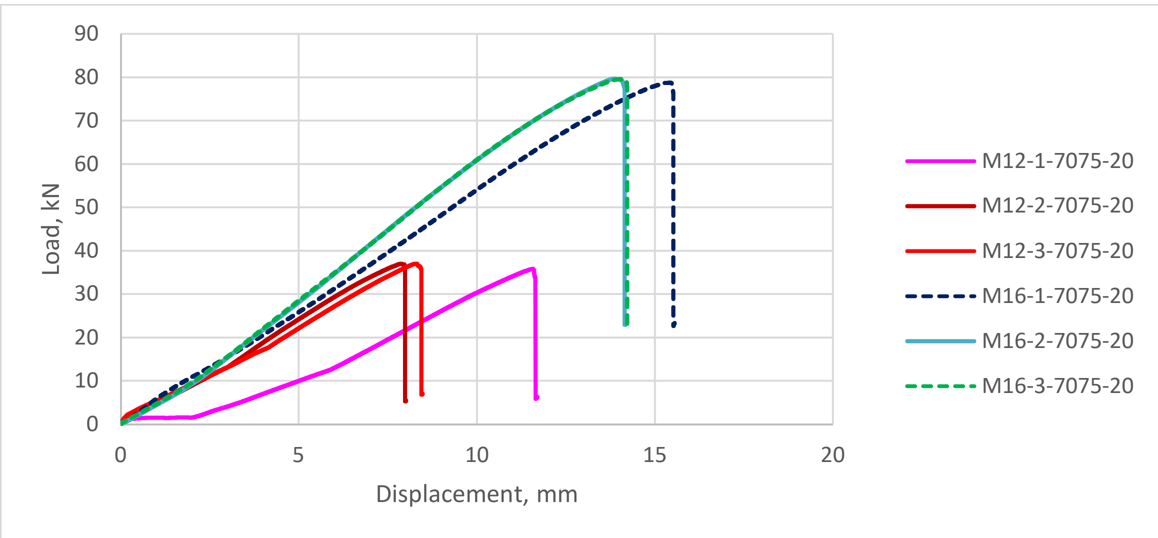

Figure 14: Measured Load-Displacement curves of AA7075 at 20°C in shear

Figure 15: Failure of AA7075 bolts at different temperature (100°C -350°C) in shear

Table 6: Results of Tested AA6061, AA6063, AA6082 bolts in shear

Designation			Measured data			Calculated
Alloy-dia-temp-threat-no	Diameter	θ (°C)	Failure	F_{max} (kN)	A_f	$R_{\theta,m,exp}$
6061-12-20-C-1	M12	20	Shaft	28.84	0.14	342.11
6061-12-20-C-2	M12	20	Shaft	29.15	0.1	345.79
6063-12-20-C-1	M12	20	Shaft	20.81	0.16	246.86
6063-12-20-C-2	M12	20	Shaft	22.25	0.13	263.94
6082-12-20-C-1	M12	20	Shaft	29.06	0.1	344.72
6082-12-20-C-2	M12	20	Shaft	28.31	0.1	335.82
6061-16-20-C-1	M16	20	Shaft	45.78	0.12	291.59
6061-16-20-C-2	M16	20	Shaft	46.40	0.14	295.54
6063-16-20-C-1	M16	20	Shaft	44.51	0.17	283.50
6063-16-20-C-2	M16	20	Shaft	45.51	0.16	289.87
6082-16-20-C-1	M16	20	Shaft	50.18	0.15	319.62
6082-16-20-C-2	M16	20	Shaft	51.59	0.1	328.60
6061-12-100-C-1	M12	100	Shaft	27.75	0.14	329.18
6061-16-150-C-1	M16	150	Shaft	41.36	0.15	263.44
6063-12-150-C-1	M12	150	Shaft	16.57	0.17	196.56
6063-16-200-C-1	M16	200	Shaft	30.09	0.12	191.66
6063-16-350-C-1	M16	350	Shaft	8.41	0.16	53.57
6082-12-200-C-1	M12	200	Shaft	14.04	0.11	166.55
6082-16-250-C-1	M16	250	Shaft	22.2	0.11	141.40
6082-16-300-C-1	M16	300	Shaft	11.98	0.2	76.31

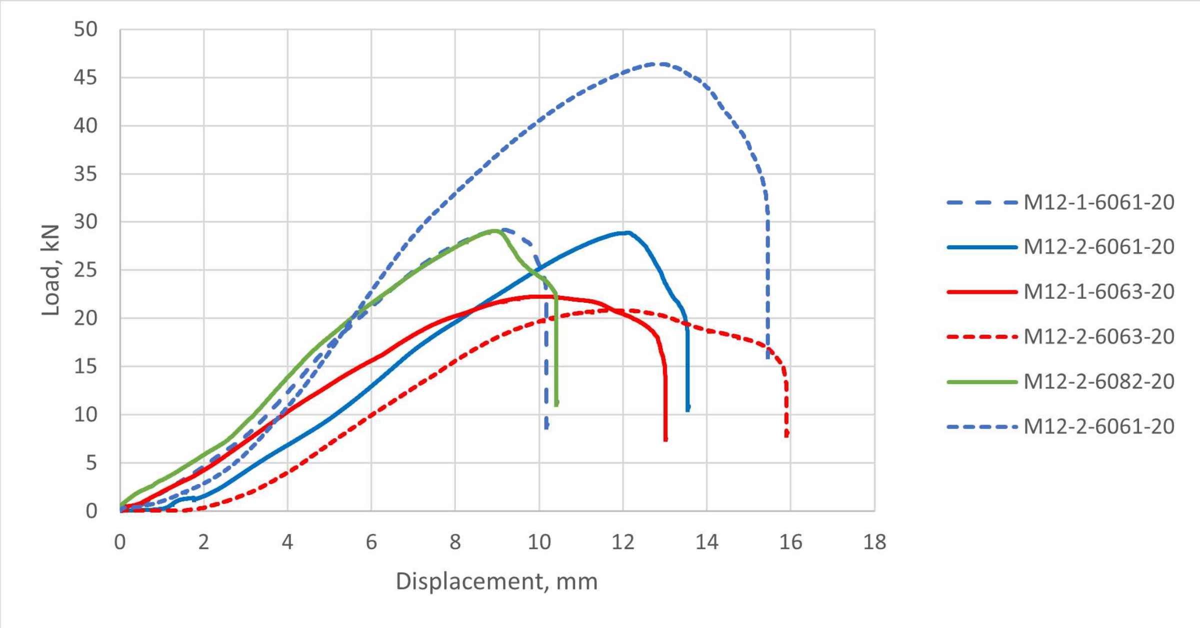

Figure 16: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 20◦C in shear

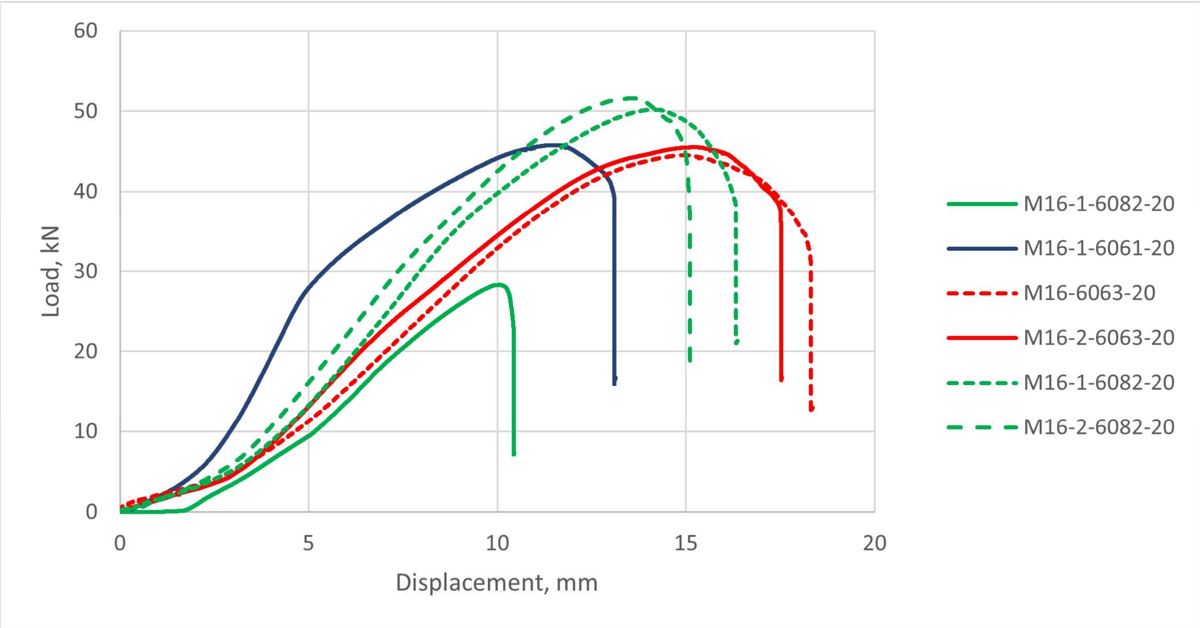

Figure 17: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 20◦C in shear

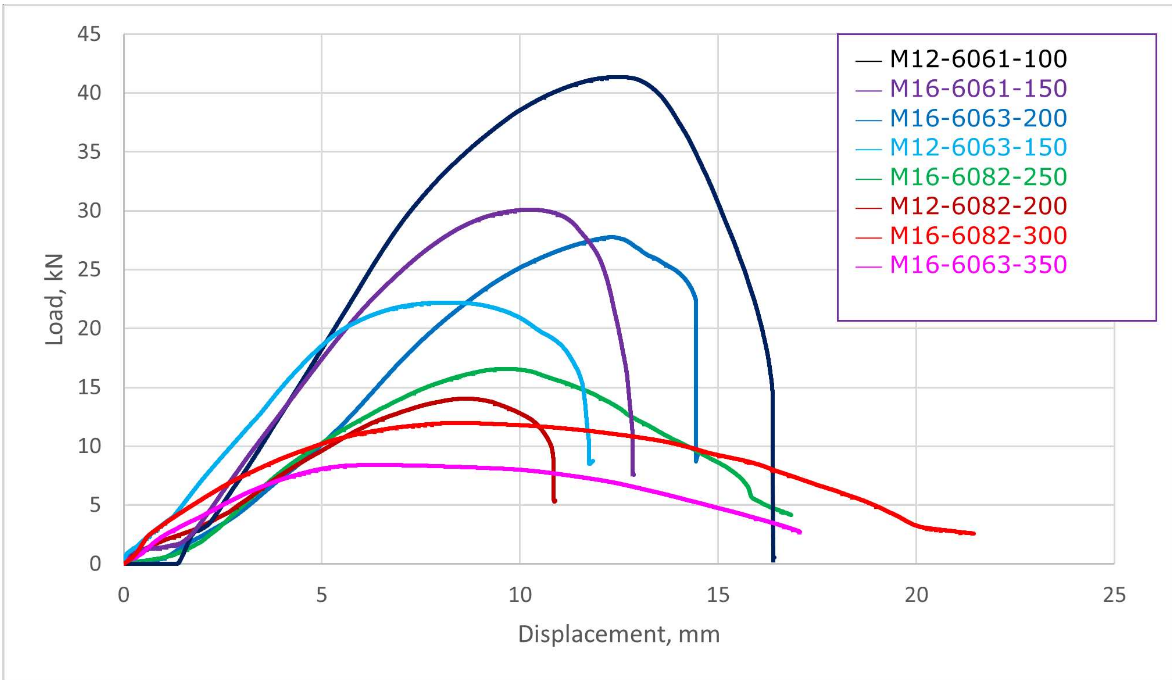

Figure 18: Measured Load-Displacement curves of AA6061, AA6063 & AA6082 at 100°C-350°C in shear

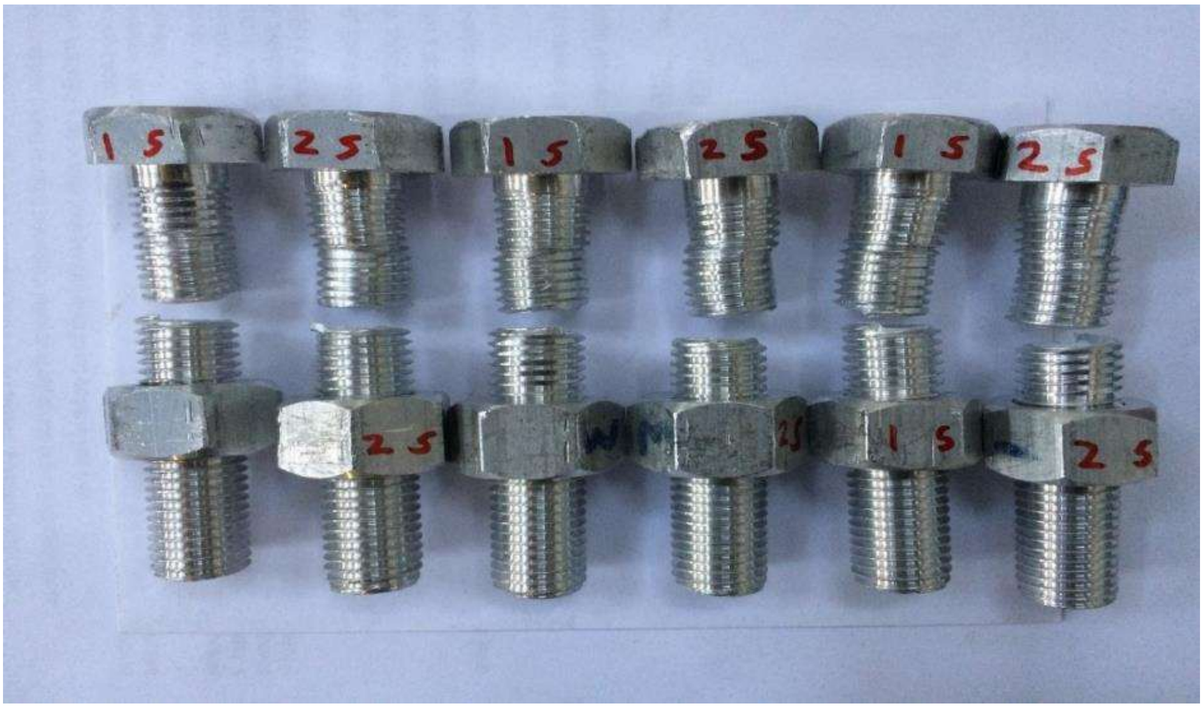

Figure 19: Failure of AA6XXX series bolts in shear at 20°C

Figure 20: Failure of AA6XXX series bolts in shear at elevated temperature (150°C- 350°C)

4 CONCLUSION

It was presented and discussed in this report the main results of tensile and shear tests performed on AA7075, AA6061, AA6063, and AA6082 bolt solutions: bolting assemblies (bolt and nut) in aluminium, which can be used to design "fusible" links, which were conducted on different types of aluminium alloys under 9 different temperatures. To better understand the bolts' tensile and shear strengths in relation to temperature, researchers used the readings acquired during the tests. Results demonstrated that heating temperature has a significant impact on the mechanical behaviour of bolts, with a quick fall in tensile and shear strength as the temperature rises. At 200°C, aluminium bolts keep only 60 percent of their strength, and at 300°C, they retain less than 20 percent of their strength. The strength of AA7075 bolts is superior to the strength of AA6061, AA6063, and AA6082 bolts. Bolts made of AA6063 were found to be strong enough to withstand temperatures of up to 100°C, while AA6061 and AA6082 produced good results up to 150-200°C, as demonstrated in the above-mentioned tables and figures.

Test results show conclusively that the bolt solutions investigated are suitable for the design of "fusible" linkages for partition fire barriers. Testing results, to ensure that the wall can be separated from a section of the structure that has been damaged by fire, "fusible" links should be used, which have a significantly lower link resistance.

5 REFERENCES

[1] EN ISO 898-1: Mechanical properties of carbon and alloy steel fasteners - Part 1: Screws, studs and threaded rods of specified quality classes - Coarse and fine pitch threads, 2013.

[2] EN 1999-1-1, Eurocode 9 - Design of aluminium structures - Part 1-1: General rules, CEN, 2007.

[3] EN 1999-1-2, Eurocode 9 - Design of aluminium structures - Part 1-2: Calculation of fire behaviour, CEN, 2007.