Electronic Supplementary Material (ESI) for CrystEngComm

Supporting Information

An Investigation of the substituent effect of Halogen Atoms to the Crystal Structures of Indole-3-Carboxylic Acid (ICA)

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Hirshfeld surface

It is a space partitioning construct that summarises the crystal packing into a single 3-D surface, and the surface can reduced to a 2-D fingerprint plot, which summarise the complex information on intermolecular interactions present in molecular crystals.[25] The 3-D Hirshfeld surfaces and 2-D Fingerprint plots are unique for any crystal structure as well as polymorph. The 3-D Hirshfeld surface is defined as a 0.5 isosurface of the weight function ($w(r) = \rho promolecul(r)/\rho procrystal(r)$), from the boundary of the region where "the electron distribution of a sum of spherical atoms for the molecule (the promolecule) dominates the corresponding sum over the crystal (the procrystal)"[25], For points on the surface, distances to the nearest atoms outside, de and inside, di, are readily defined, and them provide informations of intermolecular close contacts in a crystal. When take the size of the atoms into account, we often use the normalized contact distance dnorm (eqn (1)), which based on de , di and the van der Waals (vdW) radii of the two atoms external (revdW) and internal (rivdW) to the surface: The value of dnorm is negative or positive when intermolecular contacts are shorter or longer than rvdW, respectively. The dnorm values are mapped onto the Hirshfeld surface by using a red–blue–white colour scheme: where red regions correspond to closer contacts and negative dnorm value; the blue regions correspond to longer contacts and positive dnorm value; and the white regions correspond to the distance of contacts is exactly the vdW separation and with a dnorm value of zero. The de and di can futher form a bin and condense into a 2-D Fingerprint plots, the points on the 2-D Fingerprint plots are colored as a function of the fraction of surface points in that bin, with a range

from blue (relatively few points) through green (moderate points) to red (many points). In addition, two further colored 3-D surfaces: Shape index and Curvedness are also specified for a certain crystal structure, and can be used for structure comparison.

(1)

The substituent effect of halogen atoms to ICA can also be visualised by the Hirshfeld surfaces, which is a useful tool for describing the surface characteristics of the molecules. Hirshfeld surfaces facilitate a novel method of visualizing intermolecular interactions by colour-coding short or long contacts, the colour intensity indicating the relative strength of the interactions. The 2-D fingerprint plots complement these surfaces, quantitatively summarizing the nature and type of intermolecular contacts experienced by the molecules in the crystal. The Hirshfeld dnorm surfaces (mapped over a fixed colour scale of -0.49 (red) to 1.2 Å (blue)) and Shape index (mapped over a fixed colour scale range of -0.98 - 1) of compounds ① - ⑥ are illustrated in Fig. S1, the Curvedness (mapped over a fixed colour scale range of -4.0 - 0.4) and the 2-D fingerprint plots of compounds ① - ⑥ are illustrated in Fig. S2.

The substituent effect in terms of substituted positions and different halogen atoms are illustrated obviously. The two larger red regions on the upper right of the dnorm surfaces are correspond to both donor and acceptor of strong O–H…O hydrogen bonds, and they are highlighted equally, which are characteristic of the cyclic hydrogen-bond dimer motif. These interactions comprise 23.9%, 22.7%, 22.1%, 16.8%, 21.3%, and 21.8% to the total Hirshfeld surfaces for compounds ① - ⑥, respectively. From which, we get the conclusion that the halogen atoms reduce the proportion of O–H…O hydrogen bonds interactions slightly. For the substituted 5-position, the corresponding effect in the order of Cl > F, and for substituted 6-position, the order is Cl > F > Br. What interesting is that the O–H…O

hydrogen bonds donors are bulge than accepters, and the N–H…O hydrogen bonds accepters are highlighted by the red concave regions near the region of O–H…O hydrogen bonds accepters. These two hydrogen bonds interaction are presented as two larger spikes in the 2-D fingerprint plots, as been shown in Fig. S2, with di and de to be 0.651/1.006 Å, 0.671/1.021 Å, 0.666/1.021 Å, 0.856/1.197 Å, 0.636/1.006 Å and 0.631/1.001 Å for compounds ① - ⑥, respectively. Which represent the closest contacts in these compounds. The small red regions on the dnorm surfaces are corresponding to the significant C-H ⋯ π or X-H ⋯ π interaction (X =F, Cl, Br), which due to the close approach of a proton to the indole ring. Among these interactions, the proportion of C-H ⋯ π interaction comprise 26.7%, 19.5%, 10.3%, 7.4%, 5%, and 5.9% to the total Hirshfeld surfaces for compounds ① - ⑥, respectively. The substituent effect in terms of C-H ⋯ π interaction show almost the same trends as O–H…O hydrogen bonds interaction but with a larger extent, this may attribute to the existence of X-H ⋯ π interaction, which split the C-H ⋯ π interaction. Actually, the X-H ⋯ π interactions comprise 14.8%, 15.6%, 16.8%, 17.6%, and 17.3% to the total Hirshfeld surfaces for compounds ② - ⑥, respectively, which offset the reduction of C - H ⋯ π interaction. In the 2-D fingerprint plots, the C - H ⋯ π interactions are indicated by the ‘‘wings’’ in the upper left and lower right positions for compounds ①, ② and ⑥ (as be shown in Fig. S3), and the F-H ⋯ π interactions for compounds ② and ⑥in the inner of the “wings”. While for compounds ③, ④ and ⑤, these “wings” are corresponding to X-H ⋯ π interactions (X = Cl, Br) and C-H ⋯ π interaction in the inner of these “wings”.

The Shape index is the most sensitive to very subtle changes in surface shape, the red triangles on them (above the plane of the molecule) represent concave regions indicating atoms of the π…stacked molecule above them, and the blue triangles represent convex regions indicating the indole ring atoms of these molecule inside these surfaces. The almost identical appearances of the red and blue triangles for compounds ① and ② indicating the similarity of π…π stacking interactions in these two crystal

structures, while the other four compounds are different from them obviously.

The π…π stacking interactions also can be reveled clearly by Curvedness, which serves as a measurement of "how much shape". The flat areas of the surface are correspond to low values of curvedness, while sharp curvature areas are correspond to high values of curvedness and usually tend to divide the surface into patches, which indicating the interactions between neighboring molecules. The Curvedness of compounds ① - ⑥ are shown in Fig. S2 , it is obviously illustrated that the flat region as delineated by a blue outline on the curvedness surfaces of compounds ③ - ⑥, are larger than that of compound ① and ②, which suggest the different proportions of π…π stacking interactions to the whole intermolecular interactions. Actually, the π…π stacking interactions comprise 4.9%, 5.8%, 12%, 14.3%, 14.4%, and 16.1% to the total Hirshfeld surfaces for compounds ① - ⑥, respectively. Thus we can concluded that the halogen atoms substituted on the indole ring can strengthen the π…π stacking interactions between the indole molecules, and the contribution in the order of Cl > F and F > Br > Cl for the substituted 5-position and 6-position, respectively. Apart from those above, the presence of H-H, lone-pair…π (C-N and C-O) interactions are observed for compound ①, for the halogen substituted compounds, there also exist atom-atom interactions between halogen atom and the other atoms. Among them, the H-H interaction contributes the most to the total Hirshfeld surfaces, they are 32.7%, 23.4%, 25.8%, 25.2%, 28.4%, and 28.9% for compounds ① - ⑥, respectively. Theses interaction change slightly to the substituted halogen atoms.

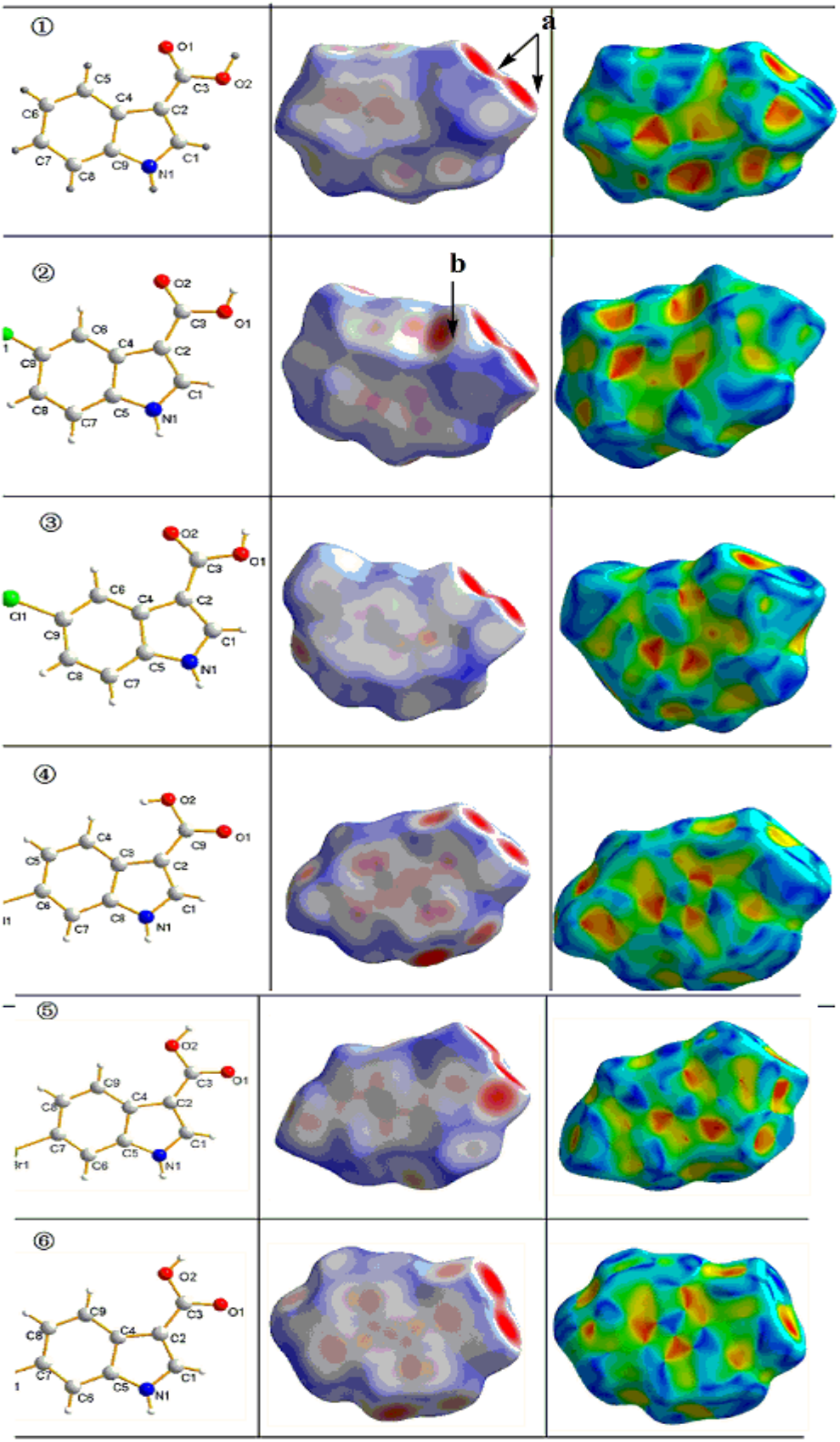

Fig. S1 Hirshfeld d_{norm} surfaces and *Shape index* of compounds ① - ⑥

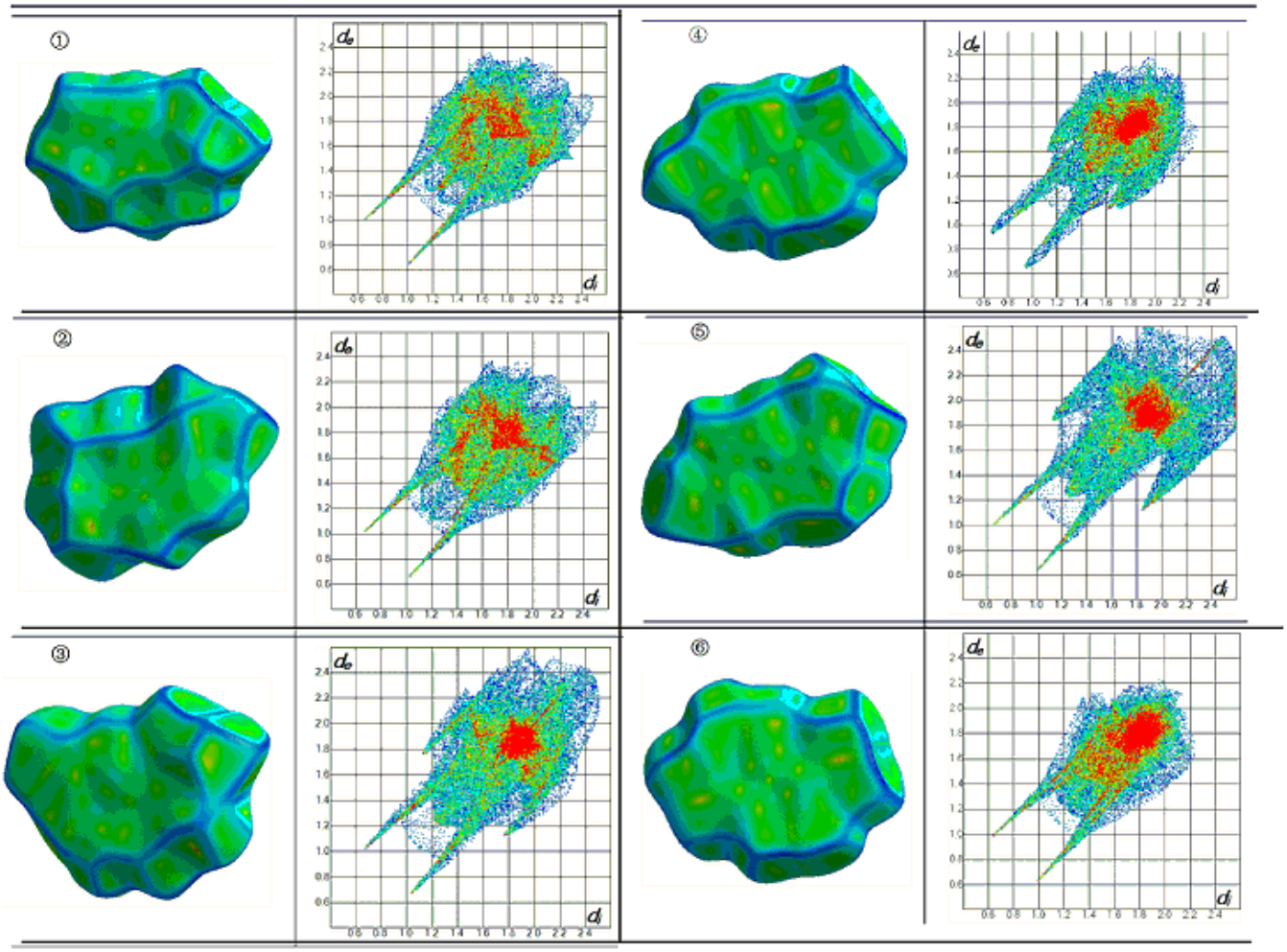

Fig. S2 *Curvedness* and the 2-D fingerprint plots of compounds ① - ⑥

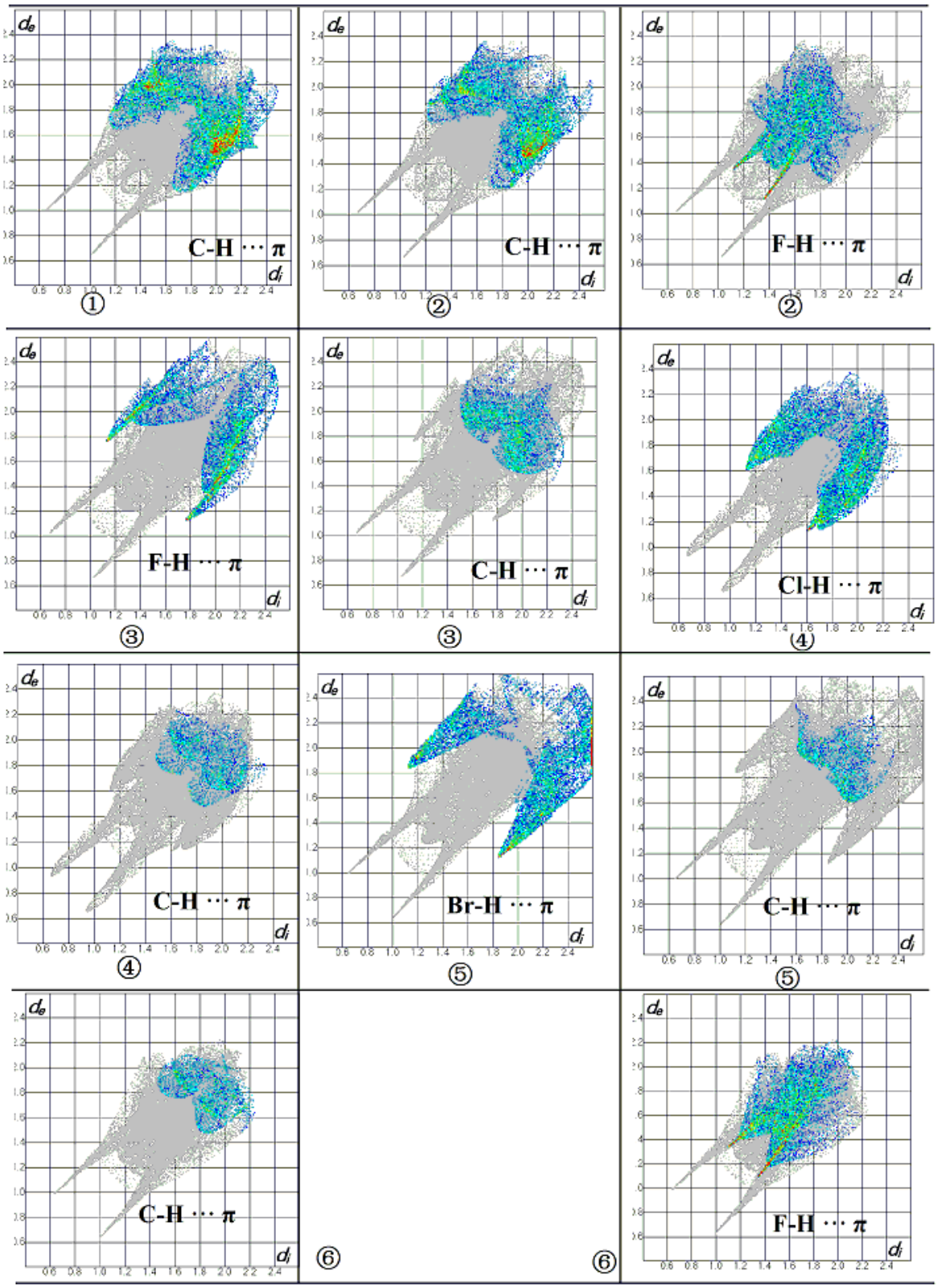

Fig. S3 Fingerprint plots for compounds ① - ⑥ resolved into C - H ··· π and X (F, Cl, Br)- H ··· π interaction; the full fingerprint appears beneath each decomposed plot as a grey shadow.

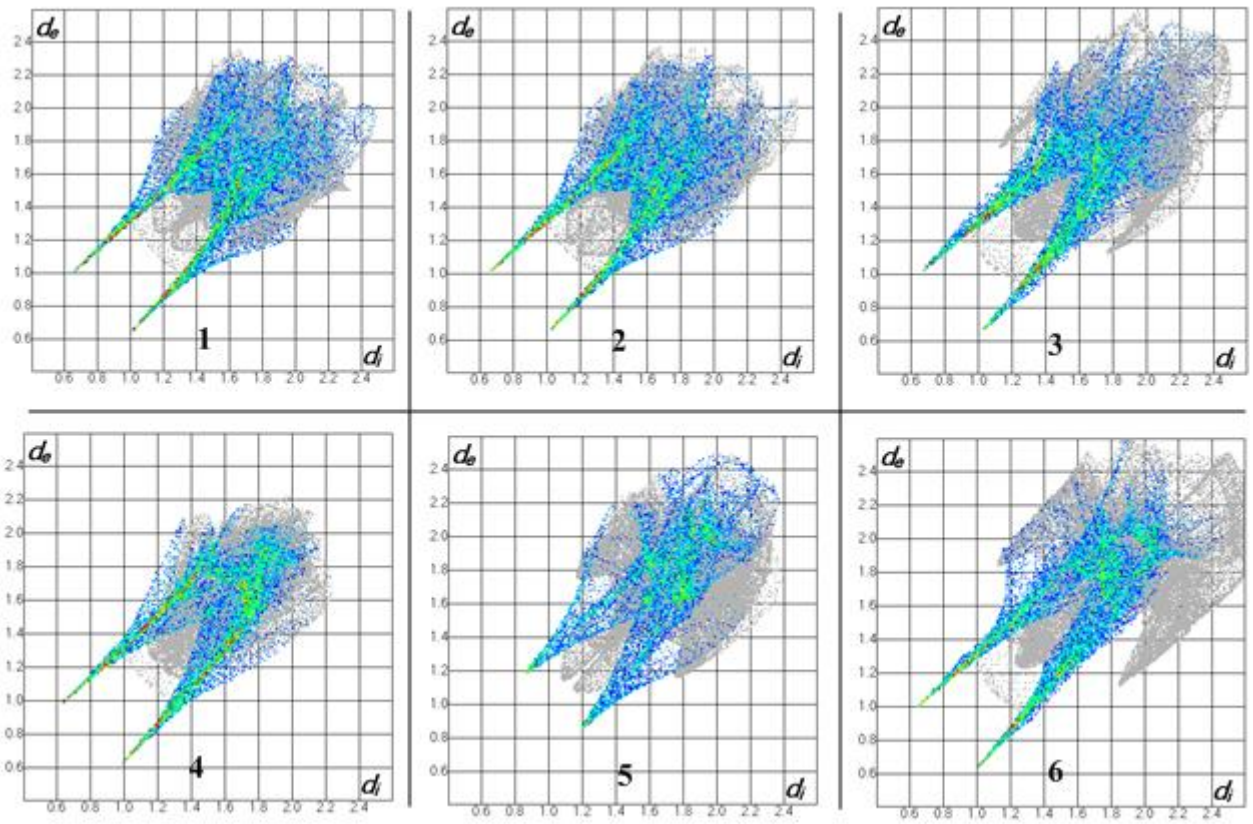

Fig. S4 Fingerprint plots for compounds ① - ⑥ resolved into O - H ⋯ O interaction, the full fingerprint appears beneath each decomposed plot as a grey shadow.

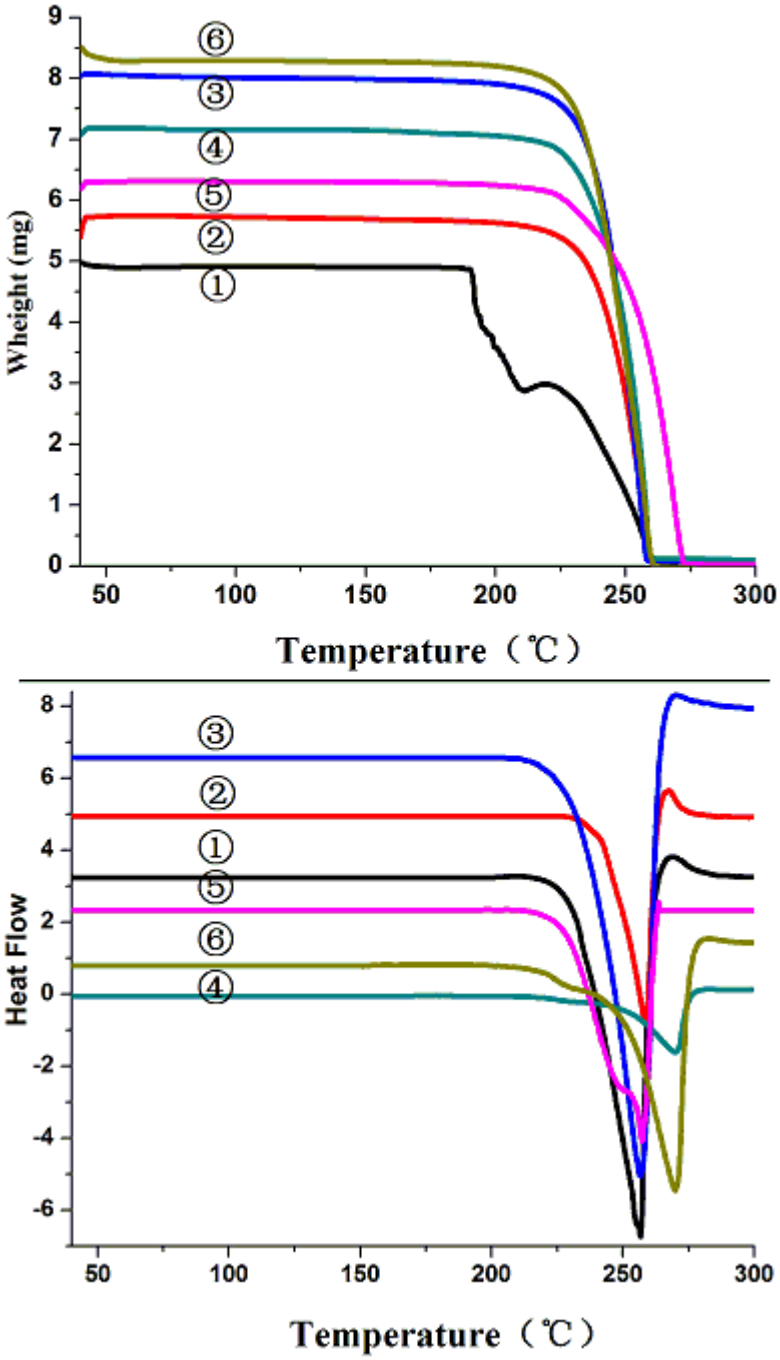

Fig. S5 The TGA and DSC profiles of compounds ① - ⑥

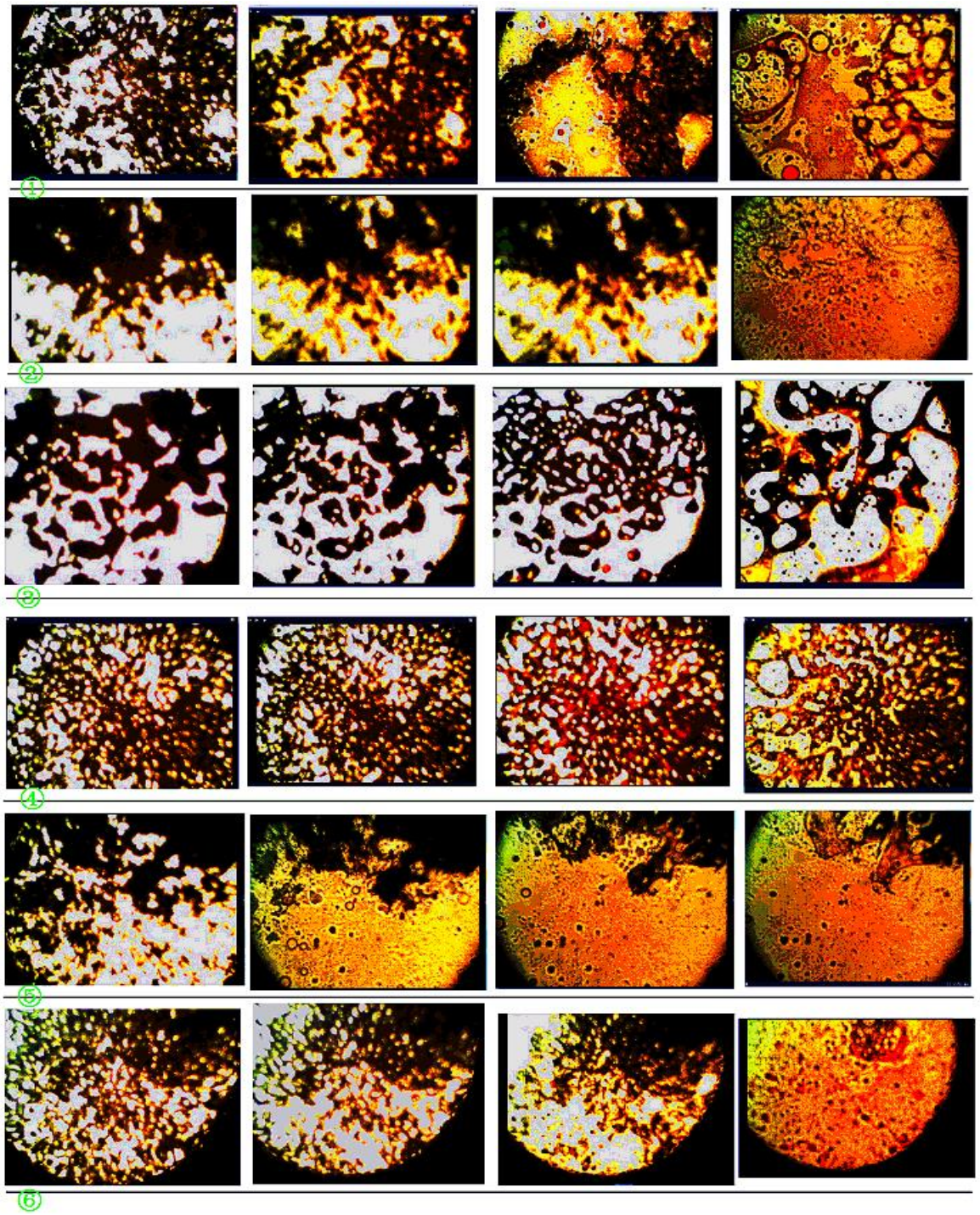

Fig. S6 Hot stage microscopy for compounds ① - ⑥.

Table S1 Melting point of compounds ① - ⑥.

Compounds	①	②	③	④	⑤	⑥
Melting Point/ ℃	189	170	174	180	175	181

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