

Supplementary material

Framework for improving Energy-Efficiency through Piston design exchange and Emission Mitigation via Gasoline Methanol blend replacement

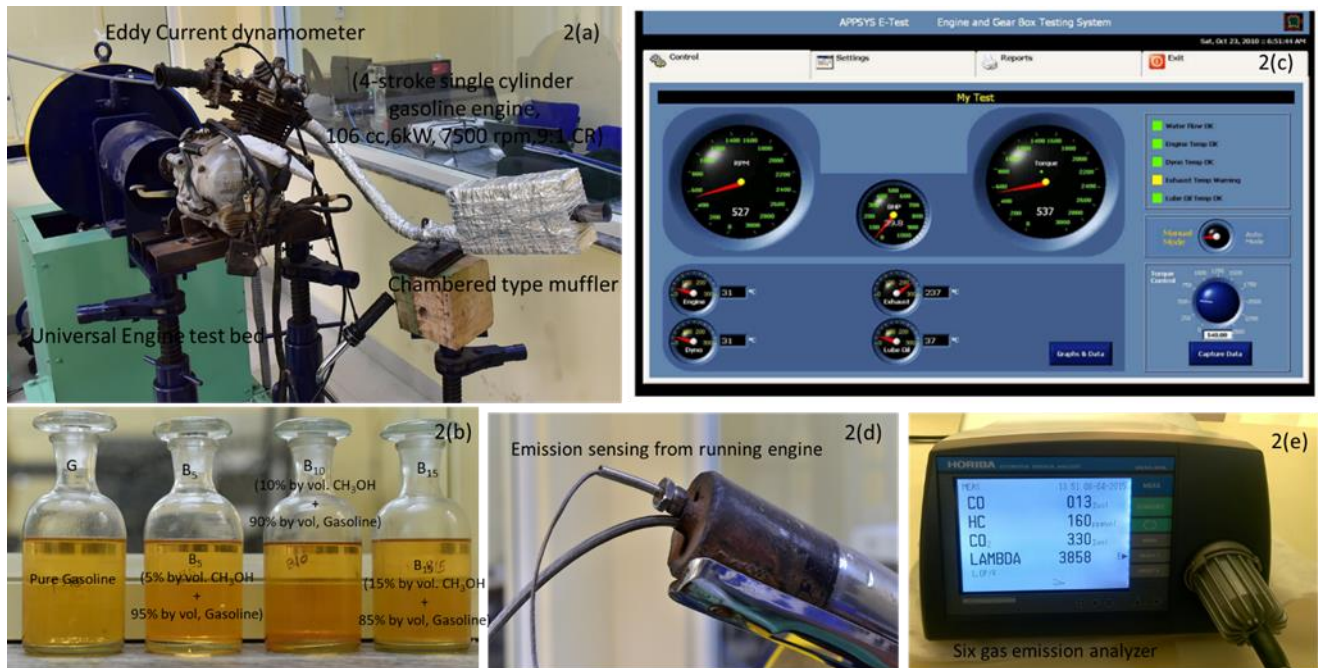


Figure S1. Emission measurement: a-Engine test bed mounted with single cylinder 4-stroke engine; b-Blend preparation; c-APPSYS E-Test Engine performance monitor; d-Emission sensor; e- Six gas emission analyzer.

Table S1. Mesh convergence test for selected design.

Sl. No	Element size(mm)	No of node	No of element	Total deformation(mm)	Equivalent stress (Mpa)
1.	0.5	330603	178042	0.26358	31.887
2.	0.6	197000	100756	0.26355	32.677
3.	0.7	150279	76073	0.26351	33.117
4.	0.8	106271	52954	0.26346	31.57
5.	0.9	83099	41219	0.26341	30.65
6.	1.0	66778	33066	0.26338	32.225
7.	1.1	56856	28123	0.26333	33.699
8.	1.2	47220	23281	0.26322	28.405
9.	1.3	42295	20861	0.26315	26.529
10.	1.4	44478	22103	0.26304	26.98

Table S2. Emission Data for Chamber-non-perforated Muffler (Pure Gasoline).

BMEP@bar	N(rpm)	CO (gm/kWhr)		CO ₂ (gm/kWhr)		NO _x (gm/kWhr)		Lambda		Exhaust O ₂ (% vol)		Unburnt (HC) (gm/kWhr)	
2.38	500	302.0031	293.0256	166.2914	178.9854	0.4977	0.484428	1.332	1.341	12.18	12	0.258258	0.222222
		294.8211	298.4121	175.1772	173.9078	0.484428	0.484428	1.334	1.335	12.11	12.09	0.23023	0.232232
2.38	1000	239.8788	196.4277	337.6604	390.9752	0.510972	0.491064	1.248	1.274	8.23	8.39	0.15015	0.116116
		194.6322	197.8641	401.1304	403.6692	0.491064	0.451248	1.264	1.248	8.56	9.26	0.12012	0.116116
2.38	1500	232.3377	212.2281	364.3178	412.555	0.550788	0.59724	1.238	1.22	8.95	8.56	0.142142	0.184184
		211.869	212.9463	407.4774	415.0938	0.59724	0.617148	1.217	1.209	8.16	8.05	0.19019	0.154154
3.57	500	169.4952	170.5725	237.3778	239.9166	0.291984	0.305256	1.709	1.698	12.49	12.39	0.324324	0.334334
		169.1361	168.777	238.6472	239.9166	0.29862	0.305256	1.705	1.703	12.39	12.38	0.322322	0.338338
3.57	1000	146.1537	149.7447	284.3456	286.8844	0.291984	0.351708	1.696	1.67	11.74	11.64	0.232232	0.25025
		145.0764	147.231	284.3456	288.1538	0.29862	0.351708	1.701	1.674	11.75	11.54	0.236236	0.25025
3.57	1500	99.4707	105.5754	383.3588	383.3588	0.345072	0.358344	1.635	1.604	10.14	10.07	0.132132	0.128128
		102.3435	109.1664	383.3588	383.3588	0.345072	0.351708	1.625	1.6	10.14	10.11	0.128128	0.126126
5.95	500	248.1381	245.6244	195.4876	196.757	0.424704	0.424704	1.468	1.479	12.36	12.45	0.42042	0.476476
		247.4199	245.6244	192.3141	199.2958	0.418068	0.43134	1.466	1.474	12.41	12.4	0.428428	0.472472
5.95	1000	197.505	180.6273	269.1128	276.7292	0.451248	0.504336	1.515	1.556	11.5	11.43	0.286286	0.276276
		197.505	187.4502	267.8434	274.1904	0.471156	0.510972	1.515	1.536	11.51	11.43	0.28028	0.28028
5.95	1500	156.2085	151.1811	341.4686	347.8156	0.504336	0.72996	1.527	1.491	10.22	10.18	0.21021	0.18018
		162.6723	145.0764	357.9708	347.8156	0.4977	0.517608	1.513	1.47	10.16	10.46	0.176176	0.178178

Table S3. Emission Data for Chamber-non-perforated Muffler (B₅, CH₃OH).

BMEP@bar	N(rpm)	CO (gm/kWhr)		CO ₂ (gm/kWhr)		NO _x (gm/kWhr)		Lambda		Exhaust O ₂ (% vol)		Unburnt (HC) (gm/kWhr)	
2.38	500	155.1312	155.1312	243.7248	241.186	0.291984	0.278712	1.772	1.779	12.57	12.59	0.318318	0.296296
		154.0539	153.6948	243.7248	242.4554	0.291984	0.278712	1.775	1.784	12.53	12.58	0.302302	0.286286
2.38	1000	137.1762	137.5353	276.7292	276.7292	0.291984	0.278712	1.774	1.776	12.11	12.15	0.202202	0.204204
		136.8171	129.9942	276.7292	275.4598	0.285348	0.285348	1.771	1.809	12.05	12.14	0.198198	0.2002
2.38	1500	64.9971	77.9247	387.167	364.3178	0.205716	0.218988	1.787	1.801	10.38	10.8	0.082082	0.1001
		85.1067	80.7975	373.2036	364.3178	0.205716	0.19908	1.735	1.793	10.54	10.92	0.1001	0.1001
3.57	500	174.8817	177.7545	248.8024	244.9942	0.557424	0.544152	1.661	1.659	12.28	12.25	0.358358	0.366366
		175.5999	177.0363	247.533	246.2636	0.550788	0.550788	1.737	1.697	12.31	12.33	0.36036	0.368368
3.57	1000	132.867	149.3856	294.5008	276.7292	0.437976	0.471156	1.737	1.697	11.76	11.82	0.25025	0.262262
		166.6224	157.6449	278.6333	275.4598	0.491064	0.477792	1.63	1.663	11.8	11.78	0.278278	0.272272
3.57	1500	93.366	96.957	370.6648	371.9342	0.36498	0.358344	1.706	1.688	10.57	10.52	0.132132	0.13013
		93.0069	96.2388	371.9342	371.9342	0.36498	0.358344	1.703	1.691	10.55	10.54	0.132132	0.132132
5.95	500	187.4502	187.0911	238.6472	236.1084	0.278712	0.318528	1.644	1.643	12.46	12.43	0.278278	0.31031
		187.4502	187.4502	233.5696	233.5696	0.291984	0.291984	1.637	1.637	12.32	12.32	0.302302	0.304304
5.95	1000	129.6351	177.3954	311.003	281.8068	0.338436	0.338436	1.713	1.578	11.53	11.58	0.188188	0.2002
		135.0216	167.3406	311.003	284.3456	0.338436	0.338436	1.694	1.61	11.55	11.6	0.188188	0.192192
5.95	1500	140.7672	158.7222	326.2358	318.6194	0.345072	0.849408	1.632	1.549	10.81	11.22	0.168168	0.18018
		142.5627	144.7173	324.9664	323.697	0.590604	0.802956	1.627	1.62	11.17	11.22	0.17017	0.176176

Table S4. Emission Data for Chamber-non-perforated Muffler (B₁₀, CH₃OH).

BMEP@bar	N(rpm)	CO (gm/kWhr)		CO ₂ (gm/kWhr)		NO _x (gm/kWhr)		Lambda		Exhaust O ₂ (% vol)		Unburnt (HC) (gm/kWhr)	
2.38	500	54.2241	51.3513	299.5784	291.962	0.351708	0.371616	2.274	2.303	12.68	12.87	0.15015	0.17017
		52.7877	52.7877	300.8478	293.8661	0.345072	0.345072	2.289	2.287	12.75	12.71	0.146146	0.15015
2.38	1000	42.0147	50.6331	366.8566	352.8932	0.484428	0.311892	2.02	1.945	11.66	11.11	0.078078	0.086086
		52.0695	49.9149	434.1348	355.432	0.451248	0.358344	2.025	2.043	11.49	11.24	0.078078	0.08008
2.38	1500	33.0372	35.91	410.0162	415.0938	0.56406	0.510972	1.917	1.874	10.56	10.33	0.044044	0.046046
		33.7554	35.1918	411.2856	415.0938	0.557424	0.537516	1.918	1.895	10.61	10.53	0.044044	0.046046
3.57	500	61.4061	63.5607	316.0806	314.8112	0.278712	0.291984	2.127	2.113	12.24	12.25	0.074074	0.066066
		61.047	63.2016	316.0806	314.8112	0.278712	0.285348	2.137	2.112	12.3	12.17	0.072072	0.074074
3.57	1000	58.5333	62.8425	344.0074	341.4686	0.238896	0.305256	2.018	1.989	11.65	11.55	0.052052	0.058058
		65.3562	61.7652	344.0074	340.1992	0.258804	0.29862	1.979	2.012	11.64	11.7	0.056056	0.054054
3.57	1500	40.9374	41.2965	393.514	395.4181	0.358344	0.345072	1.918	1.923	10.69	10.71	0.02002	0.018018
		40.9374	41.2965	393.514	396.0528	0.351708	0.351708	1.92	1.921	10.69	10.7	0.02002	0.018018
5.95	500	70.7427	65.7153	264.0352	262.7658	0.305256	0.29862	2.374	2.351	13.28	13.26	0.168168	0.168168
		64.638	62.8425	262.7658	261.4964	0.29862	0.26544	2.366	2.312	13.21	13.2	0.17017	0.17017
5.95	1000	22.9824	25.8552	308.4642	307.1948	0.856044	0.610512	1.872	1.844	11.98	11.88	0.134134	0.136136
		22.9824	26.2143	302.1172	304.656	0.311892	0.212352	1.87	1.887	11.97	11.97	0.146146	0.144144
5.95	1500	44.1693	34.1145	354.1626	352.8932	0.252168	0.544152	1.988	2.024	11.35	11.32	0.062062	0.068068
		41.2965	49.9149	356.7014	357.9708	0.272076	0.351708	2.083	2.049	11.55	11.51	0.072072	0.074074

Table S5. Emission Data for Chamber-non-perforated Muffler (B_{15}, CH_3OH).

BMEP@bar	N(rpm)	CO (gm/kWhr)		CO ₂ (gm/kWhr)		NO _x (gm/kWhr)		Lambda		Exhaust O ₂ (% vol)		Unburnt (HC) (gm/kWhr)	
2.38	500	47.7603	54.5832	269.1128	279.268	0.36498	0.345072	2.41	2.456	13.33	13.27	0.37037	0.214214
		49.5558	51.3513	274.1904	277.9986	0.39816	0.338436	2.427	2.446	13.33	13.34	0.272272	0.188188
2.38	1000	44.1693	35.1918	317.35	336.391	0.325164	0.391524	2.26	2.232	12.42	12.14	0.112112	0.16016
		49.9149	35.91	331.3134	335.1216	0.384888	0.371616	2.14	2.231	12.11	12.18	0.15015	0.216216
2.38	1500	30.1644	32.319	366.8566	365.5872	0.318528	0.311892	2.109	2.141	11.51	11.7	0.066066	0.06006
		30.8826	31.6008	366.8566	365.5872	0.305256	0.305256	2.133	2.141	11.68	11.63	0.074074	0.062062
3.57	500	39.1419	43.092	283.0762	285.615	0.272076	0.252168	2.473	2.535	13.33	13.24	0.118118	0.11011
		39.1419	41.2965	283.0762	284.3456	0.272076	0.26544	2.5	2.535	13.32	13.21	0.116116	0.114114
3.57	1000	58.5333	53.865	322.4276	327.5052	0.457884	0.43134	2.162	2.12	12.19	12.3	0.092092	0.066066
		54.9423	53.865	323.697	322.4276	0.457884	0.404796	2.163	2.147	12.24	12.35	0.09009	0.088088
3.57	1500	33.3963	32.319	352.8932	351.6238	0.272076	0.23226	2.197	2.185	11.91	11.93	0.036036	0.034034
		33.0372	32.6781	352.8932	351.6238	0.258804	0.238896	2.197	2.195	11.97	11.96	0.034034	0.034034
5.95	500	30.1644	31.9599	302.1172	309.7336	0.351708	0.43134	2.494	2.467	13.05	12.85	0.086086	0.116116
		30.5235	28.728	304.656	304.656	0.43134	0.510972	2.49	2.479	12.94	12.9	0.082082	0.082082
5.95	1000	43.8102	64.2789	336.391	337.6604	0.637056	0.676872	2.175	2.18	12.12	12.01	0.07007	0.086086
		43.8102	43.4511	336.391	335.1216	0.63042	0.789684	2.174	2.167	12.09	12.08	0.068068	0.07007
5.95	1500	33.0372	28.728	365.5872	361.779	0.703416	0.72996	2.122	2.135	11.6	11.62	0.03003	0.028028
		32.6781	31.6008	364.3178	354.1626	0.703416	0.6636	2.125	2.13	11.58	11.58	0.03003	0.03003

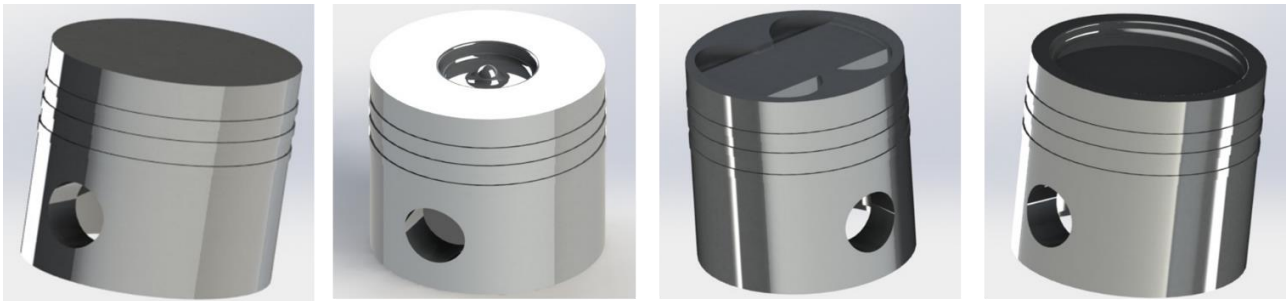


Figure S2. Multi piston design consideration: a. Flat head-A; b-bowl design-B; c-bowl design-C and bowl design-D.

Table S6. Mesh Details for multiple designs.

Piston Types	FGM Thickness on piston	Nodes	Elements	Element Size	Minimum edge length	Span angle centre	Transition Ratio	Maximum layers	Growth rate
Type-A Piston	Convectonal	26282	23639	Default	0.853880mm	Coarse	0.272	5	1.2
	0.4 mm	31647	14339	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	0.8 mm	30525	14192	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	1.2 mm	31584	14330	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	1.6 mm	31451	14311	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
Type-B Piston	Convectonal	71689	36279	Default	0.314530mm	Coarse	0.272	5	1.2
	0.4mm	194870	96366	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	0.8mm	207527	102527	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	1.2mm	209124	103793	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	For 1.6mm	209094	104093	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
Type-C Piston	Convectonal	38067	20926	Default	0.197230 mm	Coarse	0.272	5	1.2
	0.4mm	83898	42670	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	0.8mm	83264	42475	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	1.2mm	82827	42240	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	For 1.6mm	81666	41662	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
Type-D Piston	Convectonal	35492	19288	Default	0.853880mm	Coarse	0.272	5	1.2
	0.4mm	47495	24489	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	0.8mm	52115	27068	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	1.2mm	52123	27013	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2
	For 1.6mm	52380	27140	Default	10 ⁻⁴ m	Coarse	0.272	5	1.2

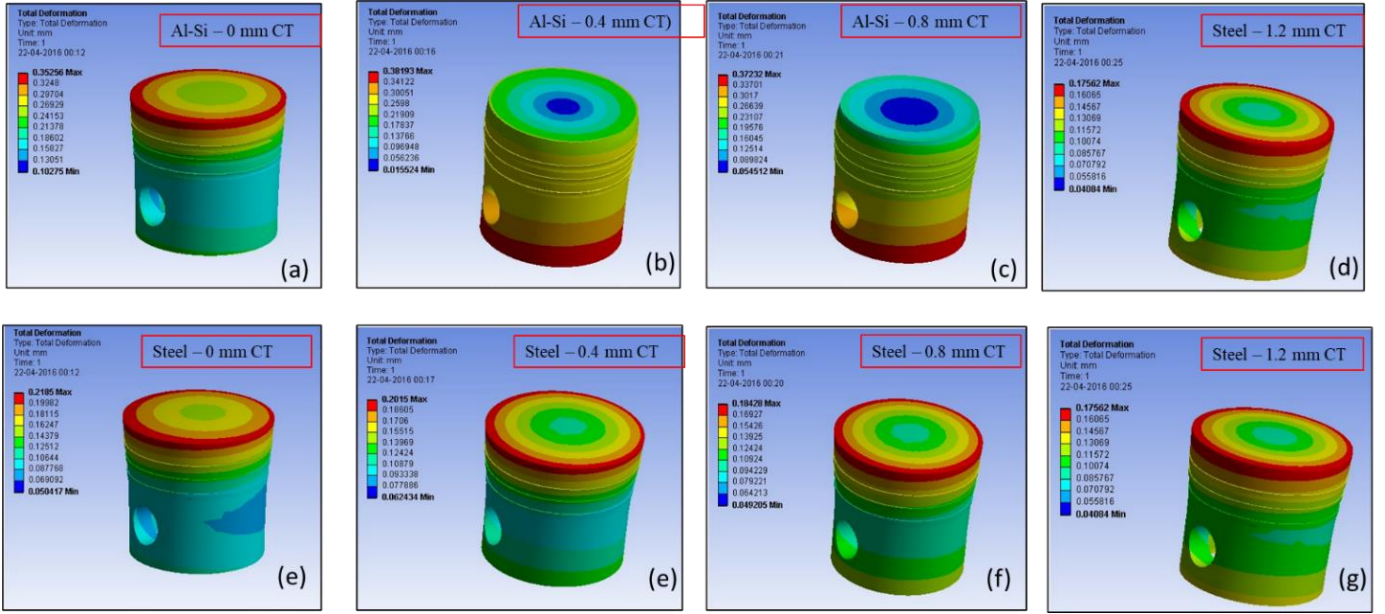


Figure S3. Structural deformation of Type-A piston design.

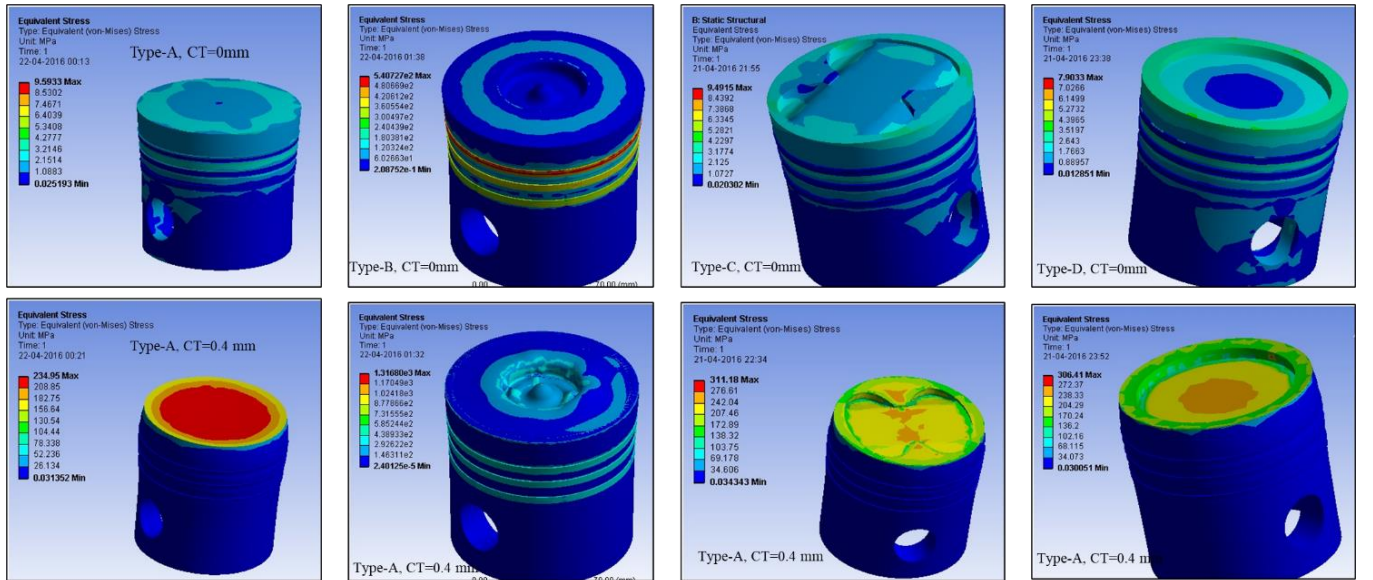


Figure S4. Von Mises stress of thin coated Al-Si pistons at 1500 rpm and BMEP@5.95 bar.

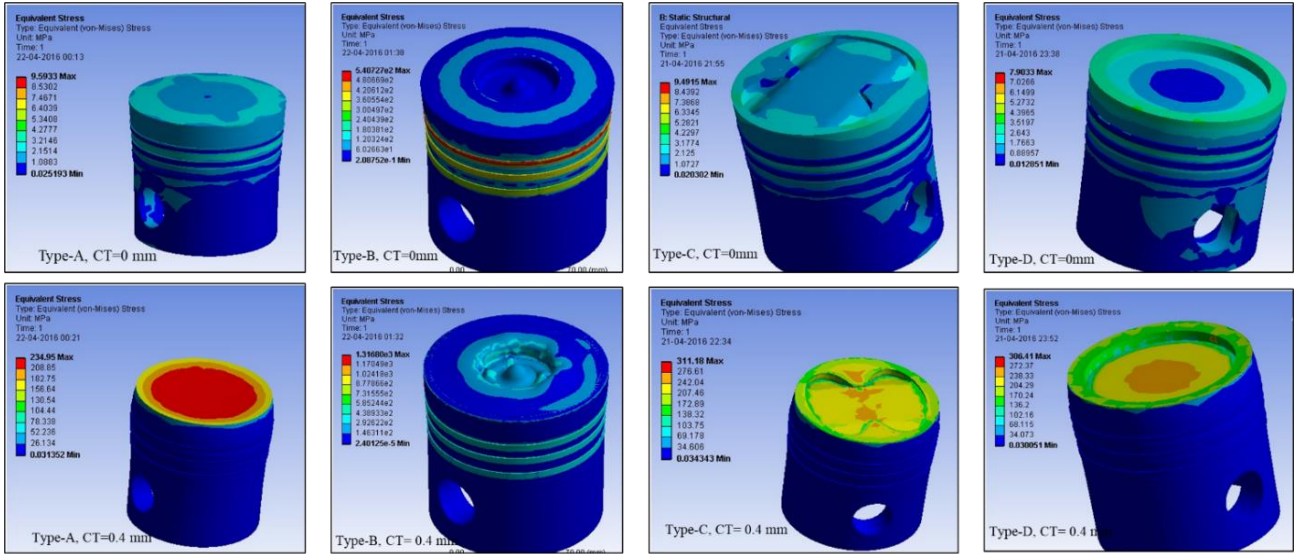


Figure S5. Von Mises stress of thick coated (0.8- and 1.2-mm CT) AlSi pistons at 1500 rpm and BMEP@5.95 bar.

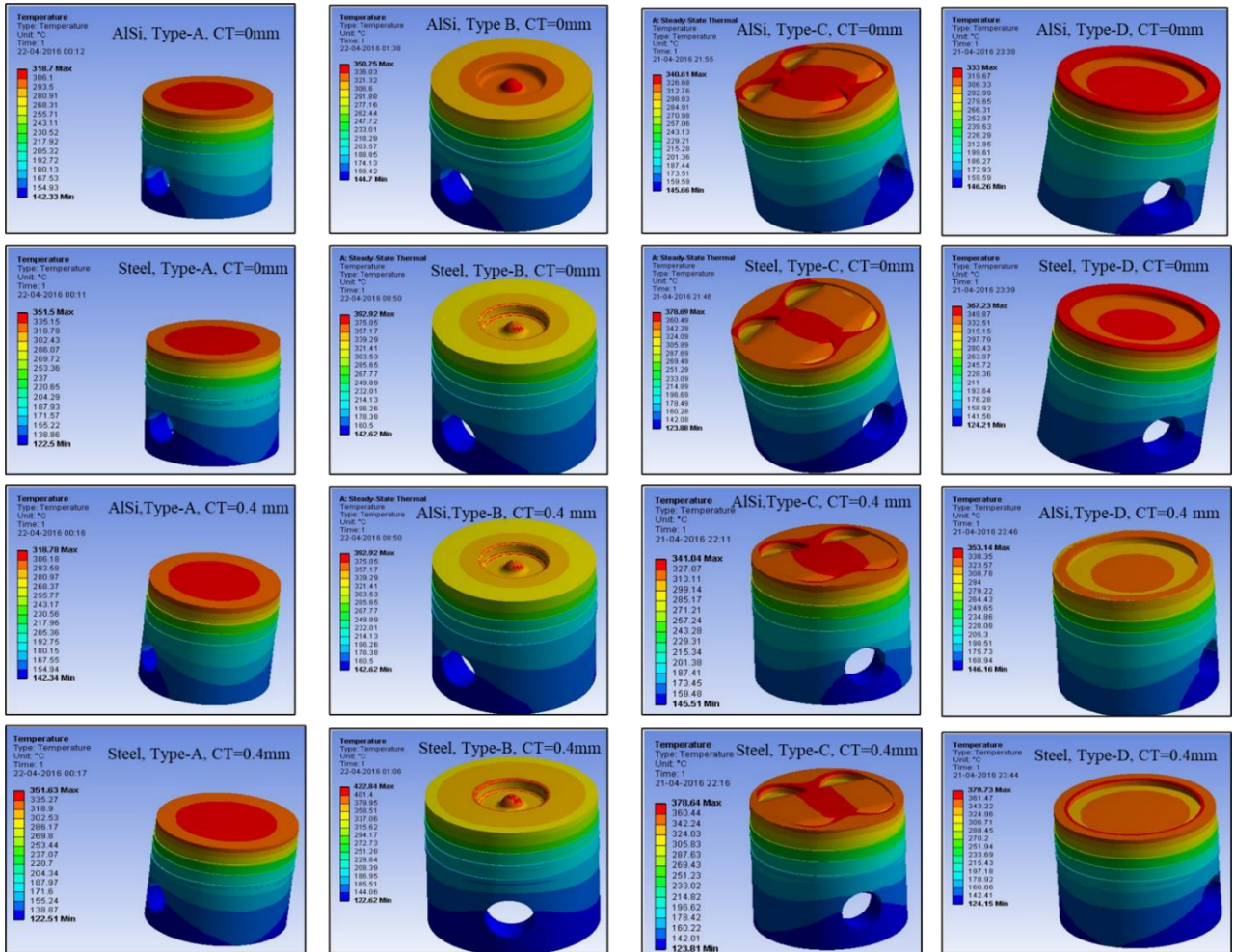


Figure S6. Temperature distribution of thin coated pistons at 1500 rpm and BMEP@5.95 bar.

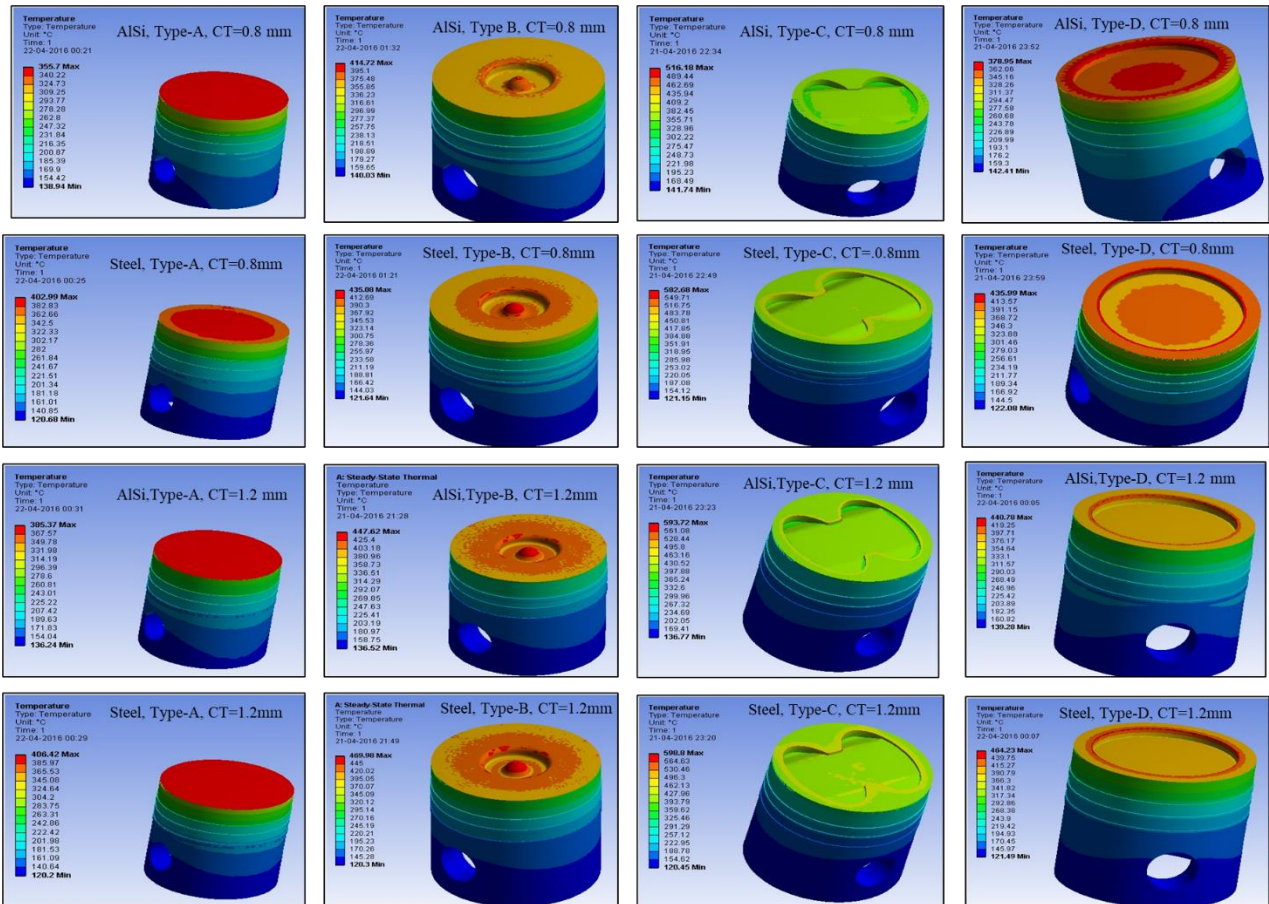


Figure S7. Temperature distribution of thick coated (0.8- and 1.2-mm CT) AlSi pistons at 1500 rpm and BMEP@5.95 bar.