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Lightweight aggregates made exclusively from waste: an alternative raw material contributing to Sustainable Construction

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INTRODUCTION

Pollution is one of the main problems that significantly affect our planet's natural resources and climate change. One of the most important anthropogenic sources of environmental pollution are cities, and the buildings that compose them. In this sense, the United Nations Environment Programme states that 'buildings are a very important part of environmental degradation', since on the one hand they consume large amounts of natural resources in their construction, and on the other hand they are responsible for 40% of greenhouse gas emissions and the generation of 35% of the EU's total waste (European Commission). In the scenario described above, there is a clear need to start using environmentally friendly techniques and materials. An evolution of the current building system towards sustainable construction is necessary. One material that has a major impact on the construction sector is aggregate, being one of the most widely used materials in this sector. Furthermore, a study published by Zhong et al (2022) indicates that the global demand for sand will increase by 45% by 2060. This increase will lead to a shortage of this material, which will encourage the use of alternative materials such as gravel, slag, aggregates, demolition waste and crushed concrete mixed with cement. This expected increase in demand for aggregates will have a negative impact on the natural reserves of this material, so alternative options such as artificial aggregates obtained from waste materials are of great interest.

MATERIALS AND METHODS

The mixtures have been obtained by design of experiments based on response surface and effect plots (Fig. 1). Six different models composed of 13 mixtures each have been designed based on the combination of six different waste material, three of mineral origin: aggregate washing sludge (AWS), granite cutting sludge (GCS) and slate cutting sludge (SCS), and three organic additives: cork dust (CD) generated in the manufacturing process of bottle stoppers, coffee grounds (CG) and olive pulp (OP), waste generated in the production of virgin olive oil. Once the aggregates had been manufactured and characterised, the data were re-included in the statistical model, thus, the composition was predicted to reach a given value of one or more properties of the aggregate obtained. Aggregates were again manufactured from these estimated mixtures and the results estimated by the models (Op_Est) and the experimentally data (Op_Exp) were analysed with the rest of the mixtures established by the model (Fig. 2).

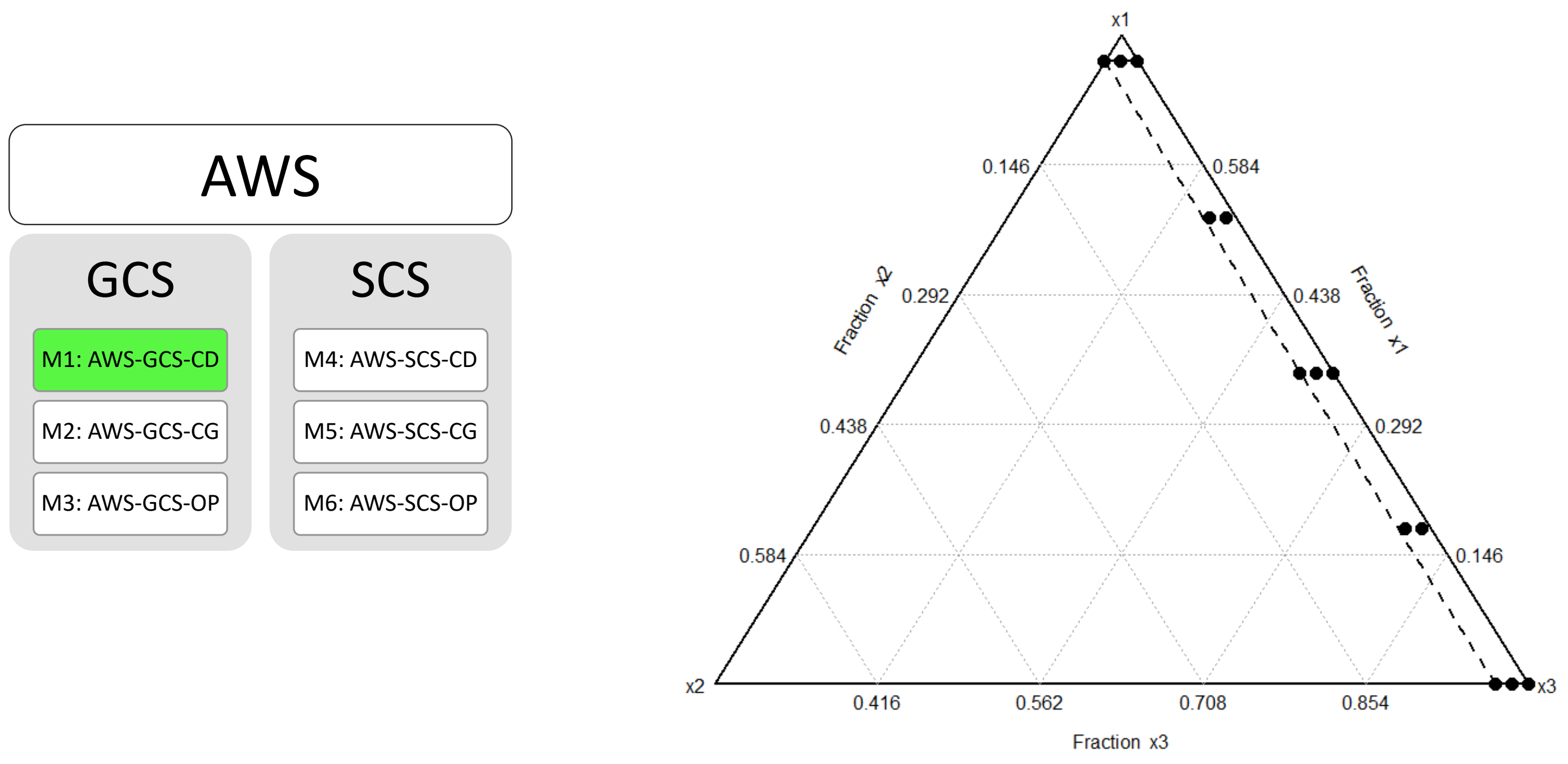

Figure 1. Mix design obtained for three components (Model 1): granite cutting sludge (fraction X1), cork dust (fraction X2) and aggregate washing sludge (fraction X3) .

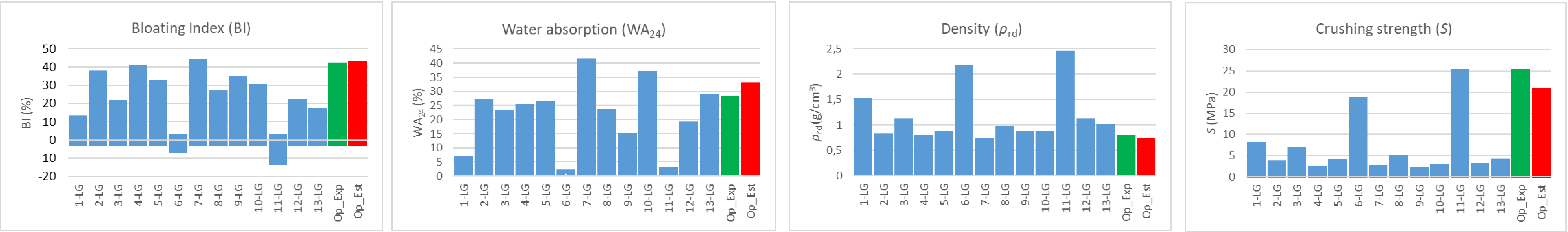

Figure 2. Representation of the main technological properties obtained for the 13 mixtures prepared with different percentages of AWS, GCS and CD, the estimated value for the optimum value of each property (Op_Est) and the value obtained experimentally (Op_Exp).

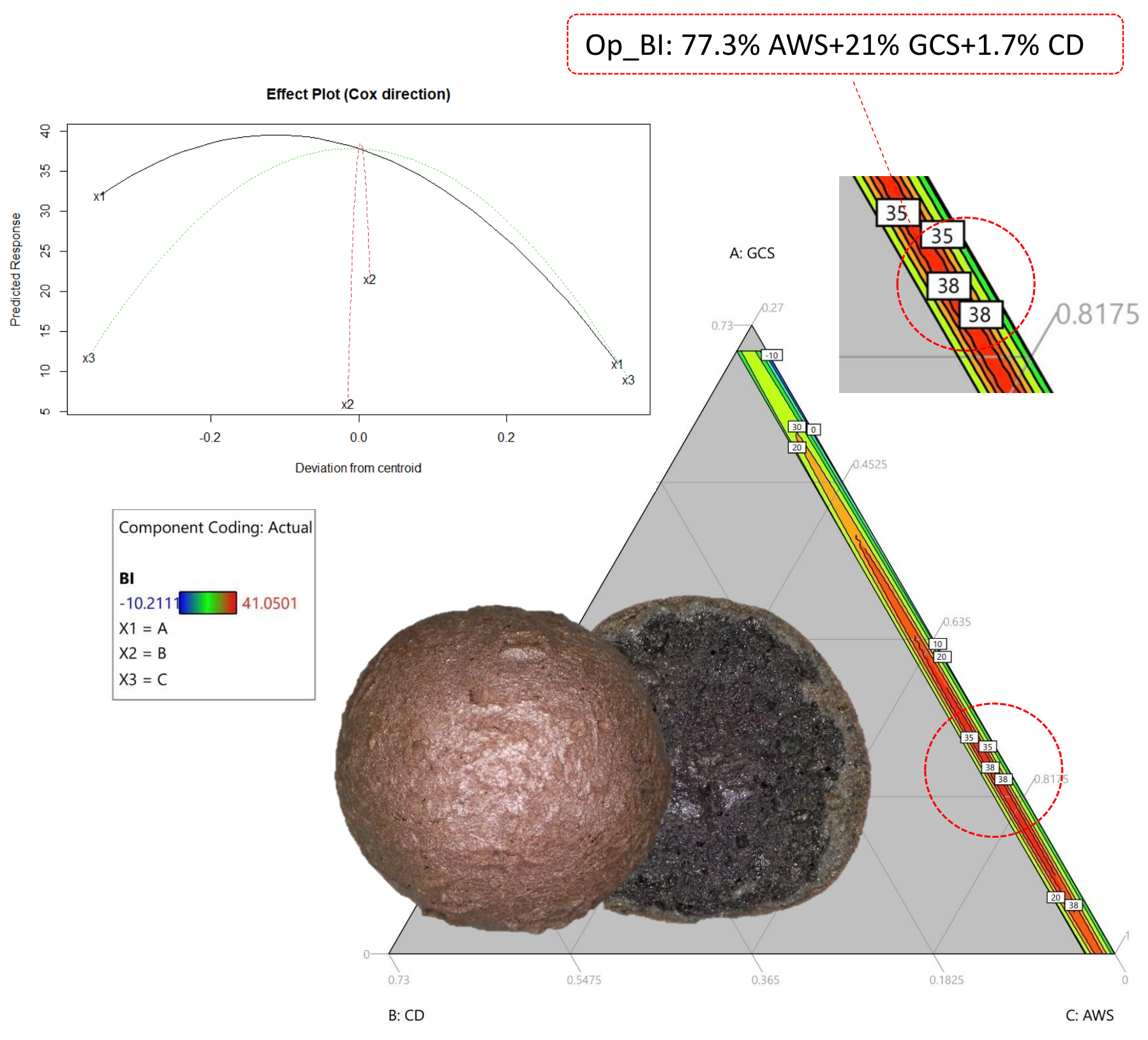
Op_BI: 77.3% AWS+21% GCS+1.7% CD

Figure 3. Effects plot and response surface obtained in model 1 for the Bloating Index (BI).

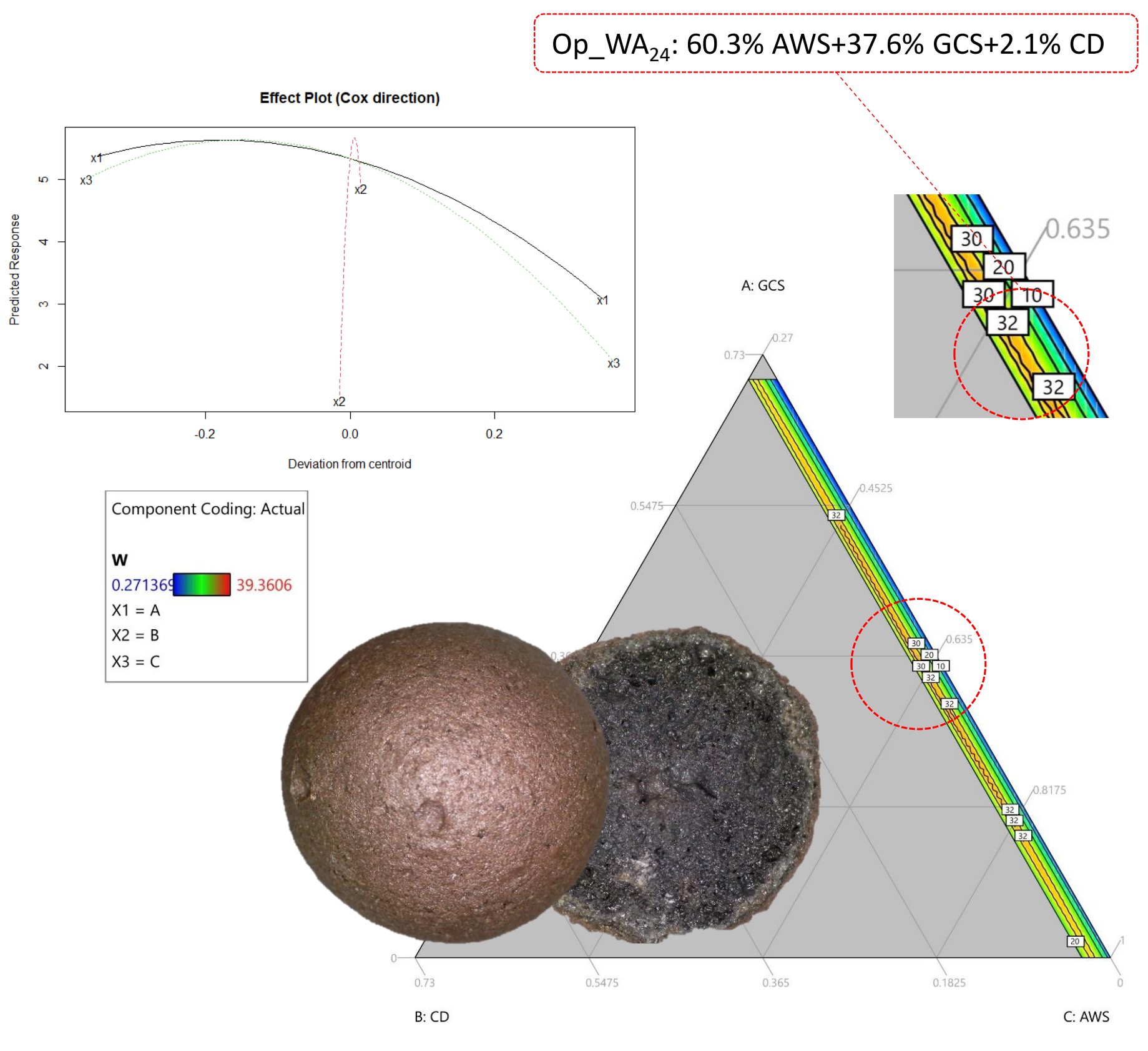
Op_WA$_{24}$: 60.3% AWS+37.6% GCS+2.1% CD

Figure 5. Effects plot and response surface obtained in model 1 for the Water Absorption (WA$_{24}$).

RESULTS AND DISCUSSION

The results obtained for the first model are shown in Figure 2. A wide variety of lightweight aggregates have been obtained with Bloating Index (BI) values between -10% and 41%; Density (ρ_{rd}) between 0.6 g/cm^3 and 2.4 g/cm^3; Water Absorption (WA$_{24}$) between 0.3% and 39.4% and Crushing Strengths (S) between 0,9MPa and 23,9MPa. As a result of the mix design carried out (Fig.1), it has been possible to obtain this wide variety of aggregates with a low number of mixes. Figures 3-6 show the effect and response surface graphs, in the case of BI, it can be seen that the variable X2 corresponding to the cork dust content has the greatest effect; small variations in the content of the mix determine large variations in the expansion of lightweight aggregates. Something similar occurs in the case of density, water absorption and resistance, again the variable X2 has the greatest effect. The compositions estimated to obtain the optimum value of BI, WA$_{24}$, ρ_{rd} and S are shown in figures 3-6, according to the response surface graphs. The optimum value was considered to be the maximum value for each study property, in the case of density the optimum value was determined to be the lowest density.

CONCLUSIONS

- Lightweight aggregates can be obtained from waste materials such as marble cutting sludge, aggregate washing sludge and cork dust.
- The design of mixtures reduces the number of experiments.
- The properties of lightweight aggregates can be predicted from the design of experiments.
- Cork dust component is the variable with the largest effect.
- The estimated optimum value for the Bloating Index (BI) has the best correlation with the experimental value (OP_Est = 39,6% vs OP_Exp = 39,0%).

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Zhong, X., Deetman, S., Tukker, A. *et al.* Increasing material efficiencies of buildings to address the global sand crisis. *Nat Sustain* **5**, 389–392 (2022). https://doi.org/10.1038/s41893-022-00857-0

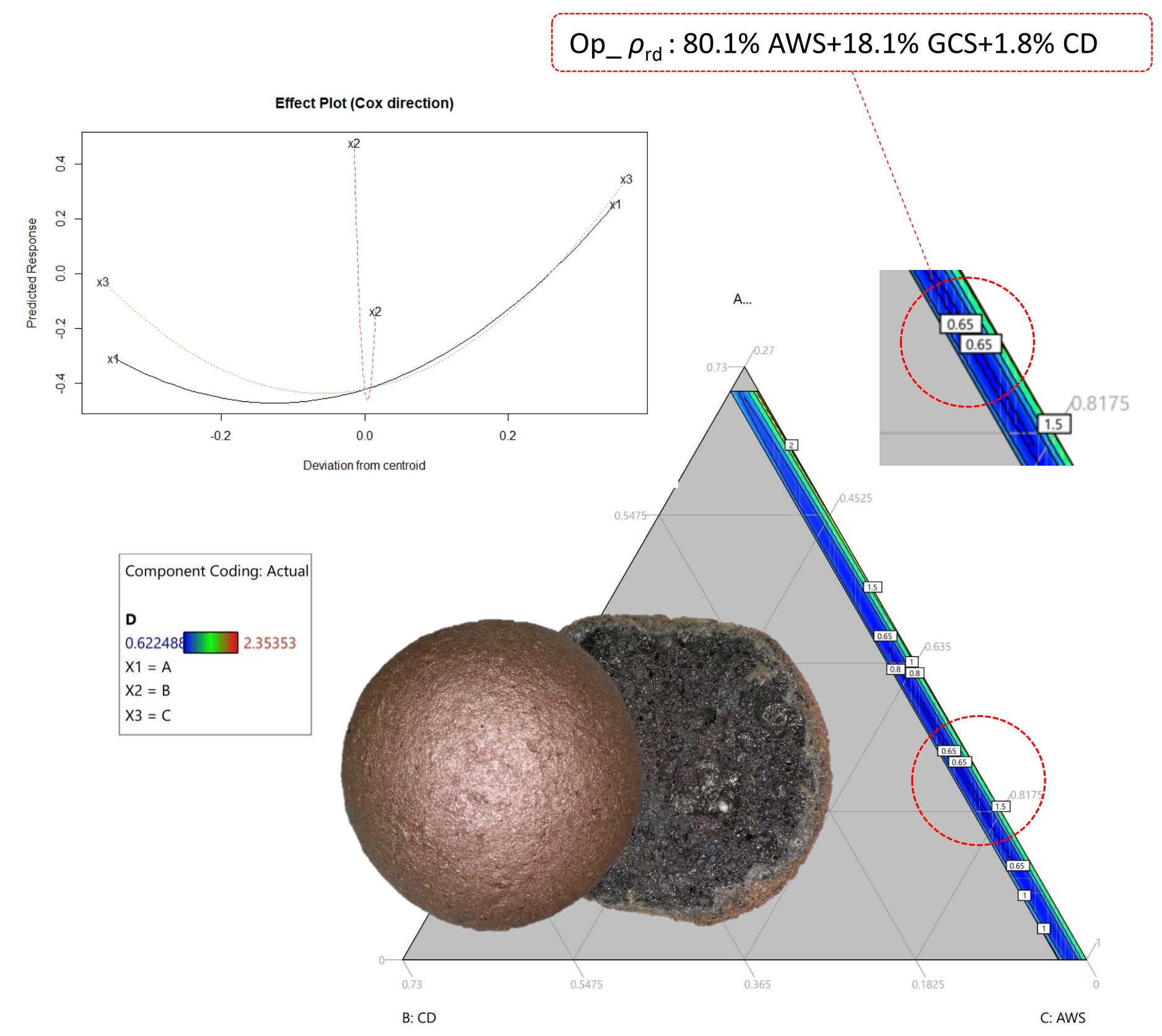
Op_ ρ_{rd} : 80.1% AWS+18.1% GCS+1.8% CD

Figure 4. Effects plot and response surface obtained in model 1 for the Density (ρ_{rd}).

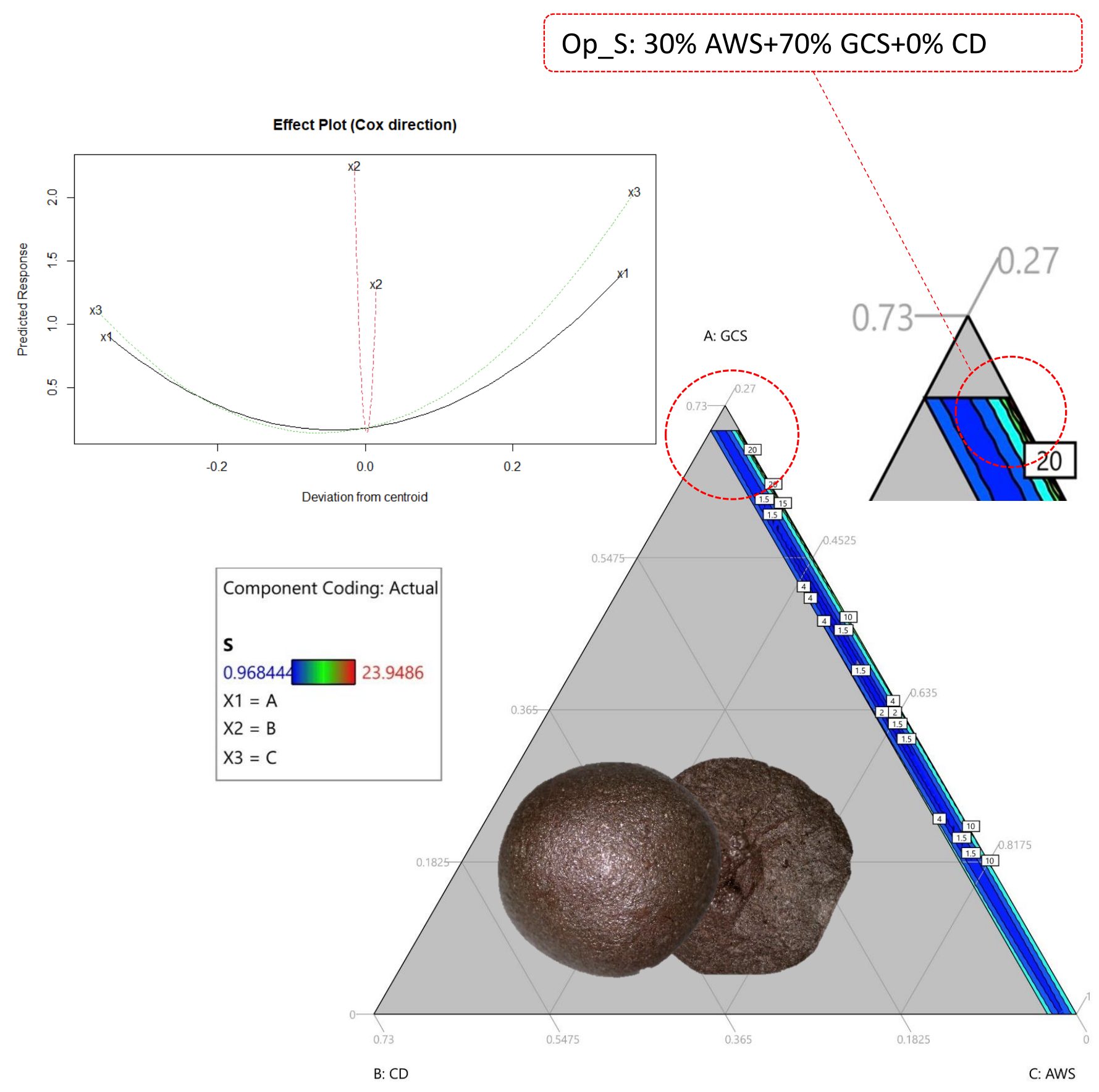
Op_S: 30% AWS+70% GCS+0% CD

Figure 6. Effects plot and response surface obtained in model 1 for the Crushing Strength (S).

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