

## **Electrostatic enamel powder - the new generation, properties and results**

Cristiano Mugnaini – Colorobbia Italia S.p.A – e-mail: [mugnainic@colorobbia.it](mailto:mugnainic@colorobbia.it)

Franco Bruni – Colorobbia Italia S.p.A. – e-mail: [brunif@colorobbia.it](mailto:brunif@colorobbia.it)

Fabrizio Bruscoli – Colorobbia Italia S.p.A. – e-mail: [bruscolif@colorobbia.it](mailto:bruscolif@colorobbia.it)

Gabriele Pasqualetti – Colorobbia Italia S.p.A. – e-mail: [pasqualettig@colorobbia.it](mailto:pasqualettig@colorobbia.it)

### **Introduction**

Porcelain enamel is well known as protective coating of metals for several types of application. Every artefact to be enamelled must be designed respecting appropriate rules and shapes. The enamel, especially the electrostatic powder, must be conceived to ensure the best possible covering properties: its final distribution on the surface depends a lot on the size of the particles composing it. The relationship between coarse and fine particles is very important to well cover deep moulded areas or zones in tight radii. The implementation of application properties was mainly focused in finding the optimal values of powder enamels particle size distribution especially in relation with the deposition rate (DR). Starting from experimental data has been developed the research described in this paper. The objective was to produce a powder with great performances on enamelling curved and angular pieces while ensuring, in industrial use, a decrease of enamel consumption, together with an improved homogeneity of the enamel thickness, in order to avoid defects linked to the application, such as back emission or burn off. To obtain enamels with improved application properties, compared to enamels prepared with traditional production processes, we first selected the best particle size distribution with regard to the deposition rate (DR), doing some industrial milling having different grinding fineness, but unchanged frits and additives composition. After laboratory evaluations, we used the best of these enamels as reference to compare the enamels produced with an innovative industrial production system that allows us to minimize the presence of the most extreme sizes of frit particles. This test was carried out on enamel for boiler, for heat exchanger panels and for household appliances. For each type of enamel we have chosen the ones with best particle size distribution to do industrial tests in enamelling plants, obtaining excellent results especially as regard the reduction of enamel consumption and improvement of thickness homogeneity, while maintaining an excellent enamelled finish and a very low reprocess rate.

### **Samples preparation**

In the present study we analyzed the differences observed in application of the enamel powder traditionally produced and those produced in order to have a specific particle size distribution. The types of enamel examined were:

- powder for household appliances,
- powder for boiler,
- powder for heat exchangers panels.

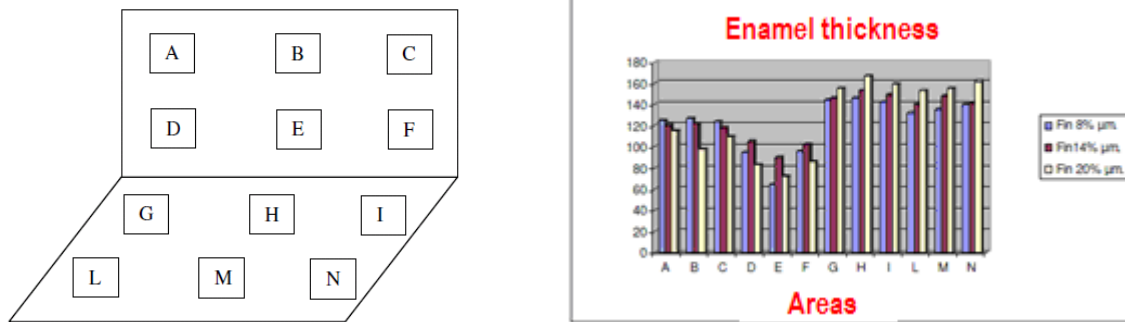
The industrial enamels selected for testing were all commercial products with was well known the reliability. All samples taken from production were evaluated thanks to a laser granulometer in order to obtain their distribution curve and used for application tests on 20 x 20 cm steel sheets bent with a bending radius of 0.8 mm.

### **Laboratory application**

The main purpose was the evaluation of the application properties of the powder enamel, produced in a traditional way, at different milling fineness intended as the residue remaining on a 45 micron mesh sieve as a percentage of the original product. We examined three degree of fineness: 8%; 14% and 20%. The parameters we kept constant during test were:

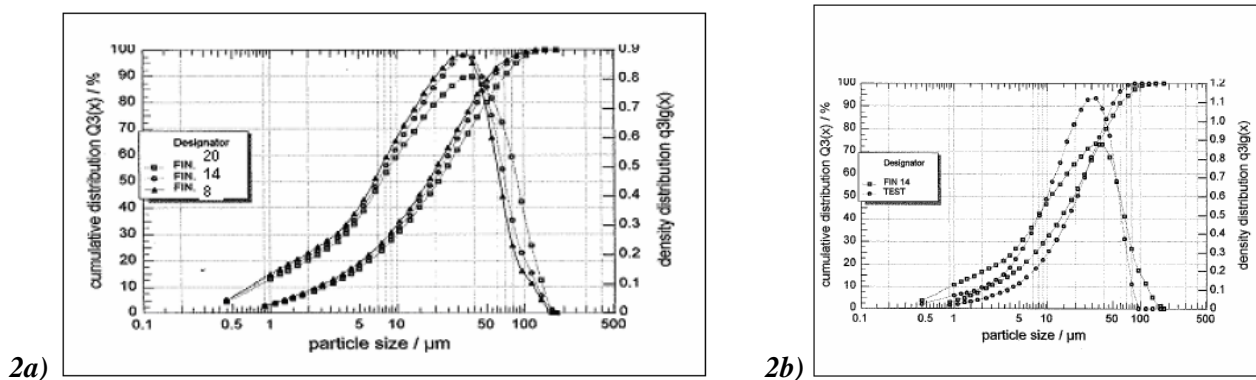
- the distance piece - gun, equal to 30 cm,
- the setting of the electrostatic gun: potential difference, air pressure, and the ratio air/enamel,
- the amount of enamel applied,
- the firing in a box furnace at 840 °C for 4 min.

After firing, the thicknesses of the applied enamel on the steel plates was measured (**Fig. 1**).



**Figure 1:** Measurement of the enamel thickness on laboratory samples

As we can see from the obtained thicknesses, a powder with finer granulometry tends to be distributed on the piece accumulating more on peaks and edges. The powder with bigger particles is distributed in a better way also in the concave part where the kinetic energy of greater size particles allows them to penetrate the "Faraday cage", being able to arrive also in the deepest parts of the piece. However the coarser particles, having less density charge, are more adversely affected by the force of gravity so that they tend to fall on the flat part of the piece, forming layers with higher thicknesses. The product with intermediate fineness tends to give a more uniform coverage of the enameled piece with minor accumulations on the flat part and not excessive thickness on the peaks. We can therefore easily understand how an appropriate fineness allows to achieve a good enameling of deep formed parts.

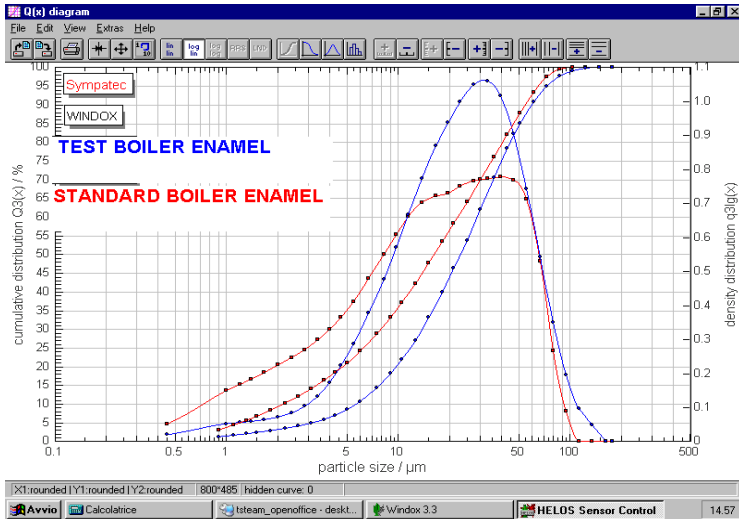


**Figure 2:** Comparison between distribution curves: a) products with fineness of 8, 14 and 20%; b) product with fineness of 14% and TEST

To evaluate the influence of the amplitude of the granulometric curve on the enamels application properties, were produced some industrial batches thanks to a new production process in order to obtain a material, practically free of fine and coarse particles, with a more contracted distribution curve, able to give uniform and homogeneous thickness on the enameled pieces. These tests were conducted on electrostatic powder enamels for different types of use. The distribution curve of the final product, called TEST, was compared with the one produced at fineness of 14%, that in the preliminary tests had shown the best application properties (**Figure 2b**). This material was then applied on to the folded plates and the thicknesses were measured in the different areas. Even if the thickness of the two samples looks similar, more detailed analysis reveals that the TEST powder has a lower peak effect despite the fact that in the angled parts the thicknesses are higher than usually are in such particular areas.

### Powder enamel for boiler

The comparison between the particle size distribution curves of commercial powder enamel for boiler and the one obtained by the new enamel called TEST BOILER, produced using the new production system, shows a significant reduction especially as regard the fine particles in the test enamel (**Figure 3**). The tests on curved plates reveal no difference on aesthetic and functional aspect between the commercial product and the one with less fine particles. Table 1 shows the application parameters of the two powders, and as you can see, there are values, such as fluidity and deposit rate (DR), which tend to increase in the powder TEST BOILER.



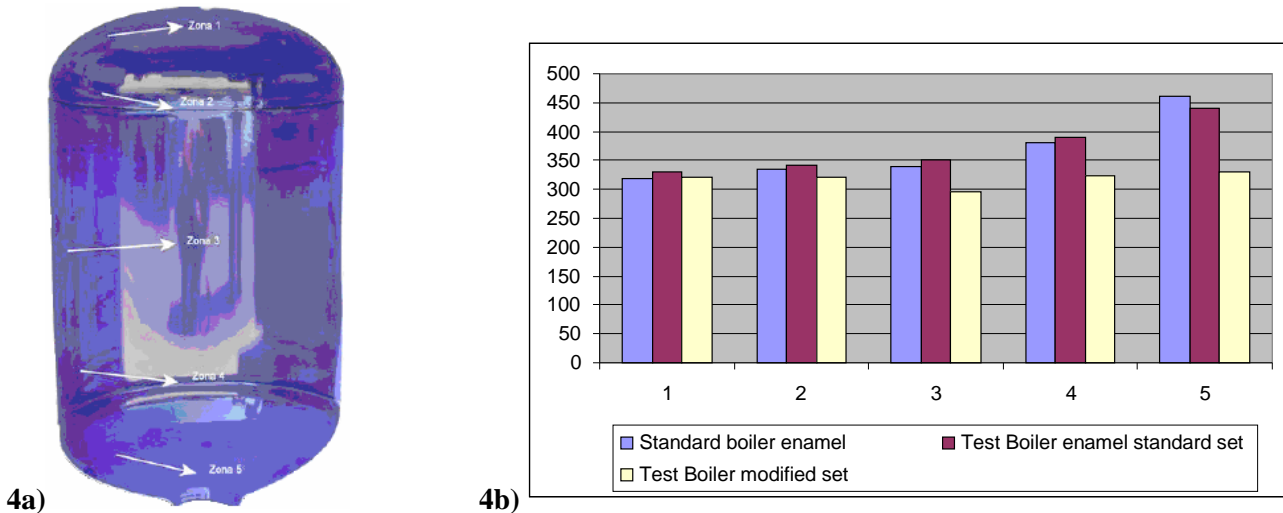
**Figure 3: TEST & STANDARD enamel**

	Standard boiler enamel	Test Boiler
Fineness	18 (x50)	22.98 (x50)
Adhesion	73	72
Fluidity	110	120
DR (Deposition rate)	32	40

curves

**Table 1: Boiler enamels application parameters**

The enamel TEST BOILER has been tested in an industrial plant, and the test was conducted with the two types of powder on 80 liter boilers. During the first enameling test the application process has not been changed from the normal settings, in order to precisely compare the application properties of the TEST with the standard enamel. During the tests, the thicknesses of the enamel were detected in the 5 zones of the boiler as shown in **figure 4a** and the averages of the obtained values are graphically expressed in **figure 4b**.



**Figure 4: a) Thickness monitoring zones on boiler 80 l. b) Measured thickness average**

Subsequently, with the TEST enamel, after an appropriate adjustments of the enamel application system, the weight of the applied enamel inside the boiler is considerably decreased while the thickness distribution has became very uniform over the whole inner surface of the boiler, as can be easily understood from the previous graph (**Fig. 4b**), in which are shown the average values of the thicknesses detected by measurements made on many 80 liters boiler, and from the following tables showing the relative standard deviation (**Tab. 2**) and the decreasing of the weight of enamel applied (**Tab. 3**).

	Standard Boiler	Test boiler enamel standard set	Test Boiler enamel modified set
Thickness standard deviation	57	45	13

**Table 2: Thicknesses standard deviation**

	Standard boiler enamel	Test Boiler enamel standard set	Test Boiler modified set
Enamel weight in g	807	767	702
Enamel weight reduction %	0	-5	-13

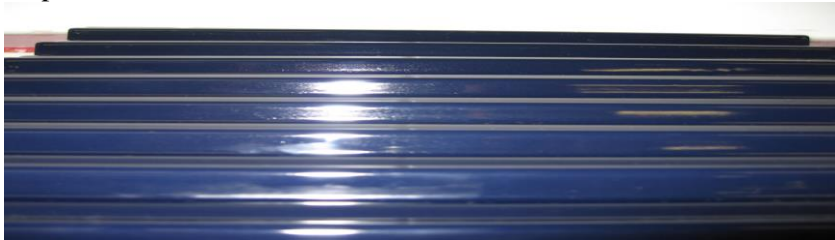
**Table 3: Enamel weight reduction**

Therefore, we can say that an enamel powder with a more selected particle size distribution, together with an appropriate adjustment of the enameling application machine, brings important advantages on coating, improving the homogeneity of thickness, with an important decrease of the enamel consumption, all

benefits that work for the optimization of industrial costs along with an increase of the overall quality of the finished product.

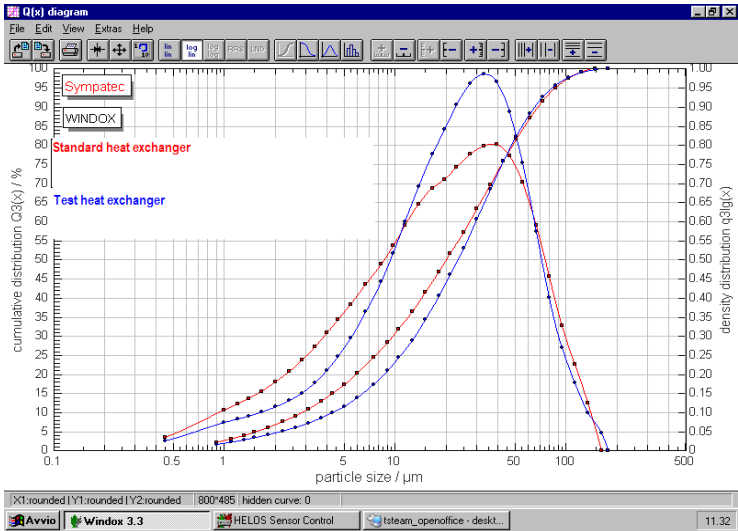
**Powder for heat exchangers**

Other tests were carried out on the powders for heat exchangers and **figure 5** is an example of such a product. The problem connected with the shape of this kind of objects is the continuous series of concave and convex surfaces that means, during the application of the enamel powder, a succession of Faraday cages close together. In addition, in heat exchanger enameling, is strictly necessary to avoid big accumulations of enamel on edges and peaks, which can cause enamel breakage and chipping ,that reduce the integrity of the product



*Figure 5: Heat exchanger panel*

The TEST HEAT EXCHANGER enamel, produced using our new production system, able to remove the most extreme particle sizes fractions, gives a more homogeneous thickness without accumulations of enamel on peaks on edges. Going to verify the granulometry curves of the STANDARD commercial product and the TEST, **figure 6**, is easy understandable that the TEST enamel contains less finer and coarser particles than in the standard enamel. As in the case of the enamel for boiler just seen, even with the powder for heat exchangers panels we did some industrial tests. Before of that we analyzed the difference between the two enamel at laboratory level obtaining the experimental results shown in the following table (**Tab. 4**):



*Figure 6: Standard and Test heat exchanger curves*

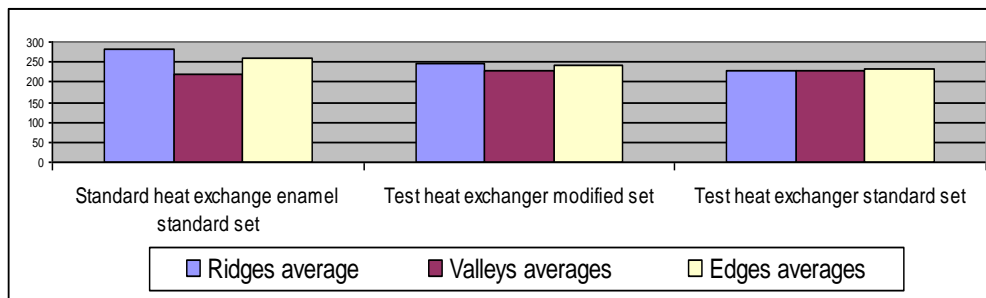
	Standard heat exchanger	Test heat exchanger
Fineness	19 (x50)	27 (x50)
Adhesion	70	70
Fluidity	100	120
DR (Deposition rate)	30	38

*Table 4:Heat exchangers enamel laboratory results*

As in the case of boiler enamel, we got an increase of the powder fluidity and deposition rate, both characteristics closely linked to the application behavior (**Tab.4**). The industrial test for the enamels for heat exchangers was made initially keeping the application machine with standard settings, comparing the STANDARD commercial product with the TEST enamel. Then in a subsequent phase we did all the appropriate adjustments of the application system as to obtain a thickness as uniform as possible on all areas with the TEST enamel.

*Table 5: Heat exchanger thickness standard deviation*

	Standard heat exchanger, standard set	Test heat exchanger, modified set	Test heat exchanger, standard set
Thickness standard deviation	30,5	7,6	4

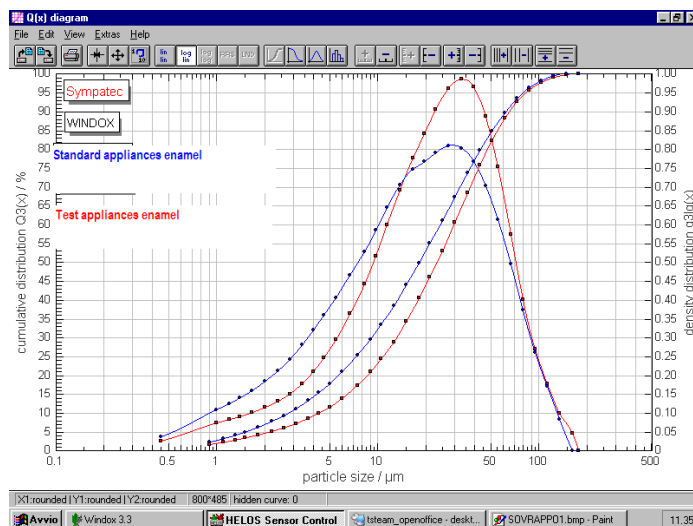


**Figure 7:** Heat exchanger thickness distribution

As clearly understandable from the graph (**Fig. 7**) and the relative standard deviation (**Tab. 5**), the thicknesses in the various areas of the pieces, became more uniform, particularly when the application machine setting has been adjusted according to the new application properties of the TEST enamel. In fact, the difference in thickness between the convex and concave parts, as well as the edges, has virtually disappeared, increasing in such way the functional properties of the enameled parts.

### Enamel powders for home appliances

Even for household appliances has been prepared a test enamel with contracted granulometry curve. By comparing the distribution curves of the APPLIANCES TEST enamel with the one produced in the traditional way called STANDARD APPLIANCES (**Fig. 8**), is easy to see that in the APPLIANCES TEST enamel the content of smaller and bigger particles is lower than in the STANDARD enamel.



**Figure 8:** Standard and Test Appliances enamel curves

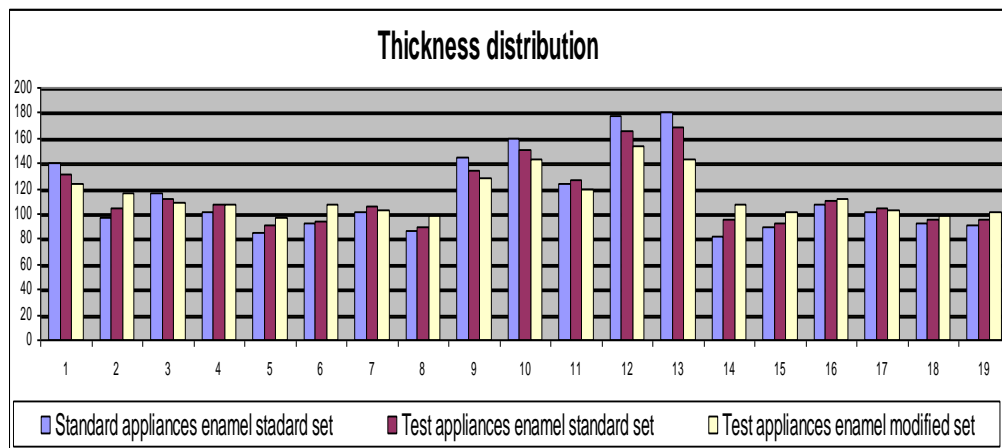
	Standard appliances enamel	Test appliances enamel
Fineness	19 (x50)	27 (x50)
Adhesion	70	70
Fluidity	120	140
DR (Deposition rate)	32	39

**Table6:** Appliances enamels laboratory results

The previous table (**Tab. 6**) shows the application parameters of the two powders and, there are values, such as fluidity and deposition rate (DR), which tend to increase in the APPLIANCES TEST enamel. The test enamel was tested in an industrial plant, producing kitchen ovens, together with the standard appliances enamel. The data of the thickness distribution have been obtained first on several pieces produced with the Standard appliances enamel and then using the same normal setting of the application system but using the enamel with restricted granulometric curve (Test appliances enamel). In according to the results obtained we provided to regulate the application machine trying to improve, in the best possible way, the thickness homogeneity in all areas of the oven. During those industrial tests we detected the thickness by following the scheme shown in the following image (**Fig. 9**).



**Figure 9:** Test thickness scheme



**Figure 10:** Appliances enamels thickness distribution

From the above graphic (**Fig.10**) it's easy to understand that mainly in the areas more influenced by the Faraday's cage effect, as in the portions from 1 to 6, there's an evident improvement of the thickness homogeneity using the Test enamel, becoming at the end more similar to the ones numbered from 9 to 11 in the flat areas. Also in the inner sides, where some ridges and valley are present, the differences between various areas tend to reduce. The evidence of the improvement done on the application properties of the Test enamel is clear by the reduction of the standard deviation (**Tab.7**) calculated on the thickness values detected during the industrial tests.

	Standard appliances enamel standard set	Test appliances enamel standard set	Test appliances enamel modified set
Thickness standard deviation	31,5	25	17

**Table 7:** Thickness standard deviation on appliances enamels

During the industrial tests we evaluated the quantity of applied enamel on each oven with different enamel and with different application machine setting. In **table 8** the averages of the weight data and the related enamel weight reduction obtained when using the TEST enamel instead the STANDARD enamel.

	Standard appliances enamel, standard set	Test appliances enamel, standard set	Test appliances enamel, modified set
Enamel weight in g	496	467	448
Enamel weight reduction %	0	-5,8	-9,7

**Table 8:** Enamel weight reduction obtained when using the *TEST* enamel instead the *STANDARD* enamel

From the obtained results we may affirm that, also for household appliances enamel, the principle of using enamels with an extremely selected granulometric particle size distribution, together with an appropriate enameling machine setting, brings many advantages especially for the application properties, making easy to control the final enamel thickness all over the areas. A more homogeneous distribution of the thickness allows us to achieve a considerable reduction of the enamel used. These performances are in favor of the optimization of manufacturing costs while maintaining, or even increasing, the aesthetic and functional quality of enameled kitchen ovens.

## Conclusions

The work described here leads us to conclude that the powder enamel particles size distribution has enormous importance in regulating the thickness in flat and deep moulded surfaces. The undoubted improvements achieved at application level are in fact the result of the use of enamels with a very selected particle size distribution, containing thus a very small percentage of the most extreme sized particles. A coating as homogeneous as possible is fundamental for the achievement of significant qualitative and economic benefits such as the reduction of defective pieces, the increase of the functional quality of the enamelled objects and the significant reduction of the consumed enamel for each piece produced.

Of course our research for a powder enamel with high efficiency application properties will require further developments in other field on which we have already turned our attention.

## Acknowledgements and References

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