CHAPTER 4

Gray Level Texture Classification Results and Discussions

In order to perform a Fuzzy Co-Occurrence Matrix (FCOM), three significant parameters were studied in this chapter. The first parameter was the number of clusters (C) or the number of quantization levels (Ng) in Gray Level Co-occurrence Matrix (GLCM). The second parameter was the distance between a pixel pair (d). The orientation of pixel pair (θ) was the last parameter. To analyze these parameters, the experimental design was investigated in section 4.1. The results of gray level texture classification from the proposed FCOM texture feature were presented in section 4.2. Finally, summarized of this chapter was also presented.

4.1 Experimental design

Generally, we calculated a two groups of textural features. It was a pair of feature sets extracted from the FCOM and GLCM. The first group was created from FCOM called FzCM1, FzCM2, FzCM3, FzCM4, FzCM5, and FzCM6. The second group was extracted from GLCM namely GLCM1, GLCM2, GLCM3, GLCM4, GLCM5, and GLCM6.

Four texture features, i.e., f_2: contrast, f_3: correlation, f_1: energy, and f_5: homogeneity at $\theta = 0°$ were extracted to produce the FzCM1 and GLCM1. Hence, there were $4 \times C$ dimensional features for FCOM and 4 dimensional features for GLCM. These four texture features at $\theta = 0°$, 45°, 90°, and 135° were computed to create the FzCM2 and GLCM2. This will be $16 \times C$ dimensional features for FCOM and 16 dimensional features for GLCM. For the third pair of feature sets, we computed the average and standard deviation from FzCM2 and GLCM2 of all directions to produce the FzCM3 and GLCM3. We had $8 \times C$ dimensional features and 8 dimensional features for FCOM and GLCM in this case, respectively. Similar to those three pairs of feature sets, we also created another three pairs of feature sets with fourteen properties, f_1 to f_{14}, which was

28

explained in section 3.3, called FzCM4, GLCM4, FzCM5, GLCM5, FzCM6, and GLCM6, respectively. The FzCM4 and GLCM4 were generated at $\theta = 0°$ while FzCM5 and GLCM5 were generated at $\theta = 0°$, 45°, 90°, and 135°. For the last two feature sets, we computed the average and standard deviation from FzCM5 and GLCM5 of all directions to produce the FzCM6 and GLCM6, respectively. A comparison of the FCOM and GLCM feature sets are shown in table 4.1.

Table 4.1 A comparison of the textural feature sets.

FCOM		GLCM	
Feature set name	Feature dimensions	Feature set name	Feature dimensions
FzCM1	$4 \times C$	GLCM1	4
FzCM2	$16 \times C$	GLCM2	16
FzCM3	$8 \times C$	GLCM3	8
FzCM4	$14 \times C$	GLCM4	14
FzCM5	$56 \times C$	GLCM5	56
FzCM6	$28 \times C$	GLCM6	28

where C is the number of clusters in FCM clustering algorithm.

For unbiased comparisons, we used the multi-classes support vector machine mentioned in section 2.4 as classifier for all studies. Moreover, each feature dimension was normalized by using

$$x' = \frac{x - \mu_x}{\sigma_X},$$
(4.1)

where μ_x and σ_x is mean and standard deviation of each feature, respectively.

4.2 Classification results and discussions

In this section, a four well-known benchmark gray scale texture data sets were collected, i.e., Brodatz [45], Kylberg [5], UIUC [46], and UMD [47]. In [48], we proposed the preliminary results of a texture classification using FCOM. The number of clusters was used only 8 clusters. The pixel pair distance in this case was extracted only $d = 1$. In this report, we implemented Fuzzy C-Means clustering with $C = 4$, 8, 16, and 32. For GLCM, we also quantized the images using $N_g = 4$, 8, 16, and 32. Then, the FCOM was calculated with $d = 1$ to 5 and $\theta = 0°$, 45°, 90°, and 135°. After that, six pairs of texture feature sets were extracted. The RBF $\sigma = 0.1$, 0.25 to 20 step 0.25 was used in all cases.

29

Next, we provided the explanation for each data sets followed by the classification results and discussions. The first benchmark gray scale texture data set used in this experiment was Brodatz. The data set consisted of 32 texture classes, each with 16 images. There were 512 images in total. The size of each image was 64×64. Some examples from the Brodatz data set are shown in figure 4.1.
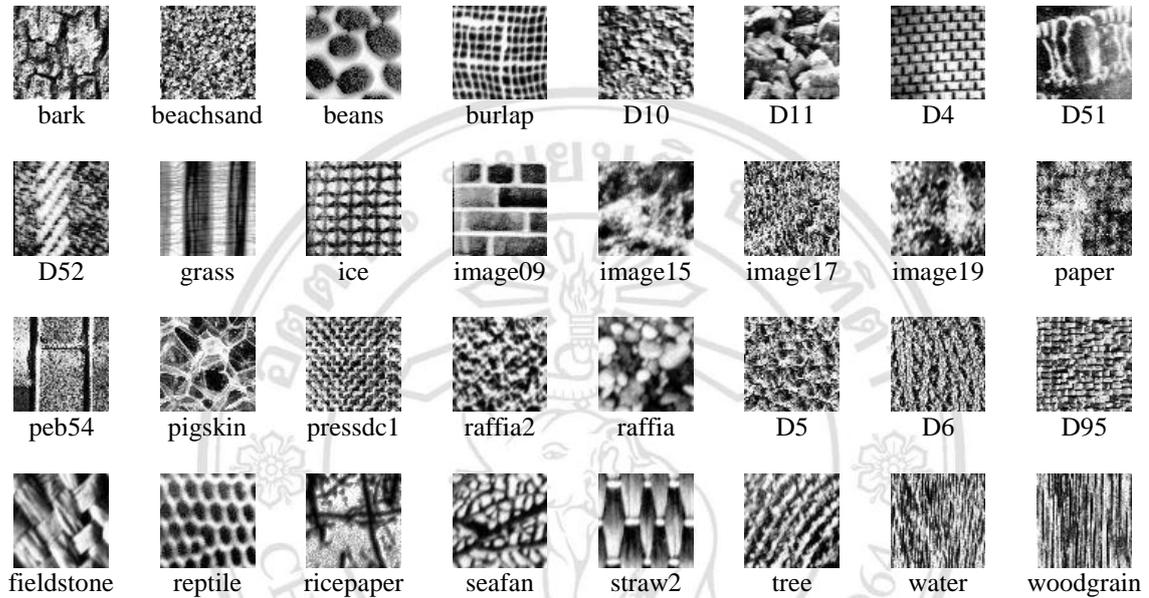

Figure 4.1 An example of Brodatz texture data set.

We computed feature sets using the FzCM1, FzCM2, FzCM3, FzCM4, FzCM5, and FzCM6 for the FCOM. We also created GLCM1, GLCM2, GLCM3, GLCM4, GLCM5, and GLCM6 feature sets for the GLCM. We implemented the 8-fold cross validation in this case. The best validation set classification results using $N_g = 4$, $d = 1$ to $N_g = 32$, $d = 5$ are shown in figure 4.2 to 4.21, respectively. Table 4.2 to 4.6 show the summary of the best correct classification results from the validation set for each distance of a pixel pair, $d = 1$ to 5, respectively. The summarized results for the best classification on the validation set are shown in table 4.7. From all tables, we can see that the classification results on the validation set from the feature sets extracted from FCOM were always better than those from the feature sets extracted from GLCM.
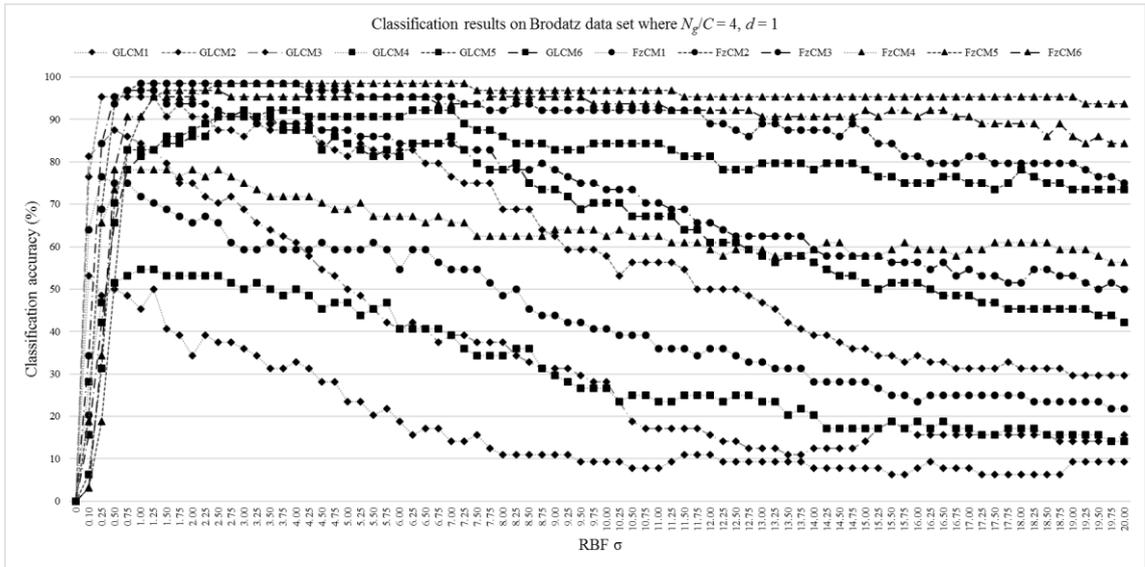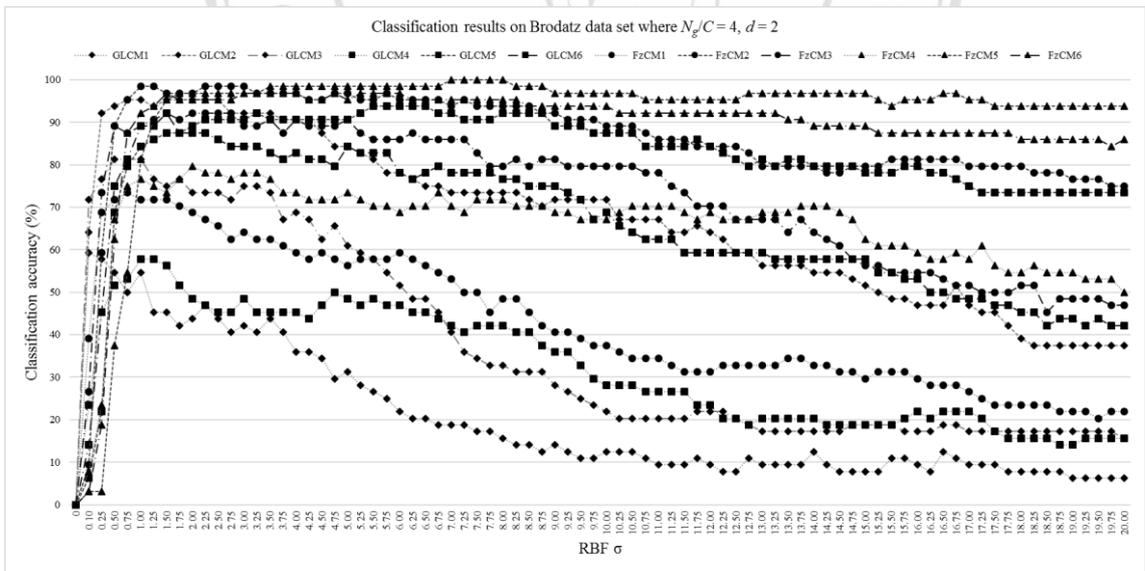
30

Figure 4.2 The best validation set classification results from the Brodatz data set where
Ng or $C = 4$ and $d = 1$.

Figure 4.3 The best validation set classification results from the Brodatz data set where
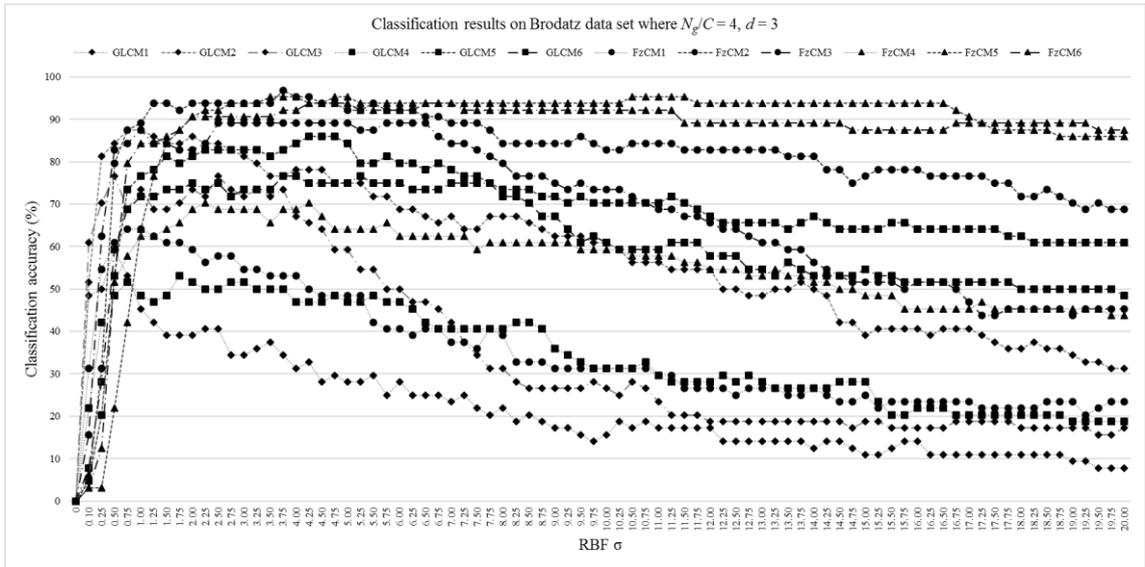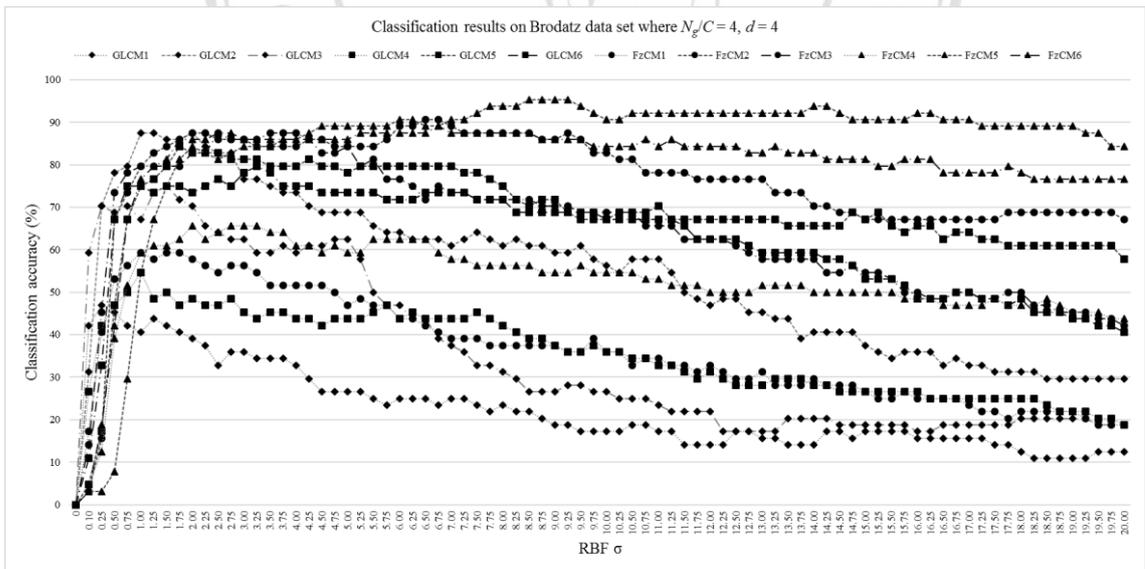Ng or $C = 4$ and $d = 2$.

31

Figure 4.4 The best validation set classification results from the Brodatz data set where N_g or $C = 4$ and $d = 3$.

Figure 4.5 The best validation set classification results from the Brodatz data set where N_g or $C = 4$ and $d = 4$.
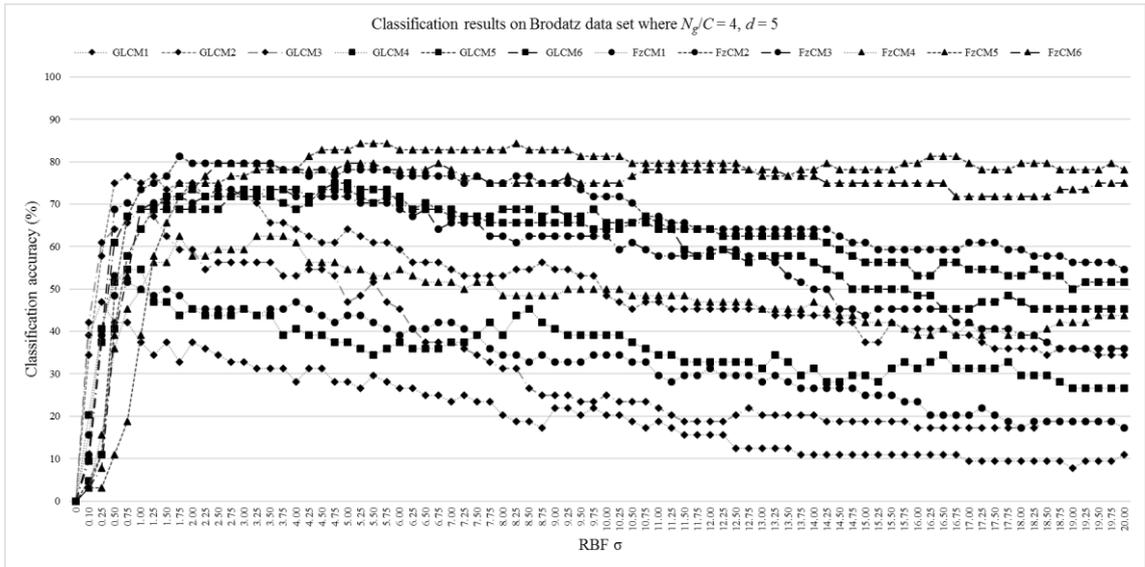
Figure 4.6 The best validation set classification results from the Brodatz data set where Ng or $C = 4$ and $d = 5$.
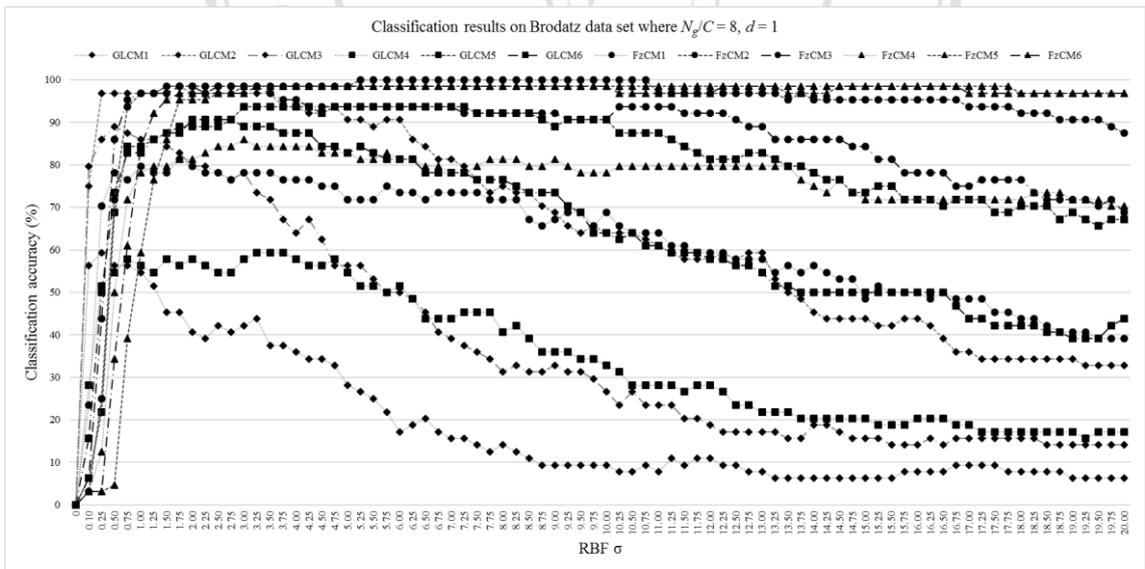

Figure 4.7 The best validation set classification results from the Brodatz data set where Ng or $C = 8$ and $d = 1$.

Figure 4.8 The best validation set classification results from the Brodatz data set where
Ng or $C = 8$ and $d = 2$.

Figure 4.9 The best validation set classification results from the Brodatz data set where
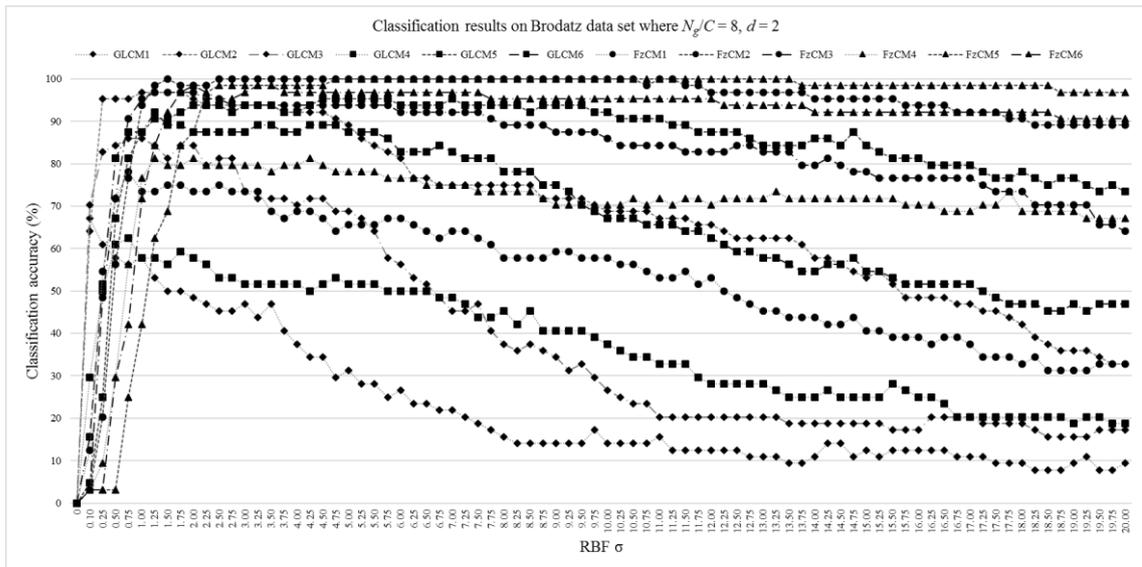Ng or $C = 8$ and $d = 3$.

Figure 4.10 The best validation set classification results from the Brodatz data set where Ng or $C = 8$ and $d = 4$.
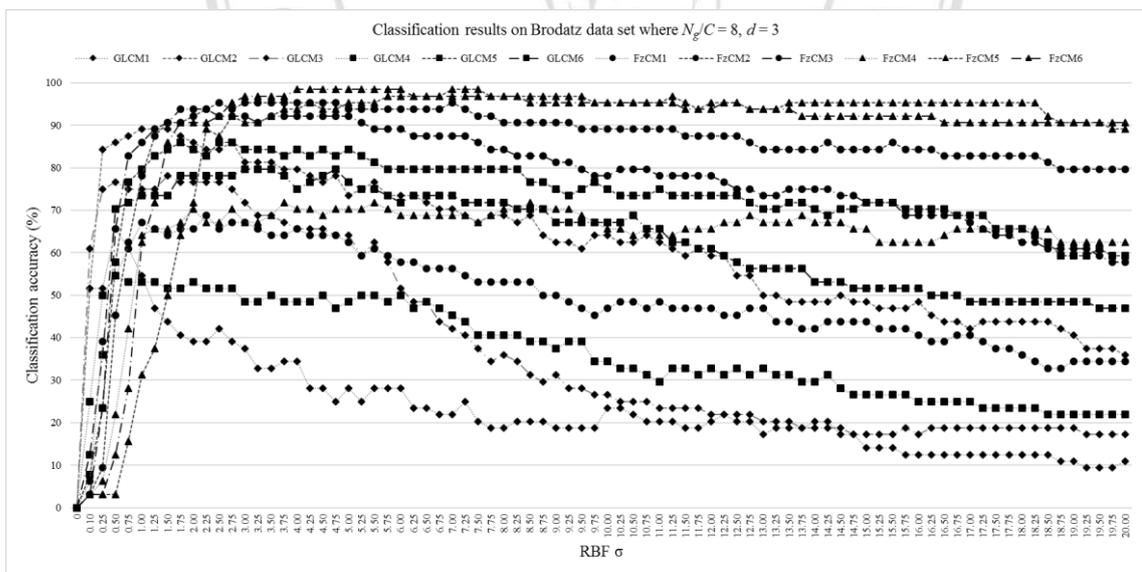

Figure 4.11 The best validation set classification results from the Brodatz data set where Ng or $C = 8$ and $d = 5$.

Figure 4.12 The best validation set classification results from the Brodatz data set where
Ng or $C = 16$ and $d = 1$.

Figure 4.13 The best validation set classification results from the Brodatz data set where
Ng or $C = 16$ and $d = 2$.

Figure 4.14 The best validation set classification results from the Brodatz data set where N_g or $C = 16$ and $d = 3$.
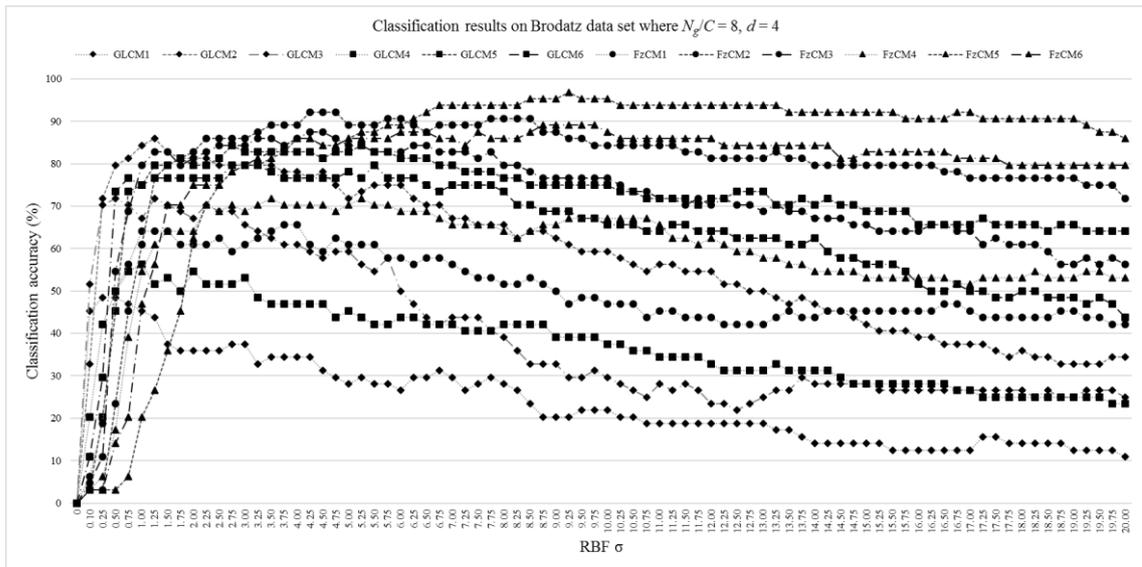

Figure 4.15 The best validation set classification results from the Brodatz data set where N_g or $C = 16$ and $d = 4$.
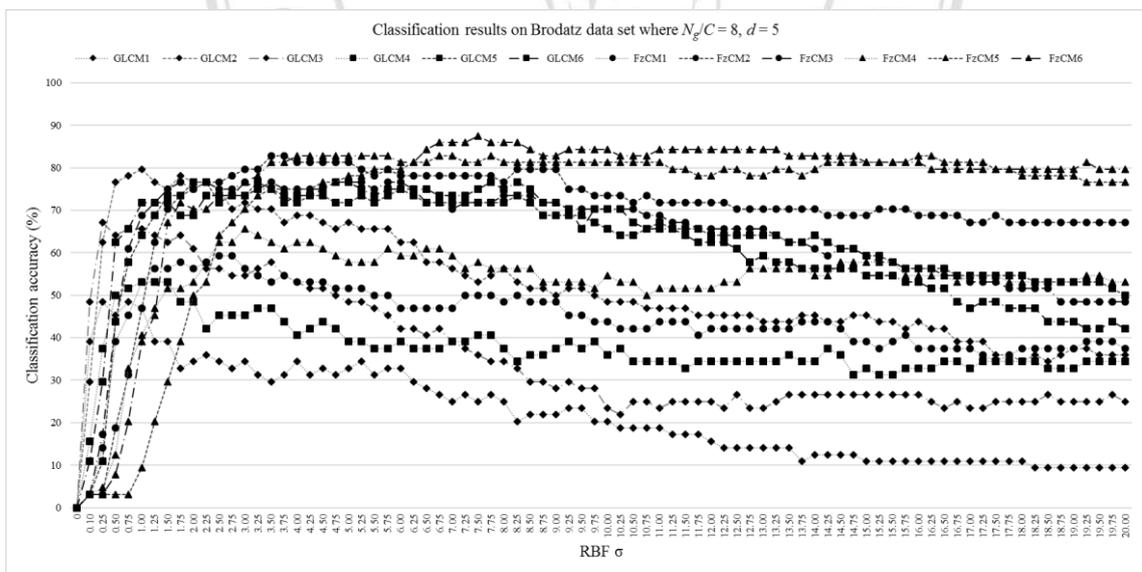
Figure 4.16 The best validation set classification results from the Brodatz data set where N_g or $C = 16$ and $d = 5$.
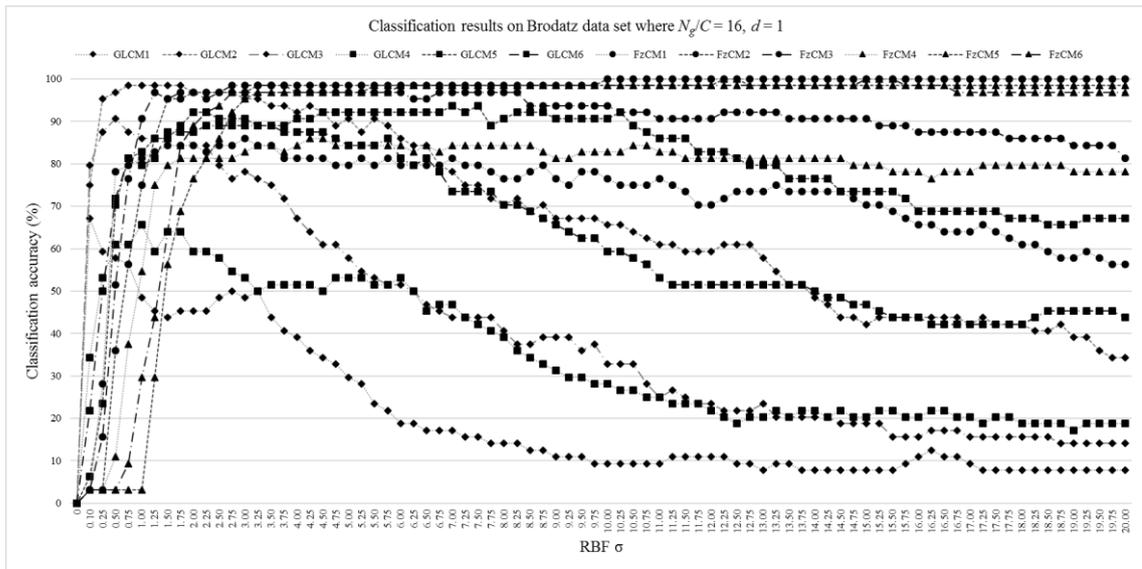

Figure 4.17 The best validation set classification results from the Brodatz data set where N_g or $C = 32$ and $d = 1$.

Figure 4.18 The best validation set classification results from the Brodatz data set where *Ng* or *C* = 32 and *d* = 2.

Figure 4.19 The best validation set classification results from the Brodatz data set where *Ng* or *C* = 32 and *d* = 3.
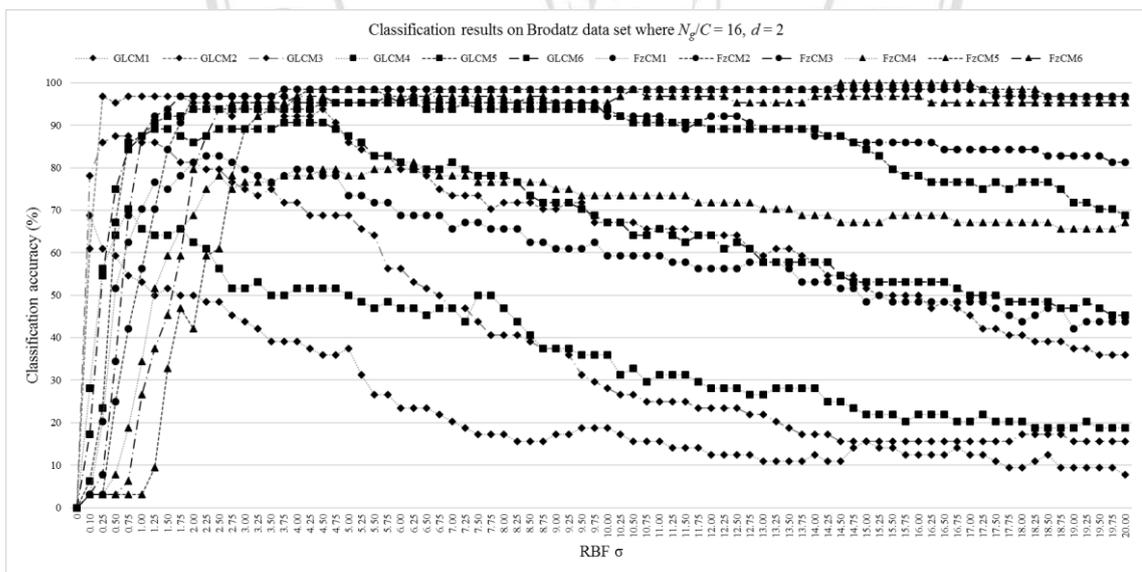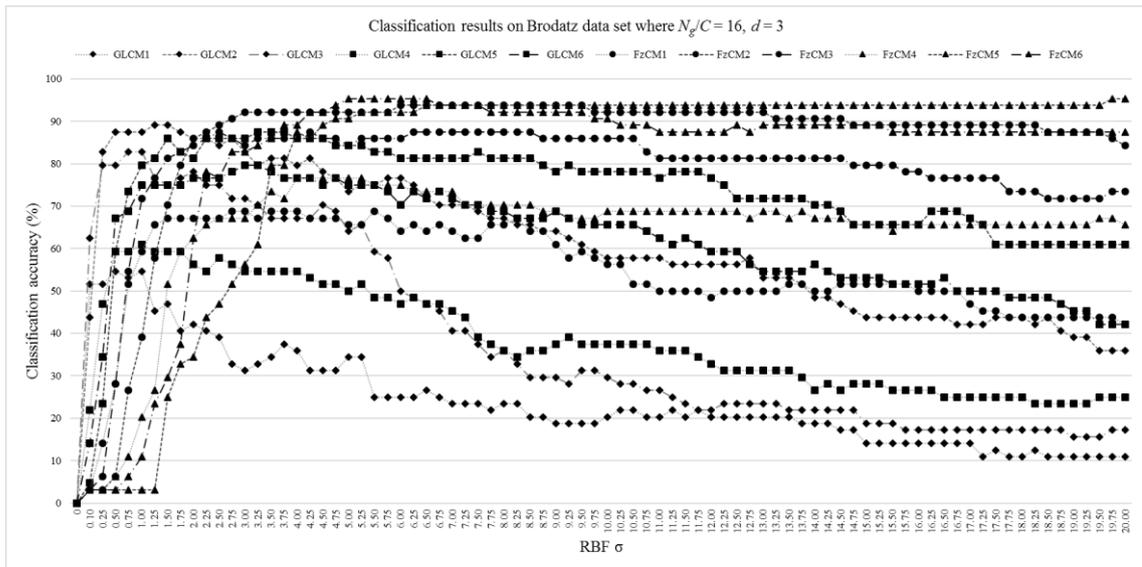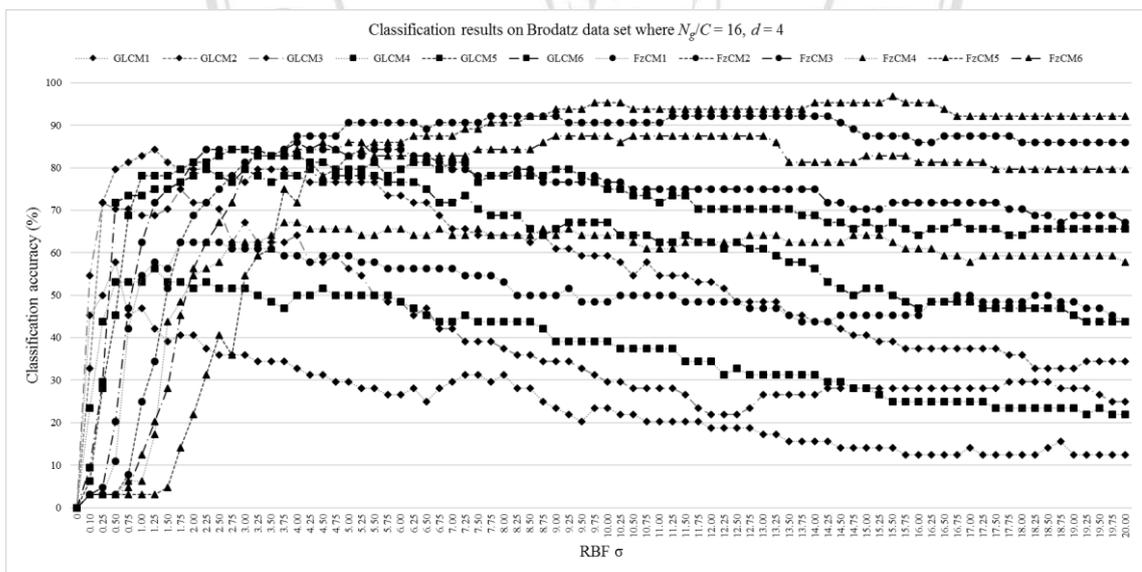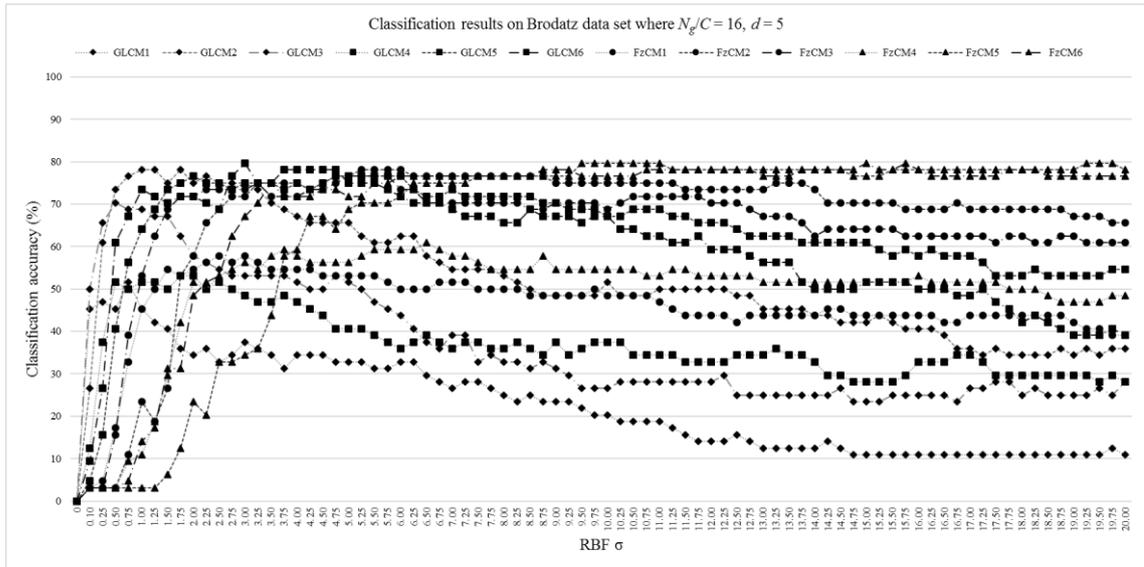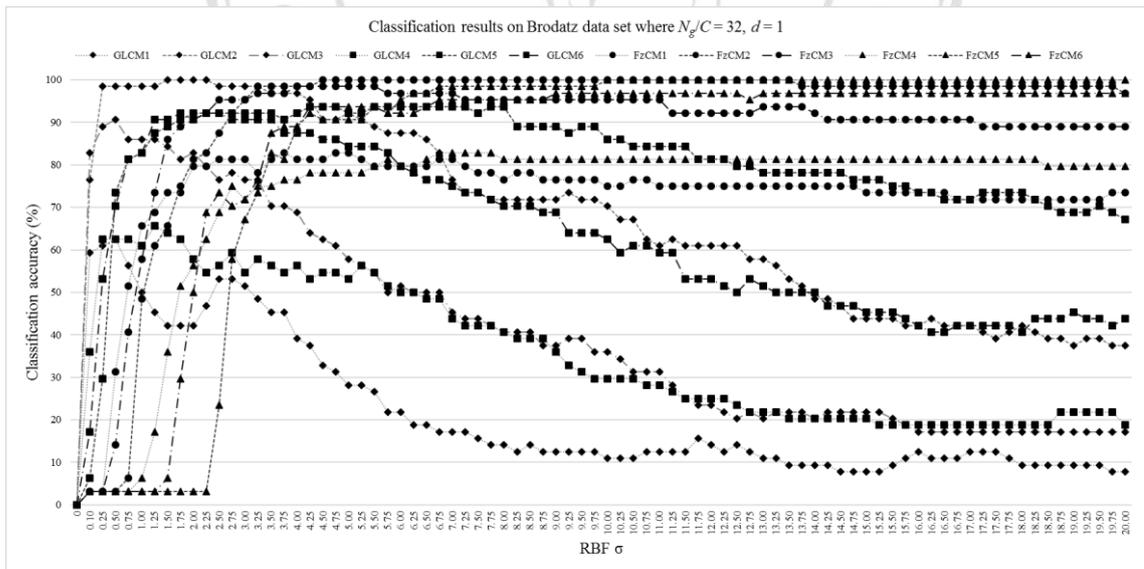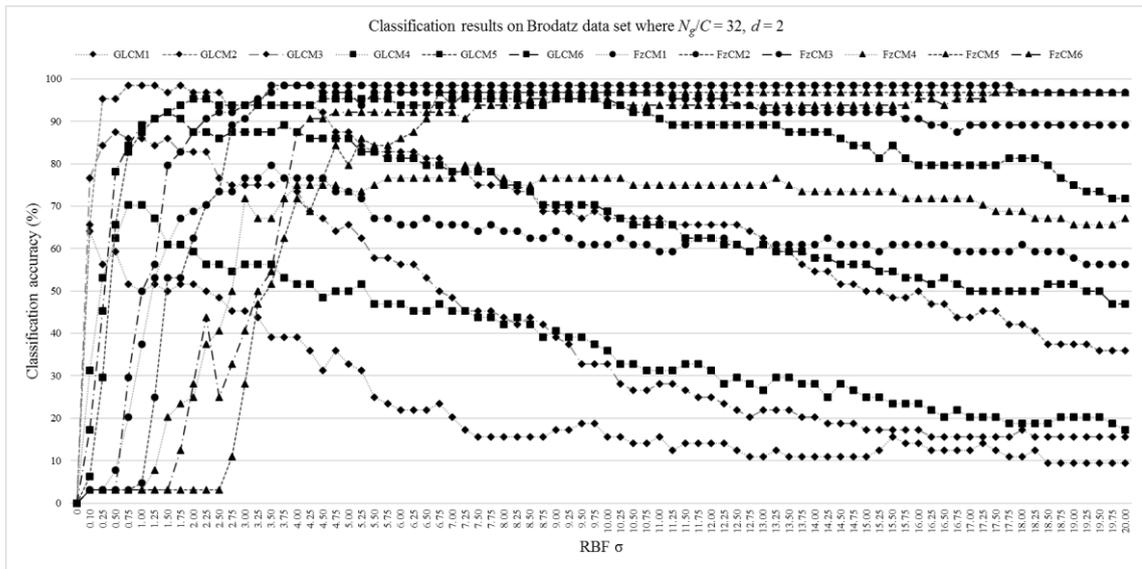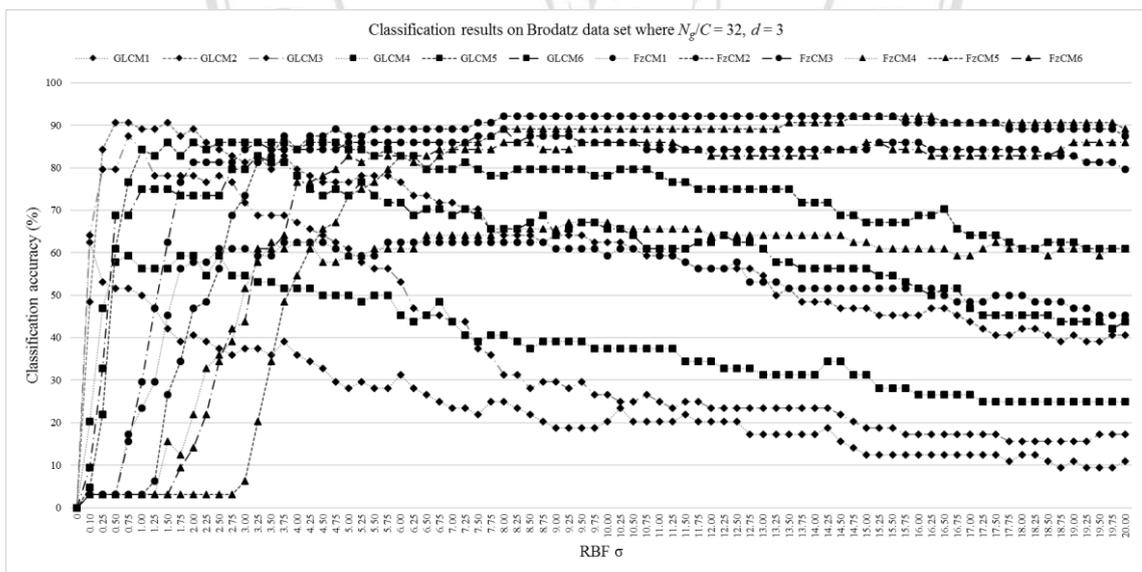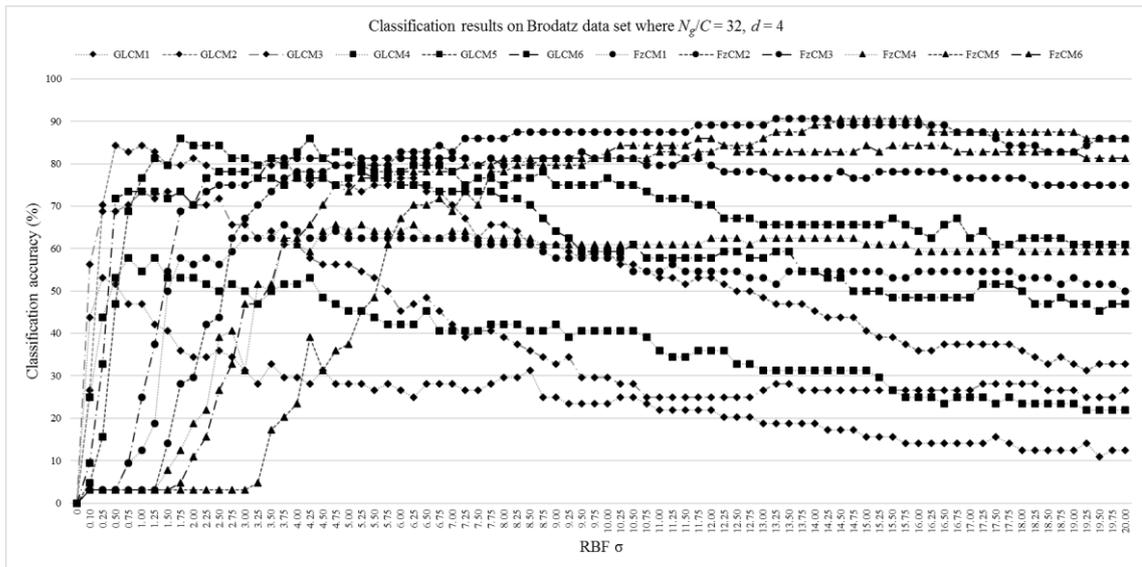
Figure 4.20 The best validation set classification results from the Brodatz data set where N_g or $C = 32$ and $d = 4$.
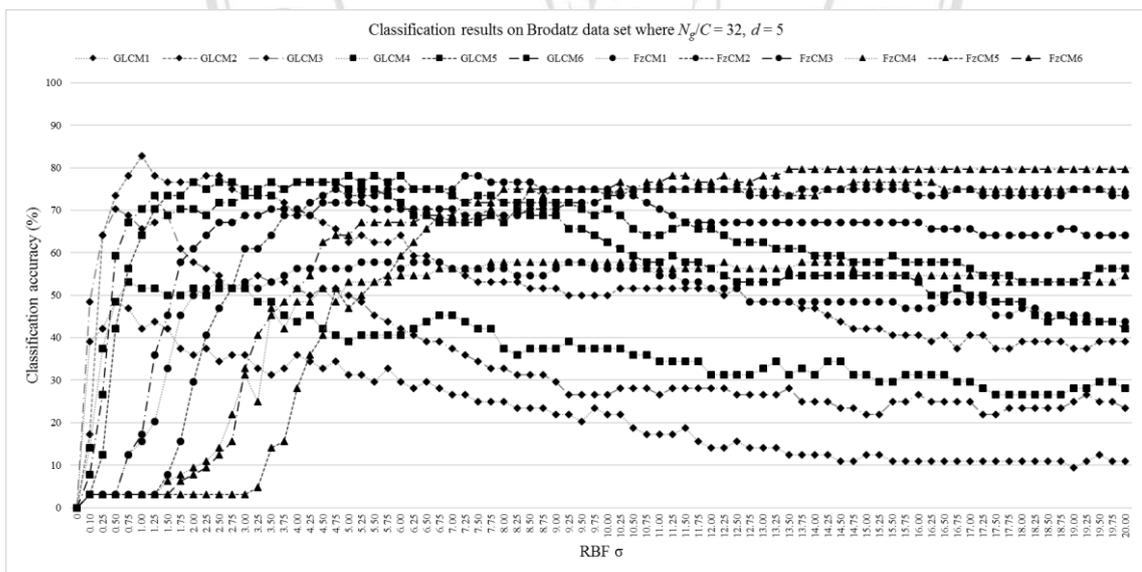

Figure 4.21 The best validation set classification results from the Brodatz data set where N_g or $C = 32$ and $d = 5$.

Table 4.2 The summarized results for the best correct classification from the Brodatz validation set where $d = 1$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	53.13	95.31	87.50	54.69	92.19	90.63	76.56	98.44	96.88	78.13	98.44	96.88
8	59.38	98.44	89.06	59.38	93.75	90.63	81.25	100.00	98.44	85.94	98.44	98.44
16	67.19	98.44	90.63	65.63	93.75	89.06	85.94	100.00	98.44	85.94	100.00	100.00
32	62.50	100.00	90.63	65.63	93.75	92.19	82.81	100.00	98.44	82.81	100.00	96.88
Minimum	53.13	95.31	87.50	54.69	92.19	89.06	76.56	98.44	96.88	78.13	98.44	96.88
Average	60.55	98.05	89.45	61.33	93.36	90.63	81.64	99.61	98.05	83.20	99.22	98.05
Maximum	67.19	100.00	90.63	65.63	93.75	92.19	85.94	100.00	98.44	85.94	100.00	100.00

Table 4.3 The summarized results for the best correct classification from the Brodatz validation set where $d = 2$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	59.38	95.31	81.25	57.81	93.75	92.19	73.44	98.44	92.19	79.69	100.00	96.88
8	67.19	96.88	85.94	62.50	95.31	92.19	78.13	100.00	96.88	81.25	100.00	98.44
16	68.75	96.88	87.50	70.31	95.31	90.63	82.81	98.44	96.88	81.25	100.00	98.44
32	64.06	98.44	87.50	70.31	95.31	92.19	79.69	98.44	98.44	79.69	96.88	96.88
Minimum	59.38	95.31	81.25	57.81	93.75	90.63	73.44	98.44	92.19	79.69	96.88	96.88
Average	64.84	96.88	85.55	65.23	94.92	91.80	78.52	98.83	96.09	80.47	99.22	97.66
Maximum	68.75	98.44	87.50	70.31	95.31	92.19	82.81	100.00	98.44	81.25	100.00	98.44

Table 4.4 The summarized results for the best correct classification from the Brodatz validation set where $d = 3$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	59.38	87.50	76.56	53.13	85.94	76.56	64.06	96.88	89.06	70.31	95.31	93.75
8	65.63	89.06	78.13	54.69	85.94	79.69	68.75	95.31	93.75	71.88	98.44	98.44
16	54.69	89.06	82.81	60.94	87.50	79.69	68.75	93.75	87.50	76.56	95.31	95.31
32	62.50	90.63	87.50	59.38	85.94	82.81	62.50	92.19	89.06	67.19	92.19	85.94
Minimum	54.69	87.50	76.56	53.13	85.94	76.56	62.50	92.19	87.50	67.19	92.19	85.94
Average	60.55	89.06	81.25	57.03	86.33	79.69	66.02	94.53	89.84	71.48	95.31	93.36
Maximum	65.63	90.63	87.50	60.94	87.50	82.81	68.75	96.88	93.75	76.56	98.44	98.44

41

Table 4.5 The summarized results for the best correct classification from the Brodatz validation set where $d = 4$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	46.88	87.50	75.00	54.69	84.38	79.69	59.38	90.63	87.50	65.63	95.31	89.06
8	48.44	85.94	71.88	56.25	84.38	79.69	65.63	92.19	87.50	71.88	96.88	89.06
16	57.81	84.38	75.00	56.25	84.38	79.69	62.50	92.19	85.94	67.19	96.88	87.50
32	53.13	84.38	73.44	57.81	85.94	78.13	65.63	90.63	82.81	65.63	90.63	85.94
Minimum	46.88	84.38	71.88	54.69	84.38	78.13	59.38	90.63	82.81	65.63	90.63	85.94
Average	51.56	85.55	73.83	56.25	84.77	79.30	63.28	91.41	85.94	67.58	94.92	87.89
Maximum	57.81	87.50	75.00	57.81	85.94	79.69	65.63	92.19	87.50	71.88	96.88	89.06

Table 4.6 The summarized results for the best correct classification from the Brodatz validation set where $d = 5$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	46.88	76.56	68.75	54.69	73.44	75.00	53.13	81.25	73.44	62.50	84.38	79.69
8	48.44	79.69	67.19	53.13	76.56	76.56	59.38	82.81	76.56	65.63	82.81	87.50
16	51.56	78.13	70.31	53.13	76.56	79.69	57.81	78.13	76.56	60.94	79.69	79.69
32	48.44	82.81	70.31	53.13	78.13	76.56	57.81	78.13	73.44	57.81	76.56	79.69
Minimum	46.88	76.56	67.19	53.13	73.44	75.00	53.13	78.13	73.44	57.81	76.56	79.69
Average	48.83	79.30	69.14	53.52	76.17	76.95	57.03	80.08	75.00	61.72	80.86	81.64
Maximum	51.56	82.81	70.31	54.69	78.13	79.69	59.38	82.81	76.56	65.63	84.38	87.50

Table 4.7 The summarized results for the best correct classification from the Brodatz validation set.

Method	Distance (d)	Accuracy	Ng or C	RBF σ	Feature set
GLCM	1	100.00	32	1.50	GLCM2
	2	98.44	32	0.75	GLCM2
	3	90.63	32	0.50	GLCM2
	4	87.50	4	1.00	GLCM2
	5	82.81	32	1.00	GLCM2
FCOM	1	100.00	8	5.25	FzCM2
	2	100.00	4	7.00	FzCM5
	3	98.44	8	7.00	FzCM5
	4	96.88	8	9.25	FzCM5
	5	87.50	8	7.50	FzCM6

42

The results showed that the best accuracy from both FCOM and GLCM feature sets were 100% at $d = 1$. The FCOM with the lower number of clusters (in this case is 4) provided the higher classification rate while the GLCM with the higher number of gray levels (in this case is 32) provided the higher recognition rate. In fact, the GLCM gives the best recognition rate when the number of quantization levels is close to the number of gray scales of the original image. When $d > 1$, the FCOM feature set provided the better classification results than that from GLCM in all distance. The correct recognition results are decrease when the distance is increase due to the high contrast, the gray level distribution, of this data set. The images in each class are not correlated to the other classes. Shape and orientation of the surfaces in each image are very different. Most of them were coarse and irregular texture. From this reason, the feature sets extracted from four directions were provided higher classification rate, i.e., FzCM2, FzCM5, and GLCM2.

The second data set was a texture surface called Kylberg. There were 28 texture classes, each of 120 images. There were 4480 images in total. The size of each image was 576×576. This data set was suitable for evaluating and comparing texture analysis, noise sensitivity and geometric transform. An example of Kylberg texture class is shown in figure 4.22. In classification task, 10-fold cross validation was implemented. The best validation set classification results of this data set are shown in figure 4.23 to 4.42. Table 4.8 to 4.12 show the summary of the best correct classification results from the validation set for each distance. The summarized results for the best classification on the validation set are shown in table 4.13.
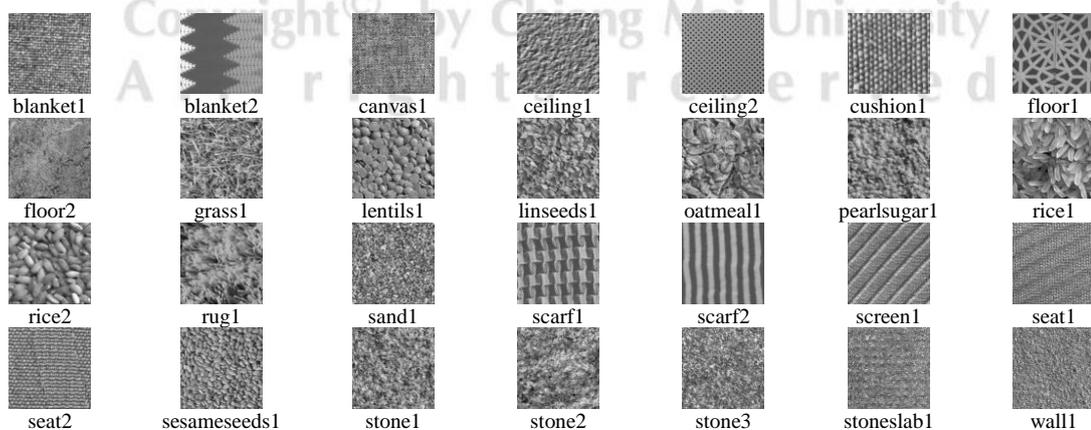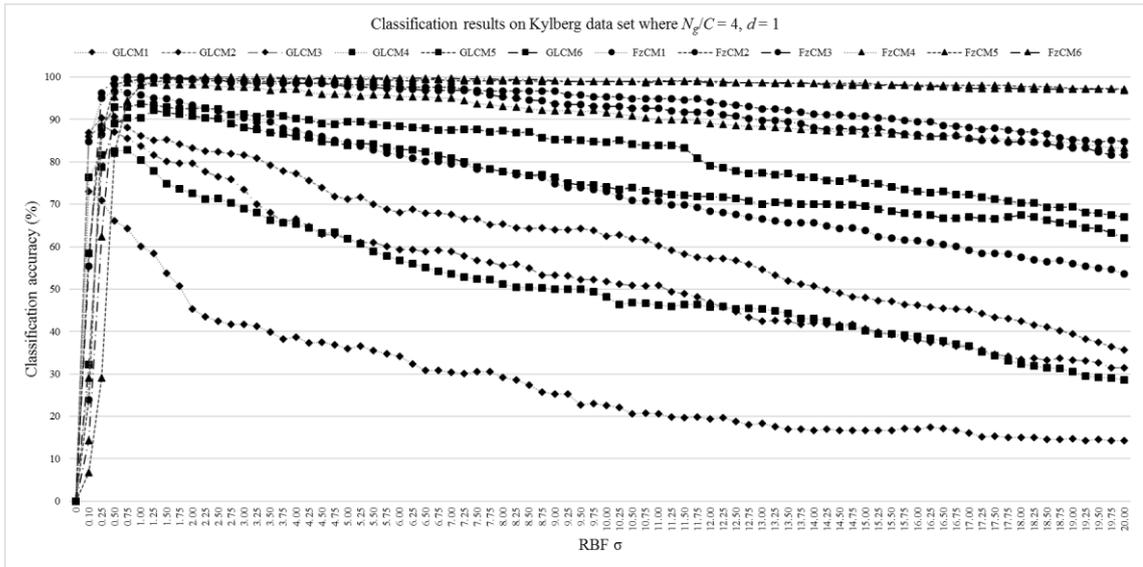
Figure 4.22 An example of Kylberg texture data set.

Figure 4.23 The best validation set classification results from the Kylberg data set where Ng or $C = 4$ and $d = 1$.
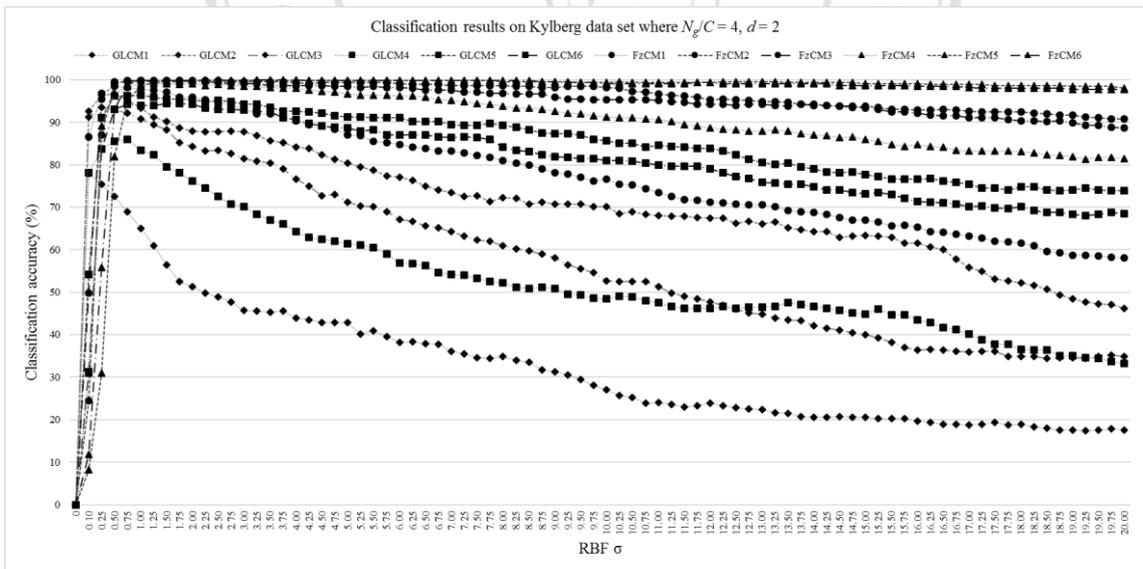

Figure 4.24 The best validation set classification results from the Kylberg data set where Ng or $C = 4$ and $d = 2$.
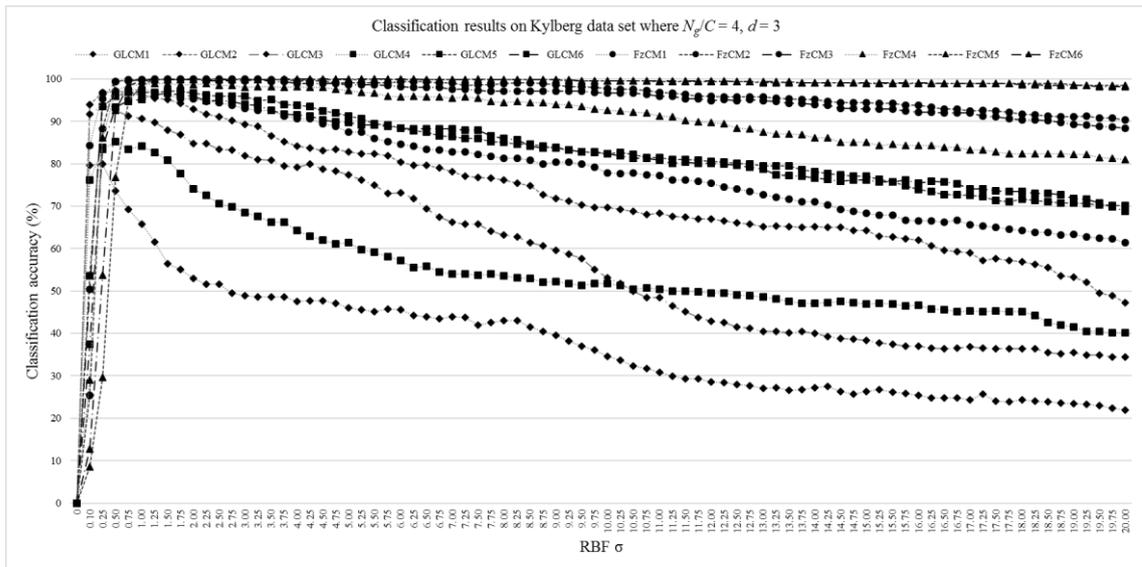
Figure 4.25 The best validation set classification results from the Kylberg data set where Ng or $C = 4$ and $d = 3$.

Figure 4.26 The best validation set classification results from the Kylberg data set where Ng or $C = 4$ and $d = 4$.

Figure 4.27 The best validation set classification results from the Kylberg data set where Ng or $C = 4$ and $d = 5$.
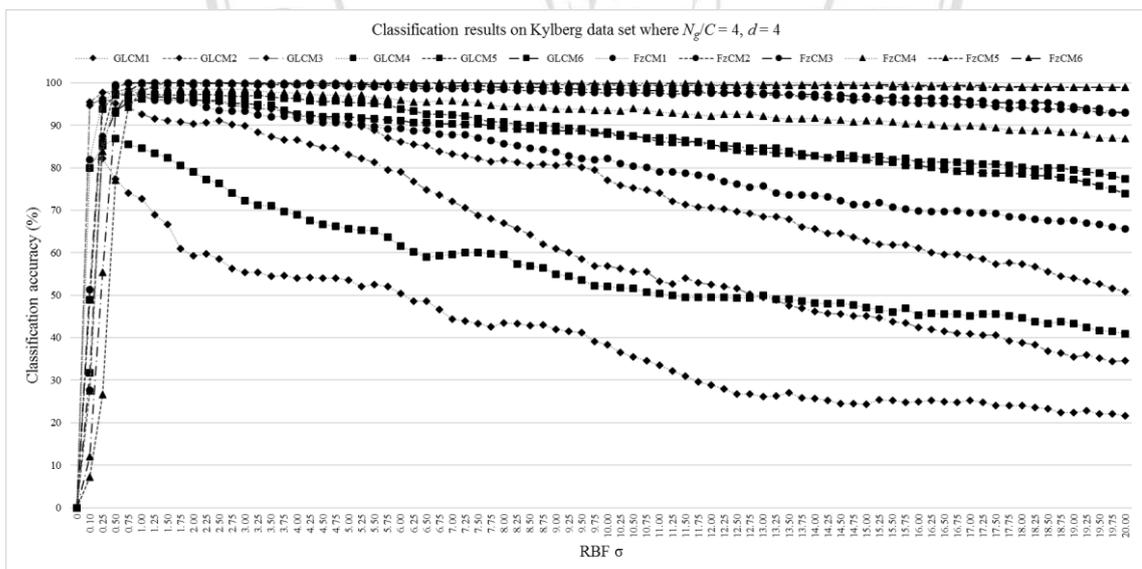

Figure 4.28 The best validation set classification results from the Kylberg data set where Ng or $C = 8$ and $d = 1$.
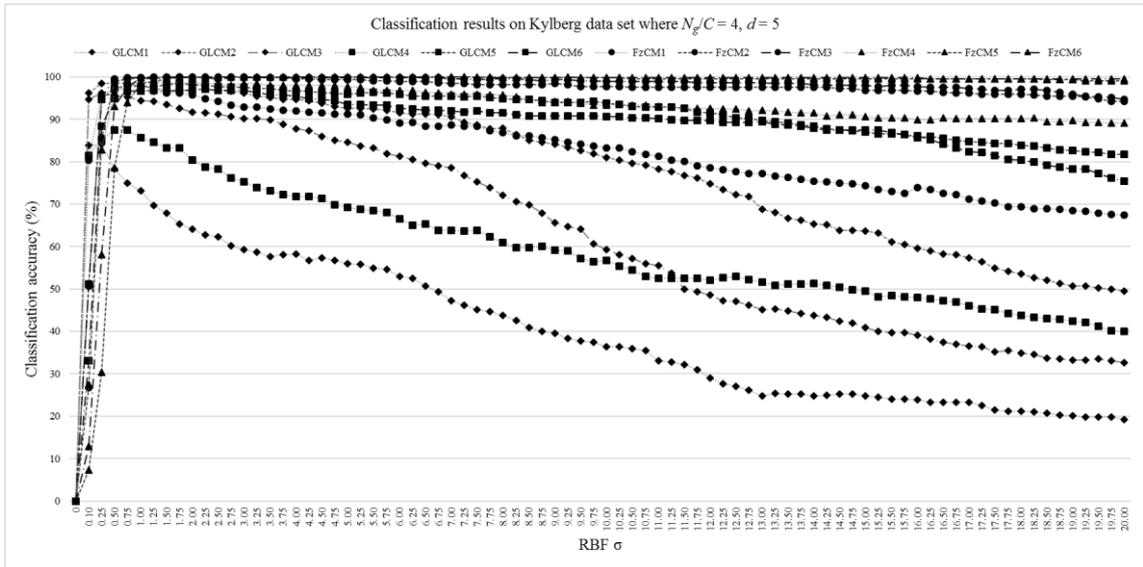
Figure 4.29 The best validation set classification results from the Kylberg data set where Ng or $C = 8$ and $d = 2$.
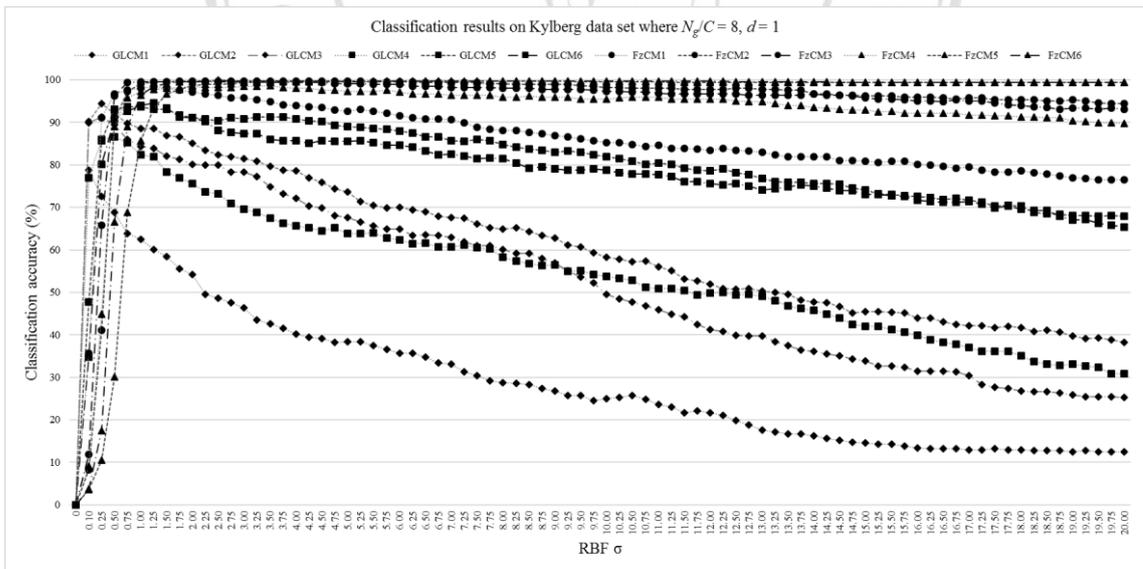

Figure 4.30 The best validation set classification results from the Kylberg data set where Ng or $C = 8$ and $d = 3$.

Figure 4.31 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 8 and *d* = 4.

Figure 4.32 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 8 and *d* = 5.

Figure 4.33 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 16 and *d* = 1.

Figure 4.34 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 16 and *d* = 2.
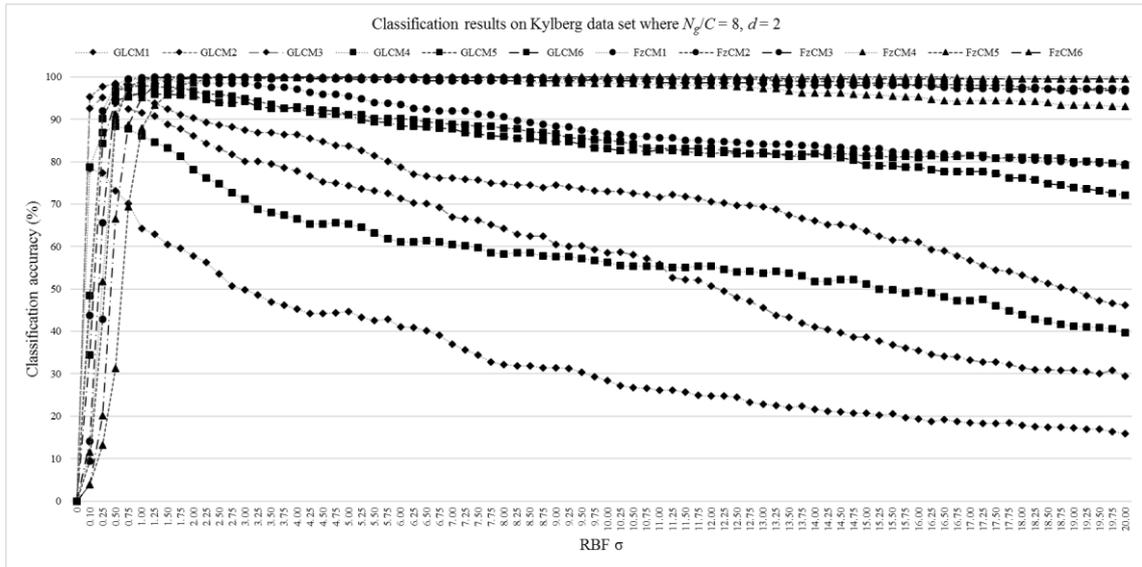
Figure 4.35 The best validation set classification results from the Kylberg data set where Ng or $C = 16$ and $d = 3$.

Figure 4.36 The best validation set classification results from the Kylberg data set where Ng or $C = 16$ and $d = 4$.
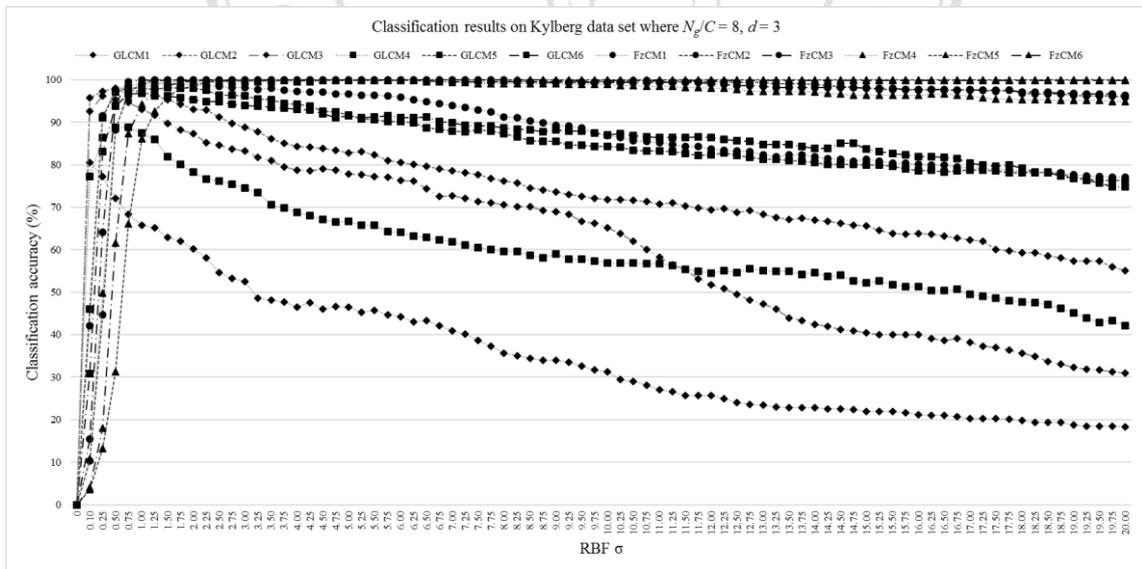
Figure 4.37 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 16 and *d* = 5.

Figure 4.38 The best validation set classification results from the Kylberg data set where *Ng* or *C* = 32 and *d* = 1.
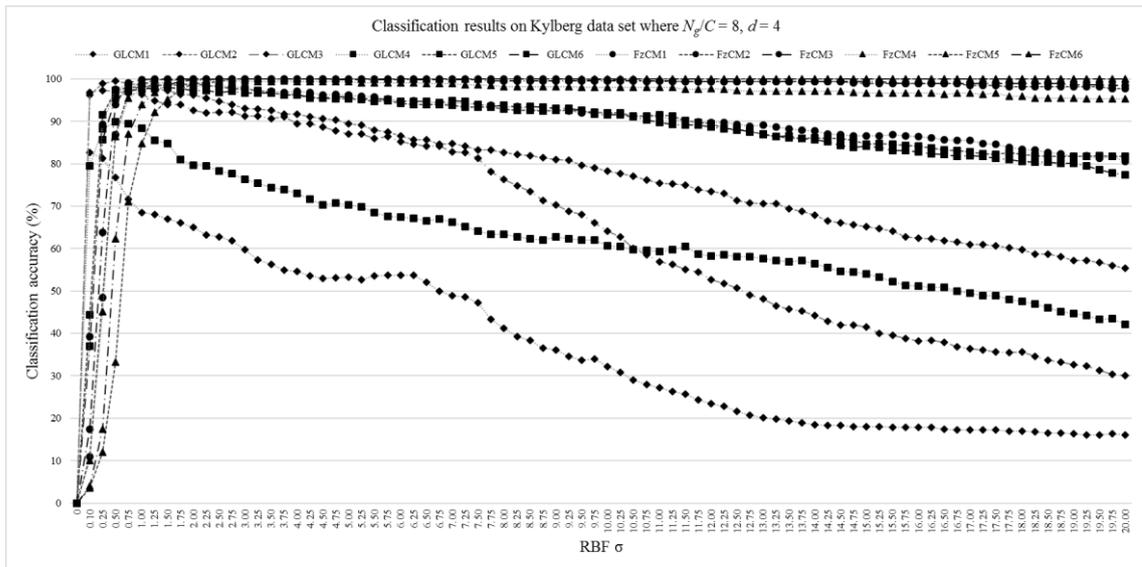
Figure 4.39 The best validation set classification results from the Kylberg data set where Ng or $C = 32$ and $d = 2$.

Figure 4.40 The best validation set classification results from the Kylberg data set where Ng or $C = 32$ and $d = 3$.
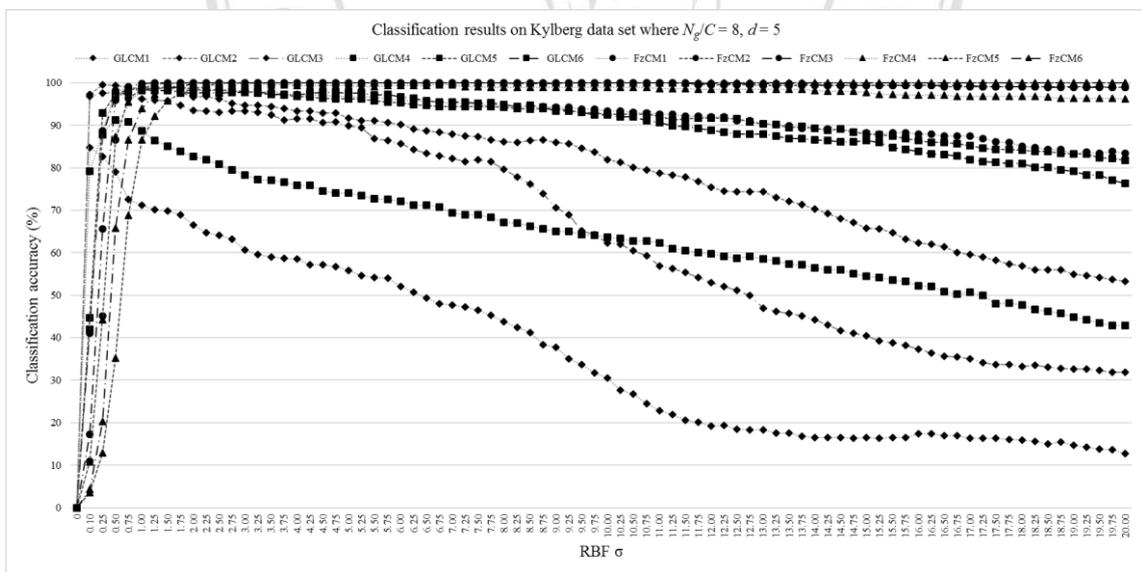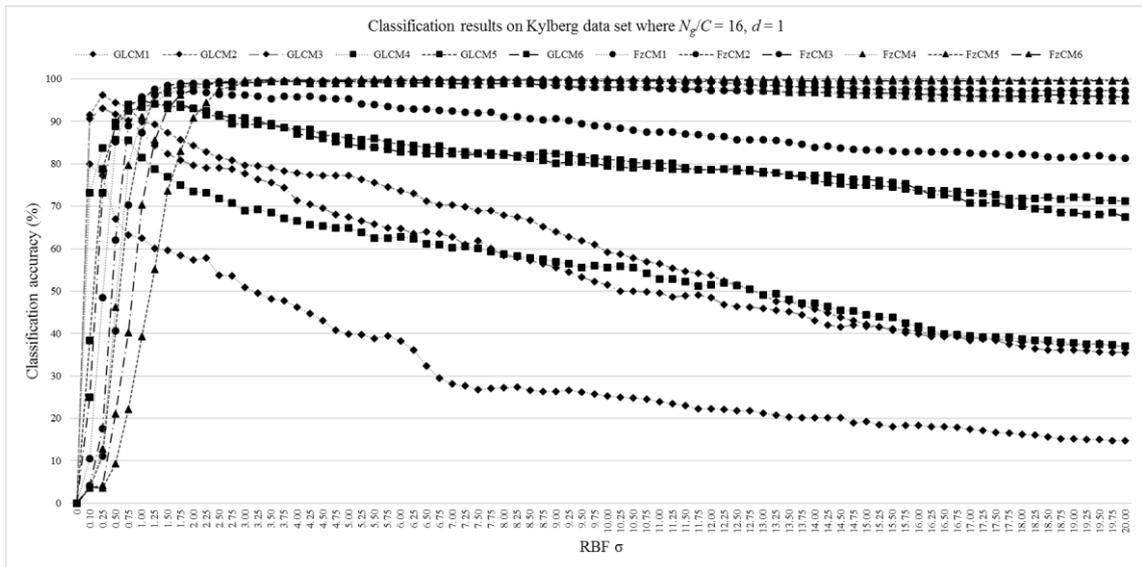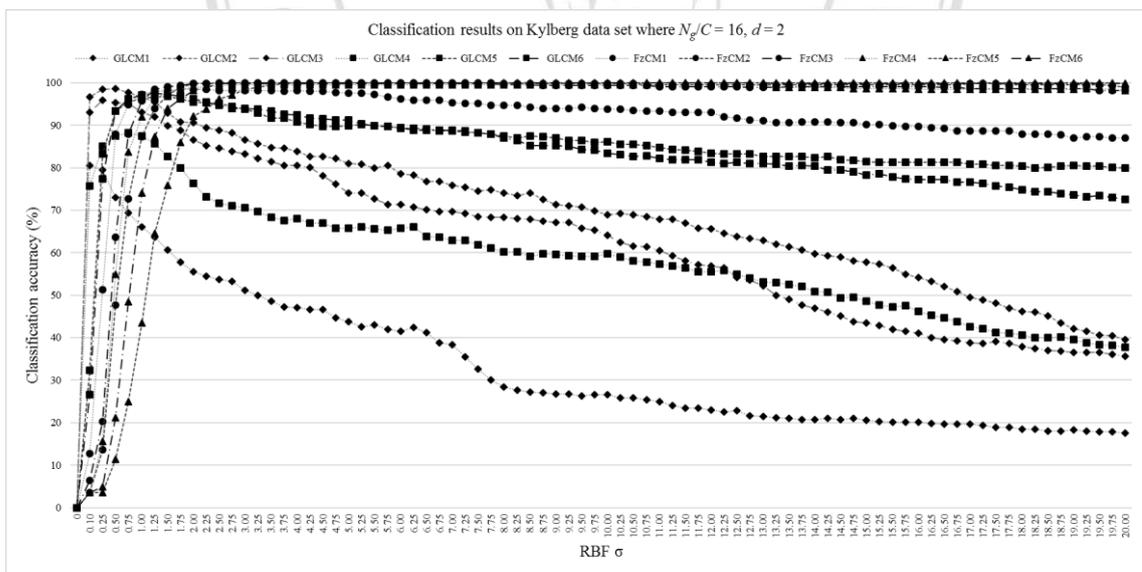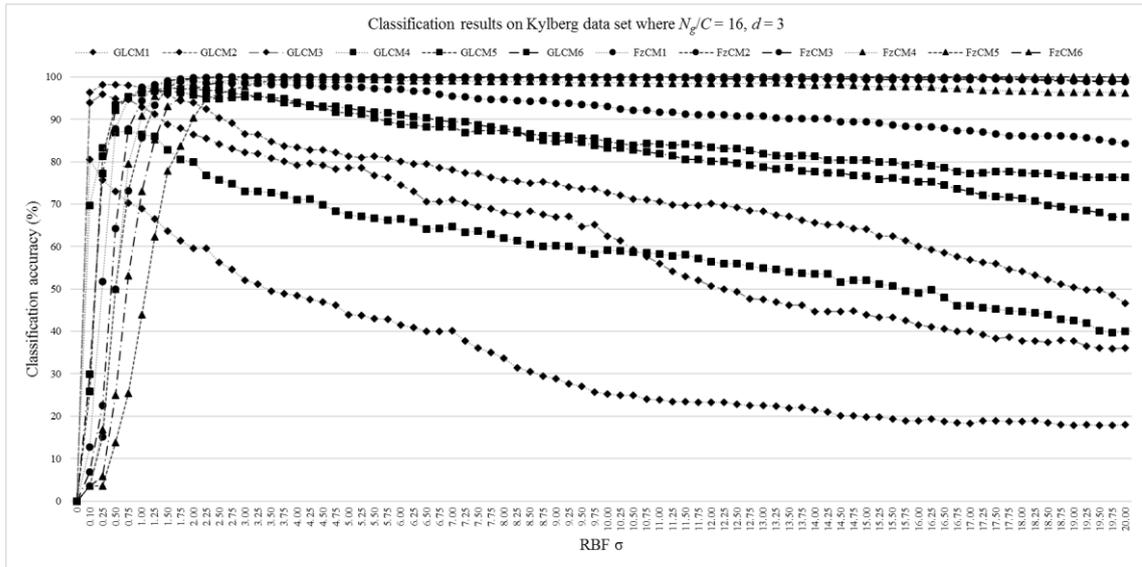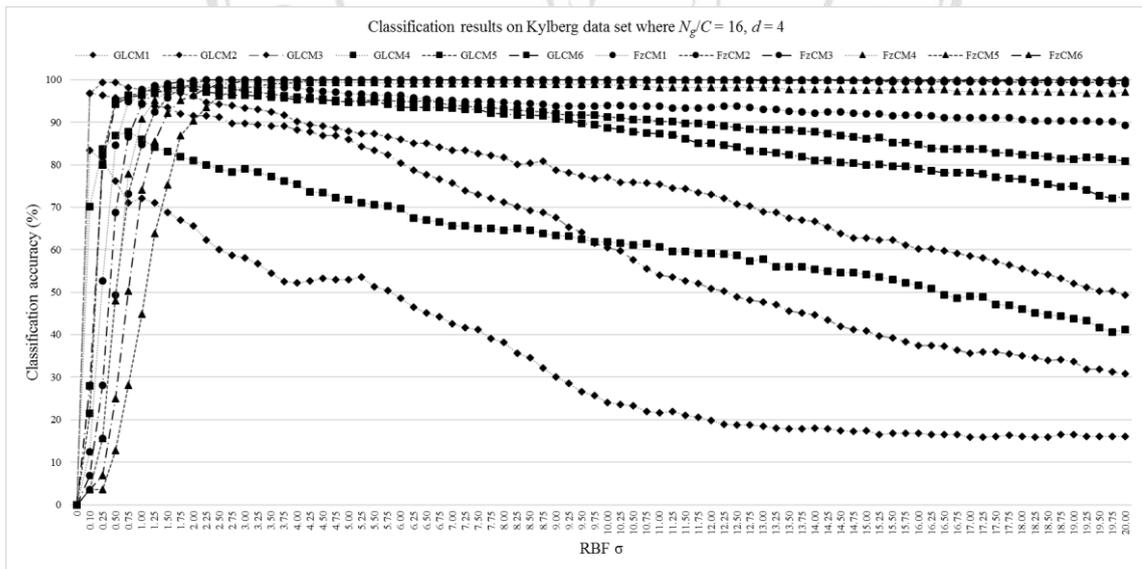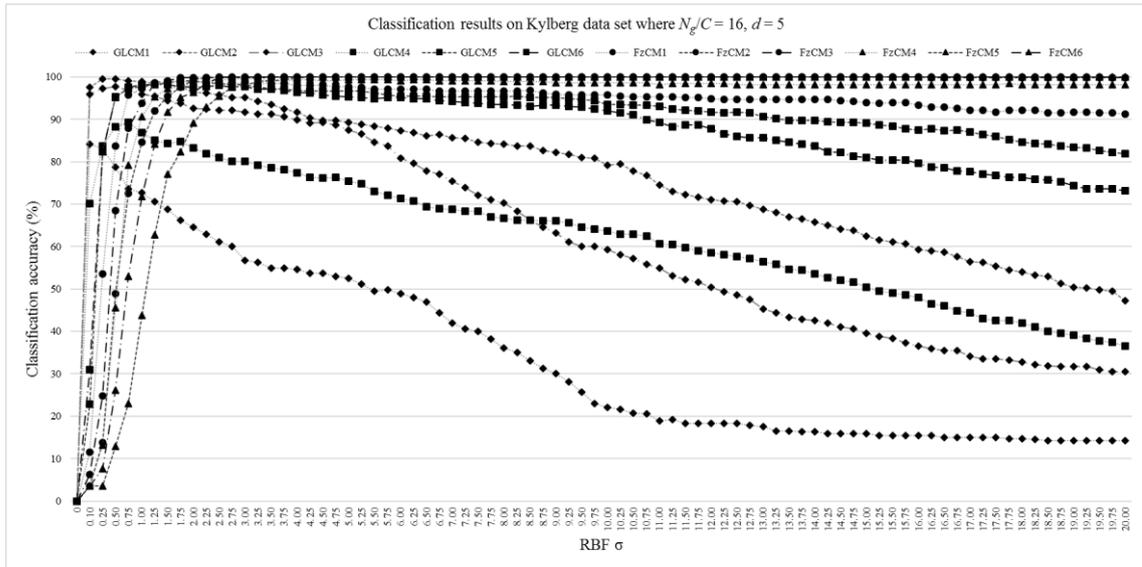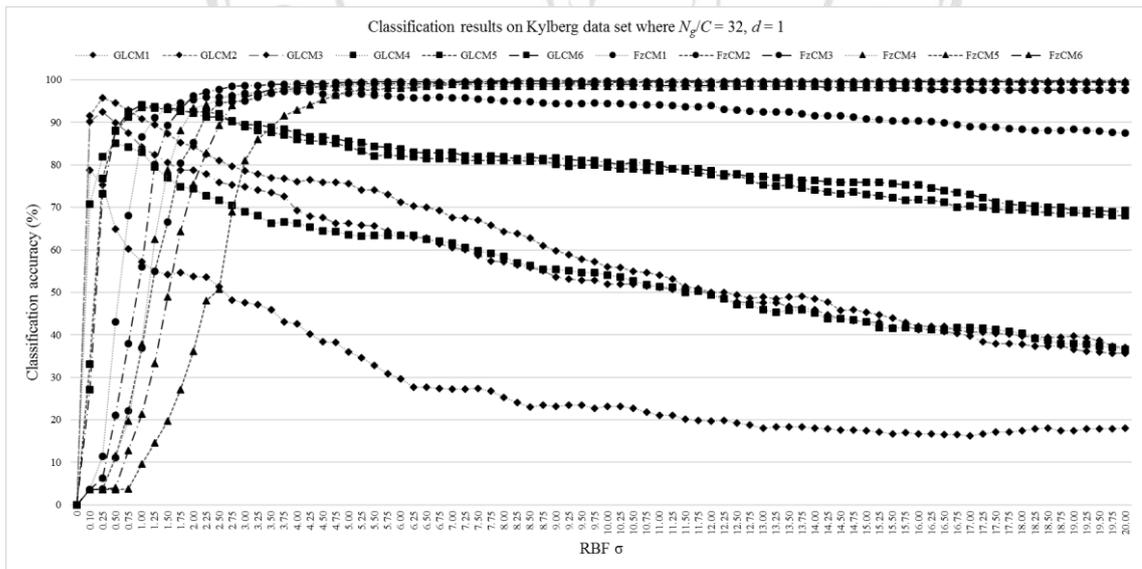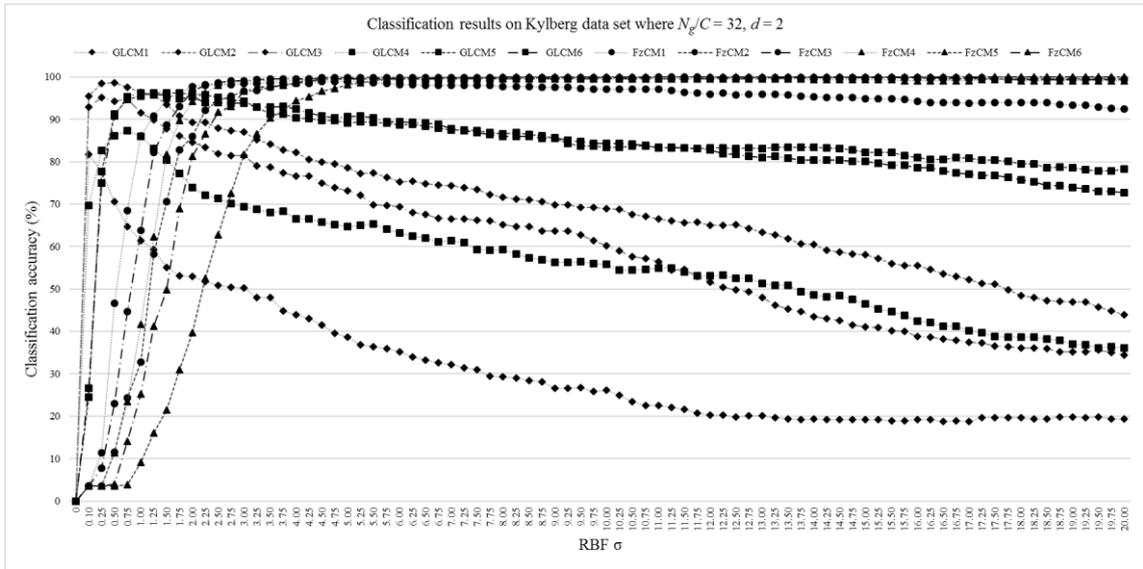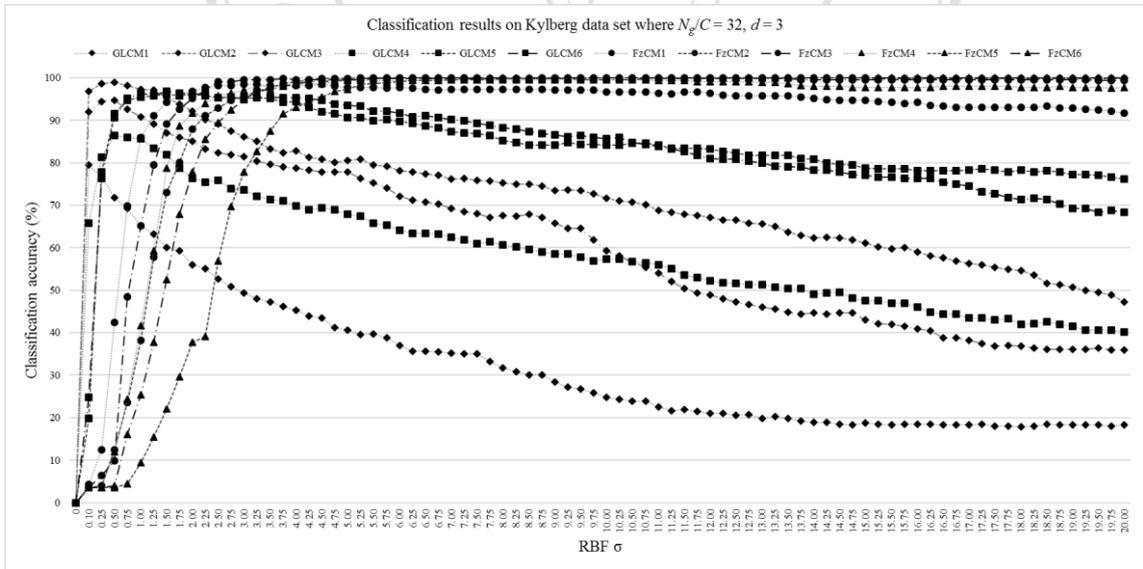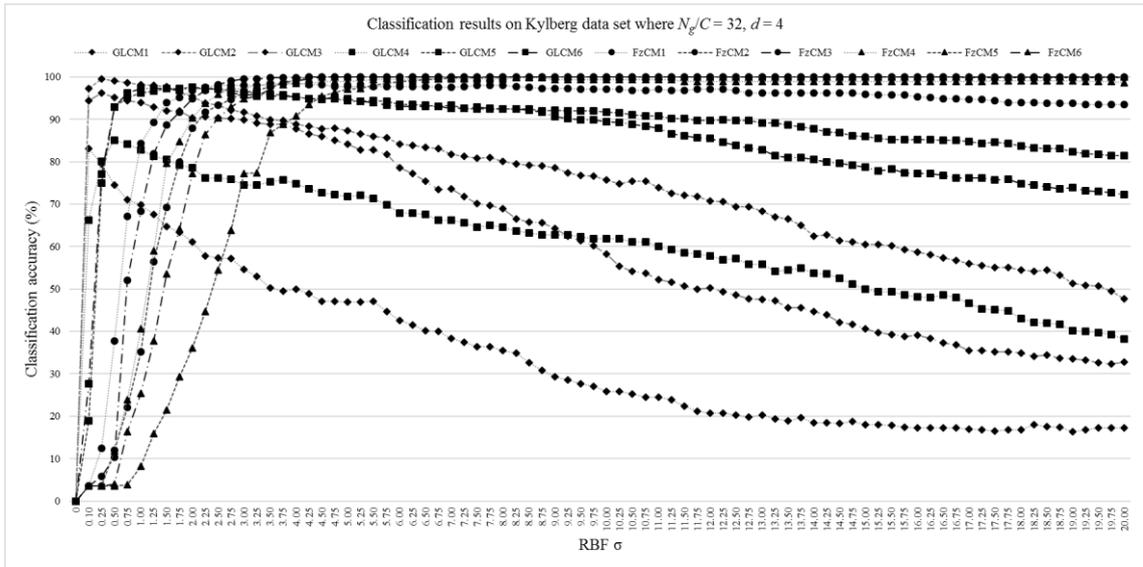
52

Figure 4.41 The best validation set classification results from the Kylberg data set
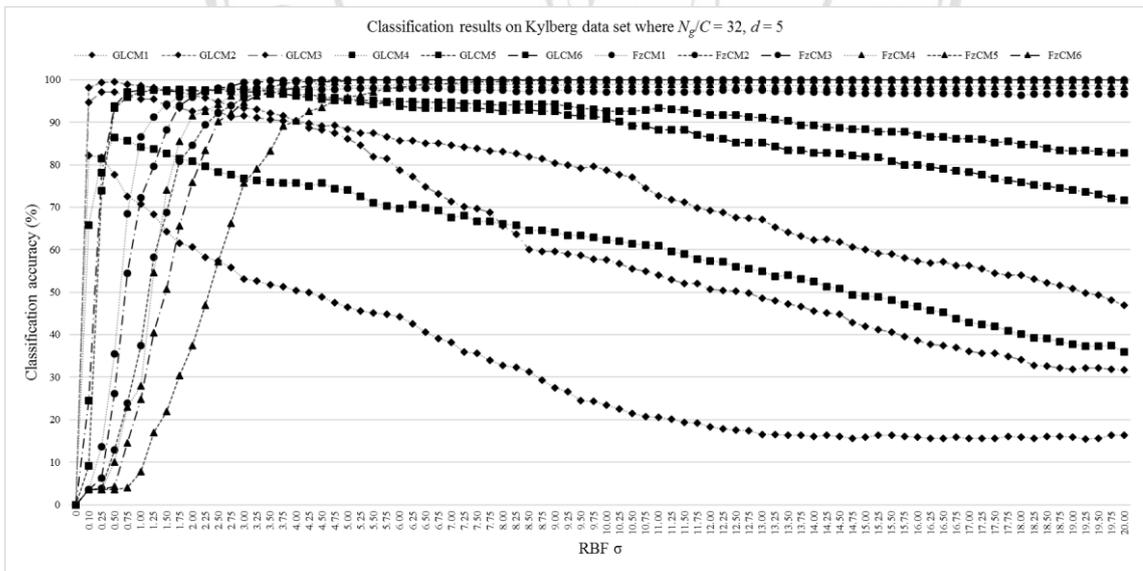where Ng or $C = 32$ and $d = 4$.

Figure 4.42 The best validation set classification results from the Kylberg data set
where Ng or $C = 32$ and $d = 5$.

Table 4.8 The summarized results for the best correct classification from the Kylberg validation set where $d = 1$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	72.99	90.63	88.62	82.81	93.75	92.19	96.65	99.78	100.00	98.66	99.78	100.00
8	78.79	94.42	91.29	86.61	93.75	94.64	98.44	99.78	99.55	98.66	99.78	100.00
16	79.91	96.21	93.08	85.71	94.20	95.09	97.10	99.78	99.33	99.33	100.00	99.78
32	78.79	95.76	92.41	85.04	93.53	94.20	97.32	99.78	99.55	98.88	99.78	99.78
Minimum	72.99	90.63	88.62	82.81	93.53	92.19	96.65	99.78	99.33	98.66	99.78	99.78
Average	77.62	94.25	91.35	85.04	93.81	94.03	97.38	99.78	99.61	98.88	99.83	99.89
Maximum	79.91	96.21	93.08	86.61	94.20	95.09	98.44	99.78	100.00	99.33	100.00	100.00

Table 4.9 The summarized results for the best correct classification from the Kylberg validation set where $d = 2$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	77.90	96.65	93.53	85.94	96.43	94.42	98.44	99.78	99.78	99.11	99.78	100.00
8	78.35	98.44	95.09	88.39	97.99	96.43	99.55	100.00	99.78	100.00	100.00	100.00
16	80.58	98.66	95.98	88.17	96.88	97.54	98.44	100.00	99.78	99.55	100.00	100.00
32	81.70	98.66	95.09	87.28	96.21	96.21	98.88	100.00	99.78	99.55	100.00	100.00
Minimum	77.90	96.65	93.53	85.94	96.21	94.42	98.44	99.78	99.78	99.11	99.78	100.00
Average	79.63	98.10	94.92	87.44	96.88	96.15	98.83	99.94	99.78	99.55	99.94	100.00
Maximum	81.70	98.66	95.98	88.39	97.99	97.54	99.55	100.00	99.78	100.00	100.00	100.00

Table 4.10 The summarized results for the best correct classification from the Kylberg validation set where $d = 3$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	79.91	97.10	93.75	85.27	97.10	96.65	97.77	100.00	100.00	98.88	100.00	100.00
8	80.58	97.99	96.21	88.84	98.21	96.88	99.11	100.00	100.00	99.78	100.00	100.00
16	80.58	98.21	95.98	87.28	97.54	96.88	99.11	100.00	100.00	99.55	100.00	100.00
32	79.46	98.88	94.64	86.38	96.21	96.88	98.44	100.00	99.78	99.55	100.00	100.00
Minimum	79.46	97.10	93.75	85.27	96.21	96.65	97.77	100.00	99.78	98.88	100.00	100.00
Average	80.13	98.05	95.15	86.94	97.27	96.82	98.60	100.00	99.94	99.44	100.00	100.00
Maximum	80.58	98.88	96.21	88.84	98.21	96.88	99.11	100.00	100.00	99.78	100.00	100.00

54

Table 4.11 The summarized results for the best correct classification from the Kylberg validation set where $d = 4$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	82.14	98.44	96.43	86.83	97.32	96.65	97.54	100.00	100.00	98.88	100.00	100.00
8	82.59	99.55	97.32	89.96	98.88	97.99	98.88	100.00	100.00	99.78	100.00	100.00
16	83.48	99.33	96.88	87.72	98.44	98.21	98.66	100.00	100.00	99.55	100.00	100.00
32	83.04	99.55	96.21	85.04	97.54	97.54	98.44	100.00	100.00	99.78	100.00	100.00
Minimum	82.14	98.44	96.21	85.04	97.32	96.65	97.54	100.00	100.00	98.88	100.00	100.00
Average	82.81	99.22	96.71	87.39	98.05	97.60	98.38	100.00	100.00	99.50	100.00	100.00
Maximum	83.48	99.55	97.32	89.96	98.88	98.21	98.88	100.00	100.00	99.78	100.00	100.00

Table 4.12 The summarized results for the best correct classification from the Kylberg validation set where $d = 5$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	84.15	98.44	96.21	87.50	98.44	97.10	97.32	100.00	100.00	98.88	100.00	100.00
8	84.82	99.55	97.77	91.29	99.11	98.44	98.88	100.00	100.00	99.78	100.00	100.00
16	84.15	99.55	97.77	89.29	99.11	98.21	98.88	100.00	100.00	99.55	100.00	100.00
32	82.14	99.55	97.10	86.38	97.77	97.54	97.99	100.00	100.00	98.88	100.00	100.00
Minimum	82.14	98.44	96.21	86.38	97.77	97.10	97.32	100.00	100.00	98.88	100.00	100.00
Average	83.82	99.27	97.21	88.61	98.61	97.82	98.27	100.00	100.00	99.27	100.00	100.00
Maximum	84.82	99.55	97.77	91.29	99.11	98.44	98.88	100.00	100.00	99.78	100.00	100.00

Table 4.13 The summarized results for the best correct classification from the Kylberg validation set.

Method	Distance (d)	Accuracy	Ng or C	RBF σ	Feature set
GLCM	1	96.21	16	0.25	GLCM2
	2	98.66	16	0.50	GLCM2
	3	98.88	32	0.50	GLCM2
	4	99.55	8	0.50	GLCM2
	5	99.55	8	0.25	GLCM2
FCOM	1	100.00	4	1.50	FzCM3
	2	100.00	4	4.00	FzCM6
	3	100.00	4	3.00	FzCM2
	4	100.00	4	2.50	FzCM2
	5	100.00	4	3.00	FzCM2

In this data set, the classification accuracies from the feature sets created by FCOM were better than that from GLCM in all distances. The FCOM with lower number of clusters (in this case is 4) provided the higher classification rate while the GLCM with higher number of gray levels (in this case is 8) provided the higher recognition rate. The correct recognition results increased when the distance was increased for GLCM due to the image contrast. For FCOM, the recognition results were equal for all distances. An example of incorrect recognition image from GLCM feature sets is shown in figure 4.43. The image in figure 4.43 (a) is incorrectly classified into the same class of images in figure 4.43 (b). This case occurred when $d = 3$, 4, and 5 since the edges or contours of texton, the putative units of pre-attentive human texture perception [17], were very similar. The shape of texton is also smaller than the original. When $d = 1$ and 2, the same image is correctly classified since the image did not look like images in figure 4.43 (b) due to the size and shape of texton being very different.

oatmeal1-c-p007   rug1-a-p007   rug1-b-p007   rug1-c-p007   rug1-d-p007

(a) Incorrect classification image   (b) Examples images of the predicted class
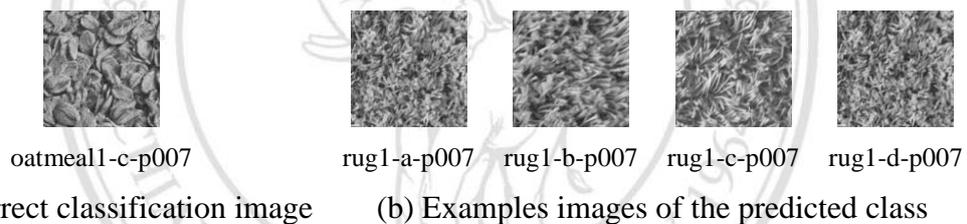
Figure 4.43 An example of incorrect classification image on Kylberg data set.

Texture in figure 4.43 is near-regular. The orientations of these texture primitives occur in all directions, i.e., vertical, horizontal, left-diagonal, and right-diagonal. Therefore, the shape of texton from the incorrect classification image is bigger than the shape of texton in the target class images that is why the correct classification result is increasing bound on the distant of pixel pair as shown in table 4.13.

For more information, both GLCM and FCOM analyze texture based on a homogeneity along the diagonal or a contrast across the diagonal of their matrices. For a vertical texture, there is more homogeneity along a vertical direction, $\theta = 90$ degree, but there is contrast in other direction, $\theta = 0$, 45, and 135 degree. On the other hand, a horizontal texture is more homogeneity along horizontal direction, $\theta = 90$ degree, but there is contrast along the other directions. For a regular texture pattern, e.g. cushion1 and scarf1 as shown in figure 4.22, there is contrast in all directions. We can summarize that there is more homogeneity as same as texture direction but contrast in a different

56

direction. For example, a vertical texture and corresponding GLCM and FCOM planes when $N_g = 2$ and $C = 2$ are shown in figure 4.44. In the third GLCM plane, there is no pixel pairs at {1, 2} and {2, 1}. In the first, second, and fourth GLCM planes, there are a few pixel pairs at {1, 2} and {2, 1}. There is the difference of gray levels at the edge of black and white bar. For FCOM, the black bar was assigned to cluster number one and the white bar was assigned to cluster number two. There are only values for {1, 1} and {2, 2} as shown in the bottom row (FCOM: 90°) where $C = 1$ and $C = 2$, respectively. The example of horizontal and corresponding GLCM and FCOM planes is show in figure 4.45. Figure 4.46 shows the regular texture and corresponding GLCM and FCOM planes.
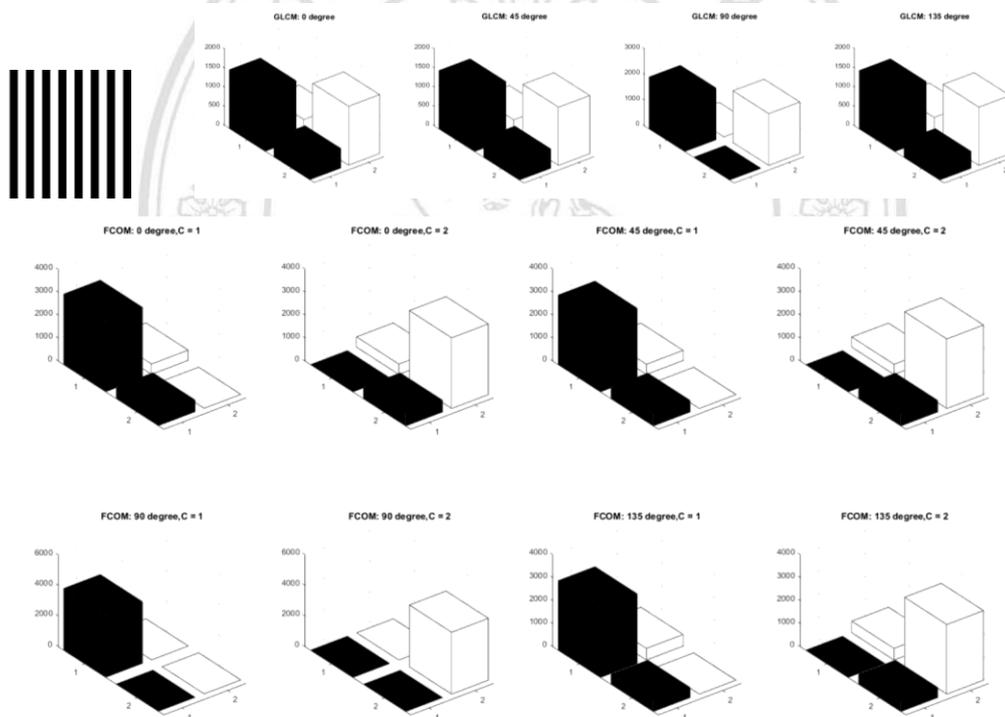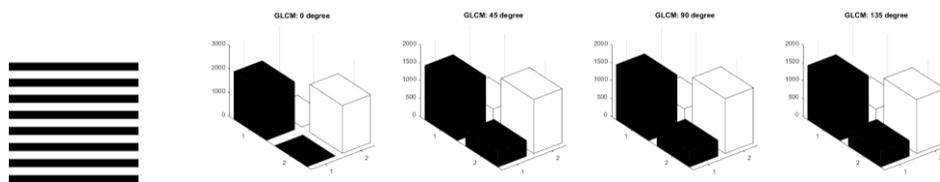

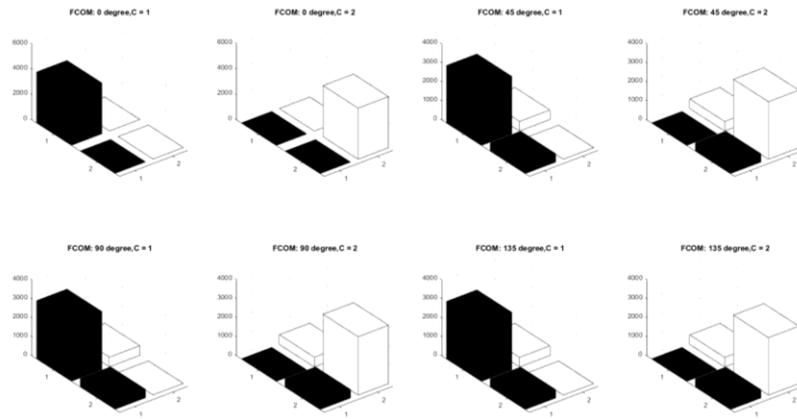Figure 4.44 Vertical texture and corresponding GLCM and FCOM planes.

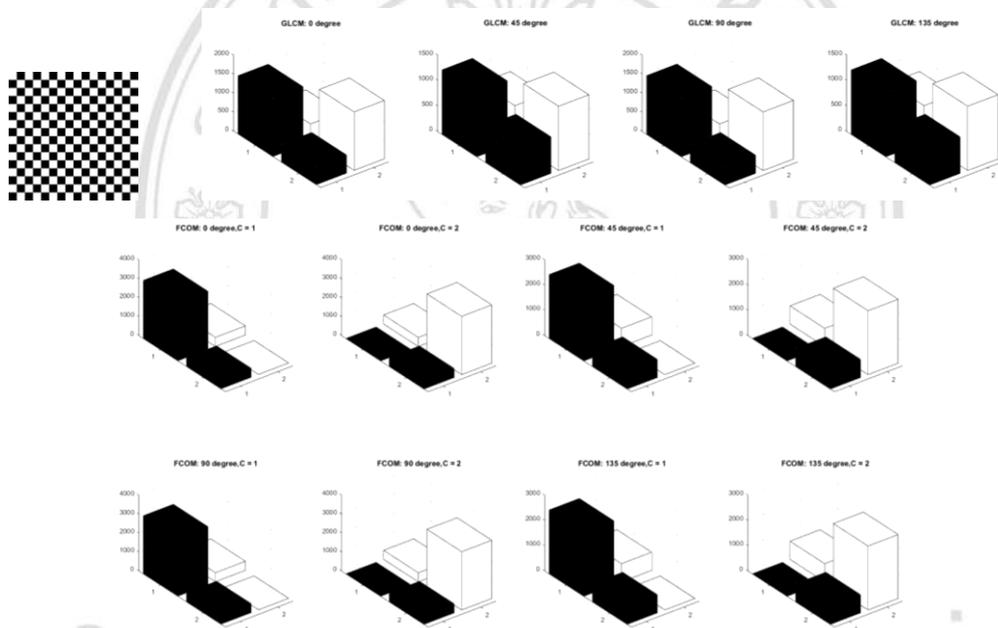Figure 4.45 Horizontal texture and corresponding GLCM and FCOM planes.

Figure 4.46 Regular texture and corresponding GLCM and FCOM planes.

In the UIUC texture data set, there were 25 texture classes, each with 40 images with the size of 640×480. Hence, there were totally 1000 images. An example from 25 classes is shown in figure 4.47. For this data set, 10-fold cross validation was used in classification task. The best validation set classification results for each gray level quantization and distance are shown in figure 4.48 to 4.67. Table 4.14 to 4.18 show the summary of best validation result for each distance of pixel pair, respectively. The summarized recognition results are shown in table 4.19. Then, the recognition results and discussions of this data set are explained.
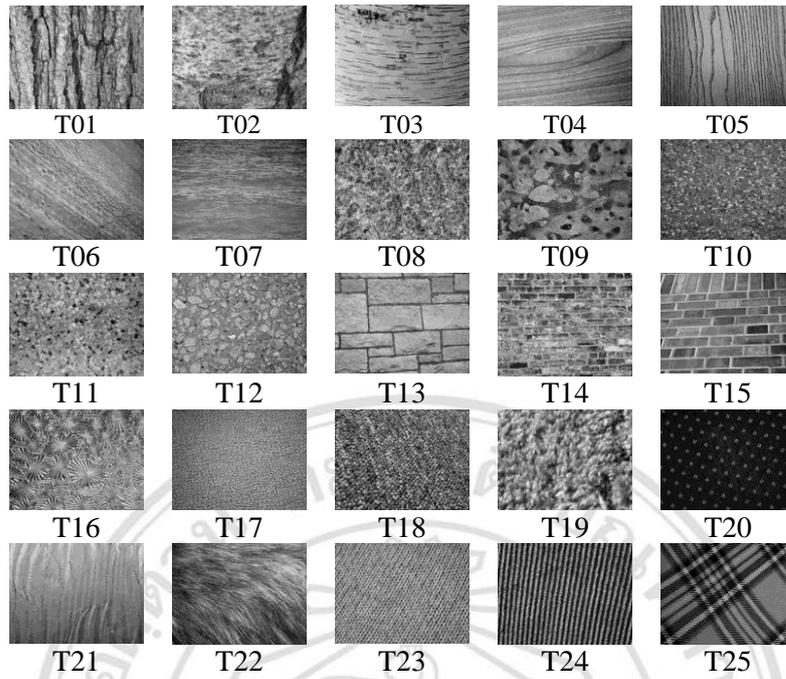
58

Figure 4.47 An example of UIUC texture data set.

Figure 4.48 The best validation set classification results from the UIUC data set where *Ng* or *C* = 4 and *d* = 1.

Figure 4.49 The best validation set classification results from the UIUC data set where
Ng or *C* = 4 and *d* = 2.

Figure 4.50 The best validation set classification results from the UIUC data set where
Ng or *C* = 4 and *d* = 3.

Figure 4.51 The best validation set classification results from the UIUC data set where

Ng or *C* = 4 and *d* = 4.

Figure 4.52 The best validation set classification results from the UIUC data set where
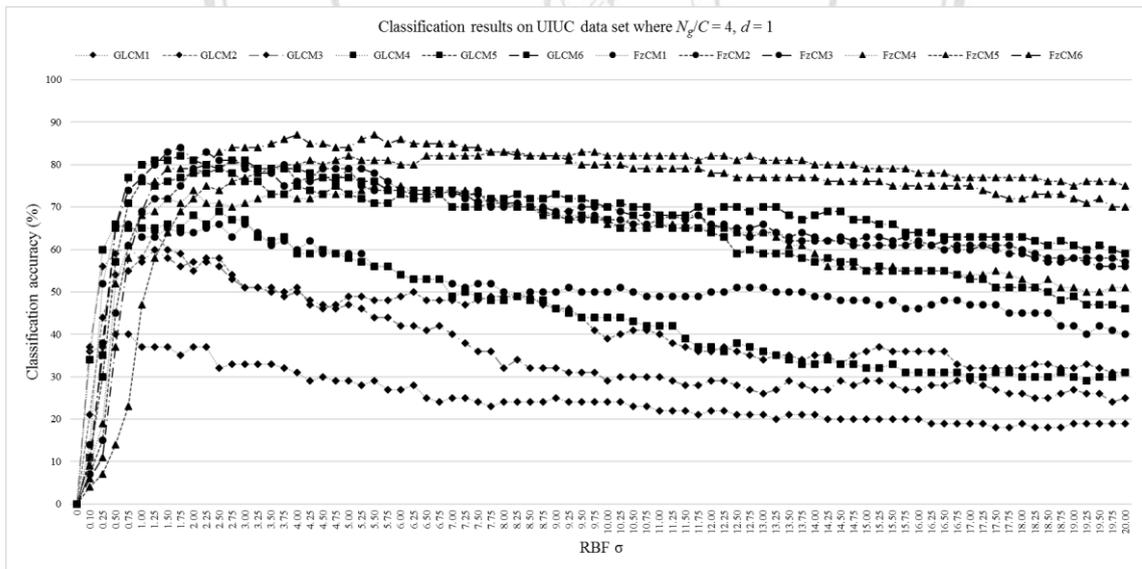
Ng or *C* = 4 and *d* = 5.

61

Figure 4.53 The best validation set classification results from the UIUC data set where *Ng* or *C* = 8 and *d* = 1.
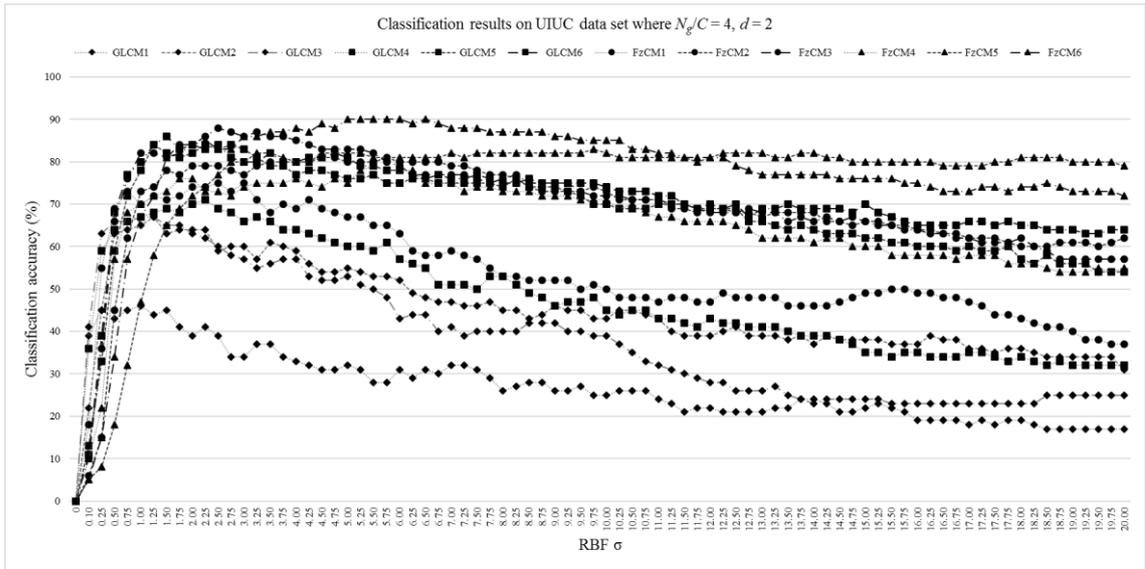
Figure 4.54 The best validation set classification results from the UIUC data set where *Ng* or *C* = 8 and *d* = 2.

Figure 4.55 The best validation set classification results from the UIUC data set where
Ng or *C* = 8 and *d* = 3.

Figure 4.56 The best validation set classification results from the UIUC data set where
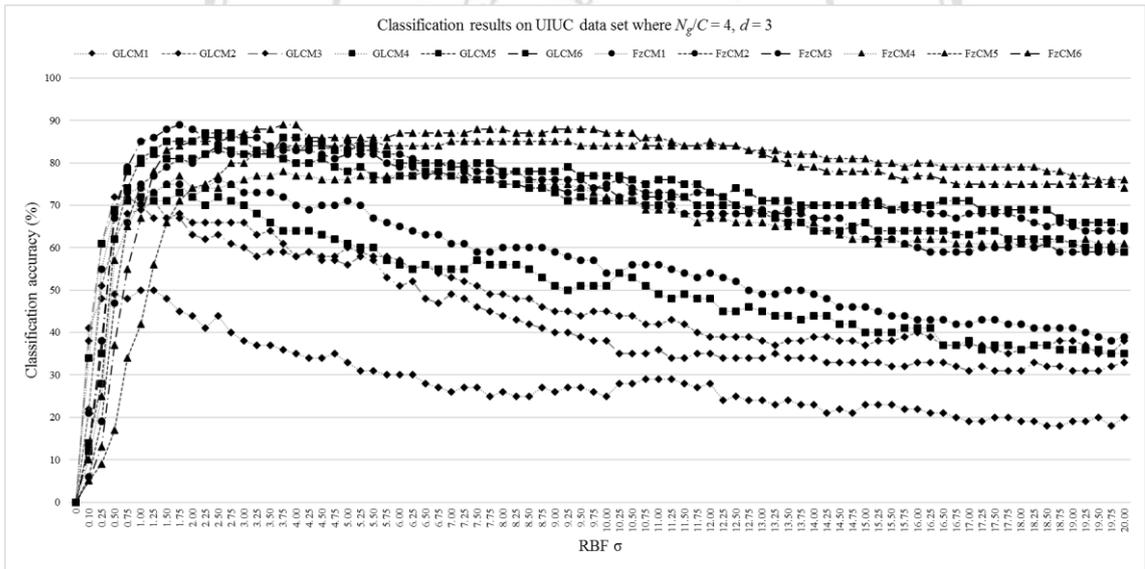*Ng* or *C* = 8 and *d* = 4.

63

Figure 4.57 The best validation set classification results from the UIUC data set where *Ng* or *C* = 8 and *d* = 5.

Figure 4.58 The best validation set classification results from the UIUC data set where *Ng* or *C* = 16 and *d* = 1.
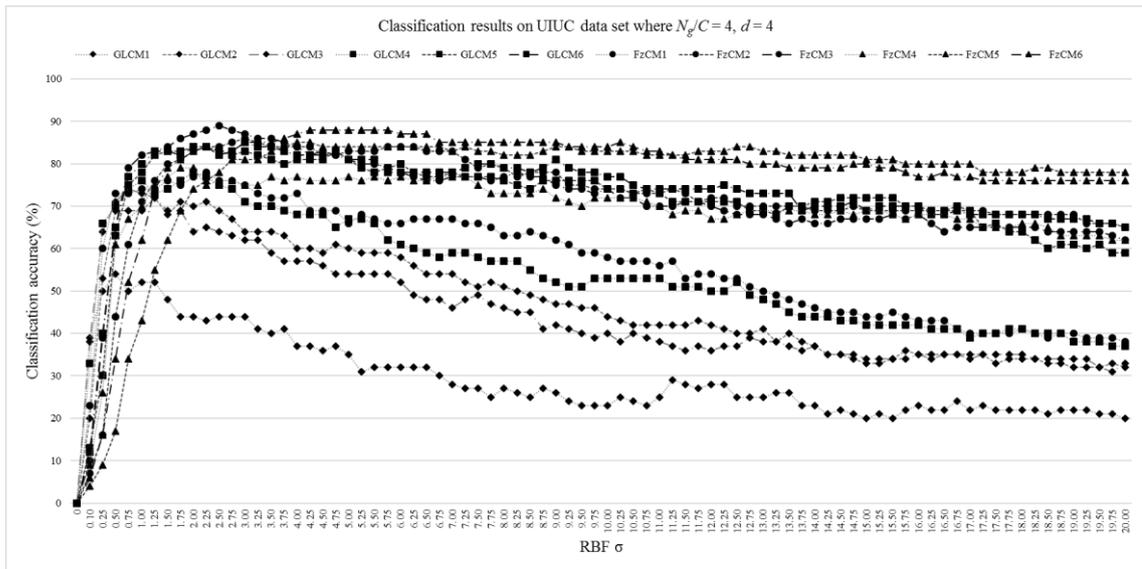
Figure 4.59 The best validation set classification results from the UIUC data set where *Ng* or *C* = 16 and *d* = 2.

Figure 4.60 The best validation set classification results from the UIUC data set where *Ng* or *C* = 16 and *d* = 3.

65

Figure 4.61 The best validation set classification results from the UIUC data set where
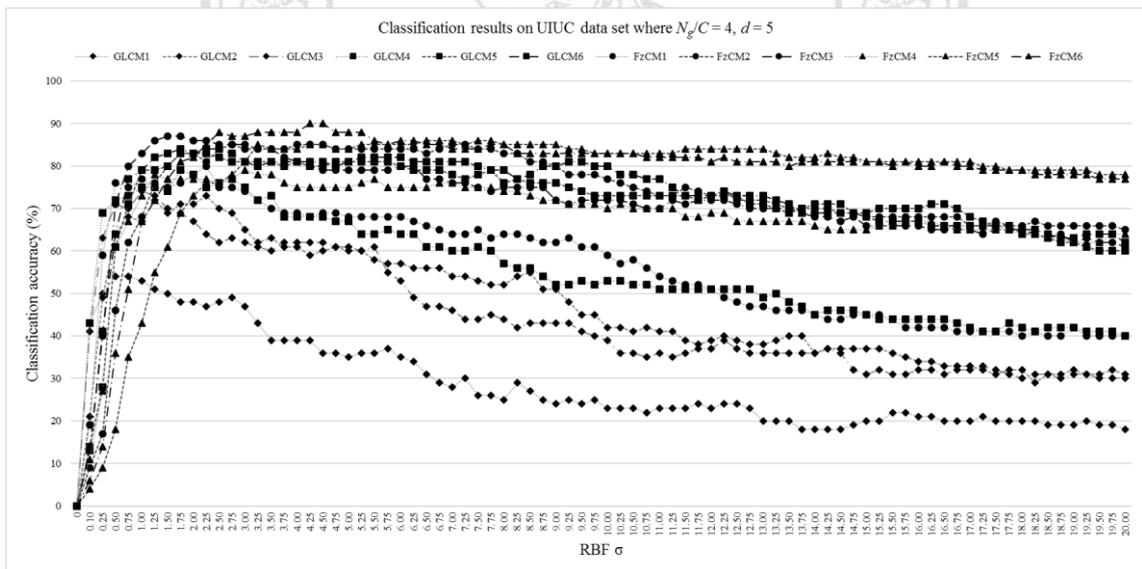*Ng* or *C* = 16 and *d* = 4.

Figure 4.62 The best validation set classification results from the UIUC data set where
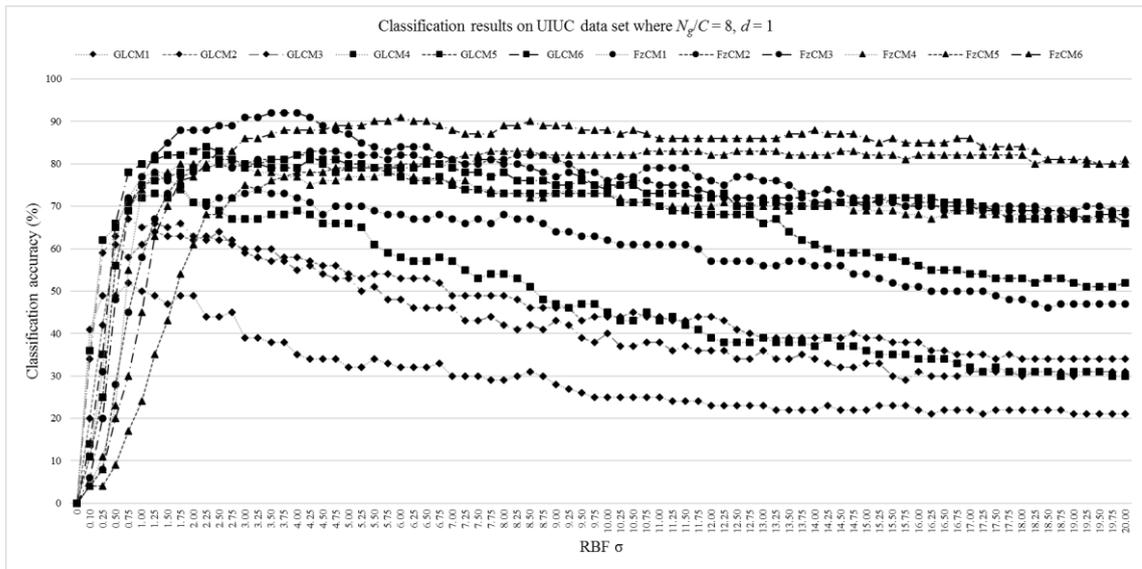*Ng* or *C* = 16 and *d* = 5.
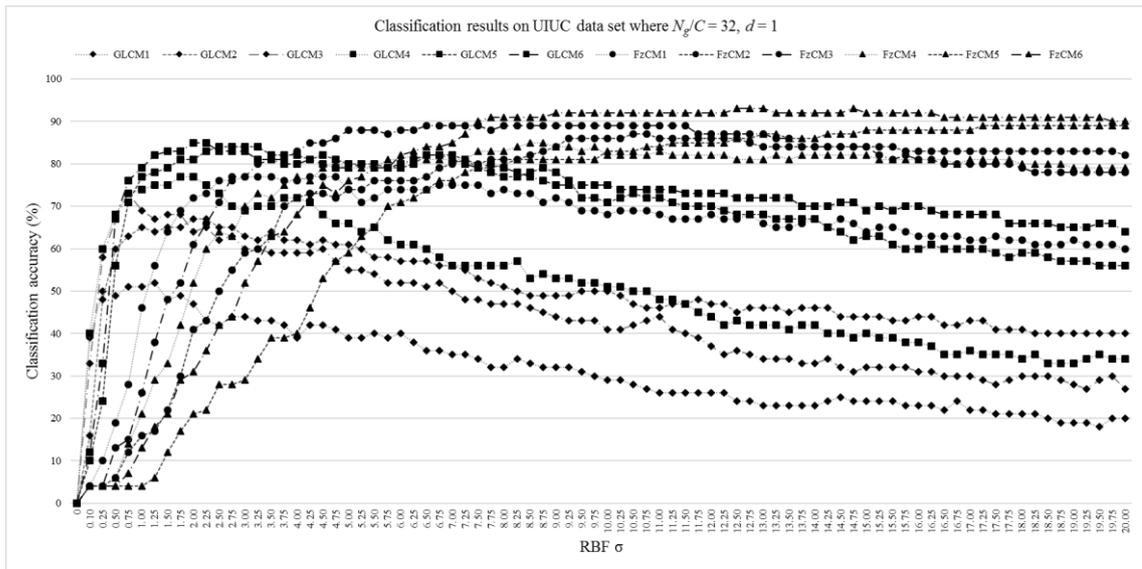
Figure 4.63 The best validation set classification results from the UIUC data set where
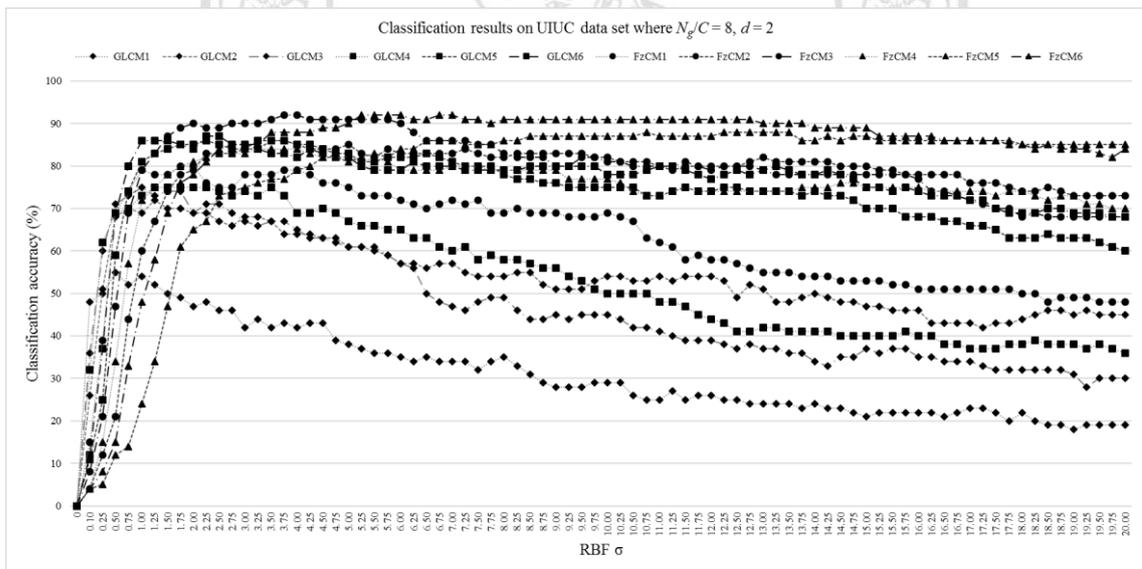*Ng* or *C* = 32 and *d* = 1.
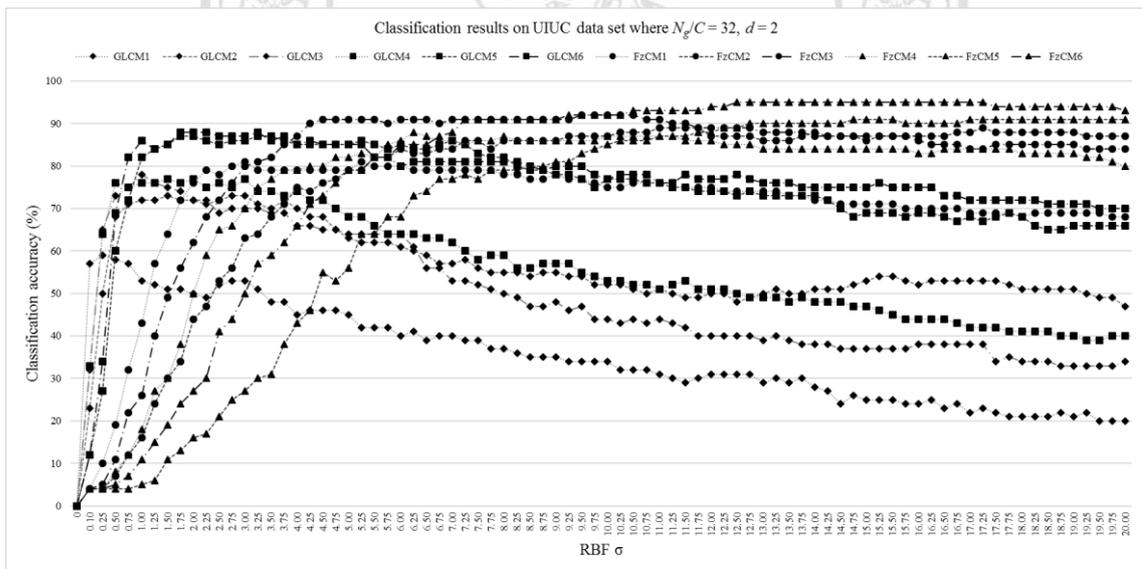
Figure 4.64 The best validation set classification results from the UIUC data set where
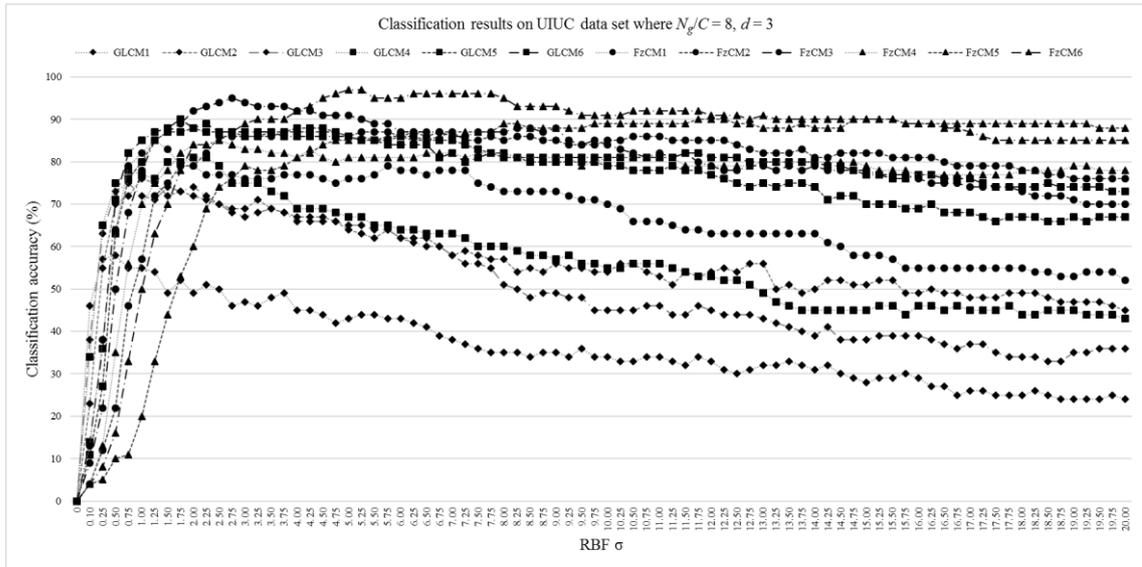*Ng* or *C* = 32 and *d* = 2.
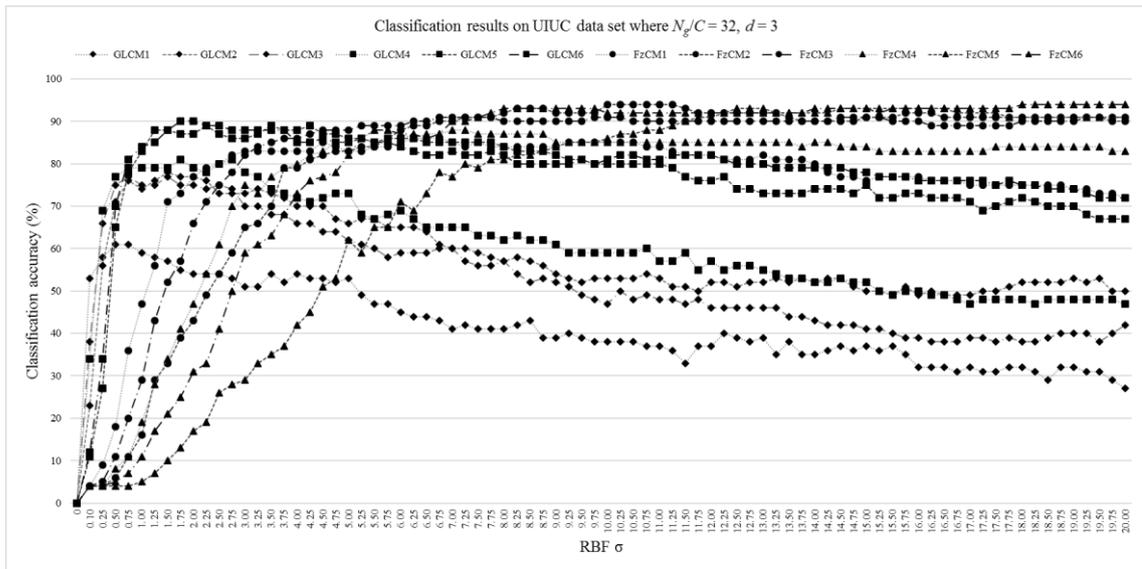
Figure 4.65 The best validation set classification results from the UIUC data set where
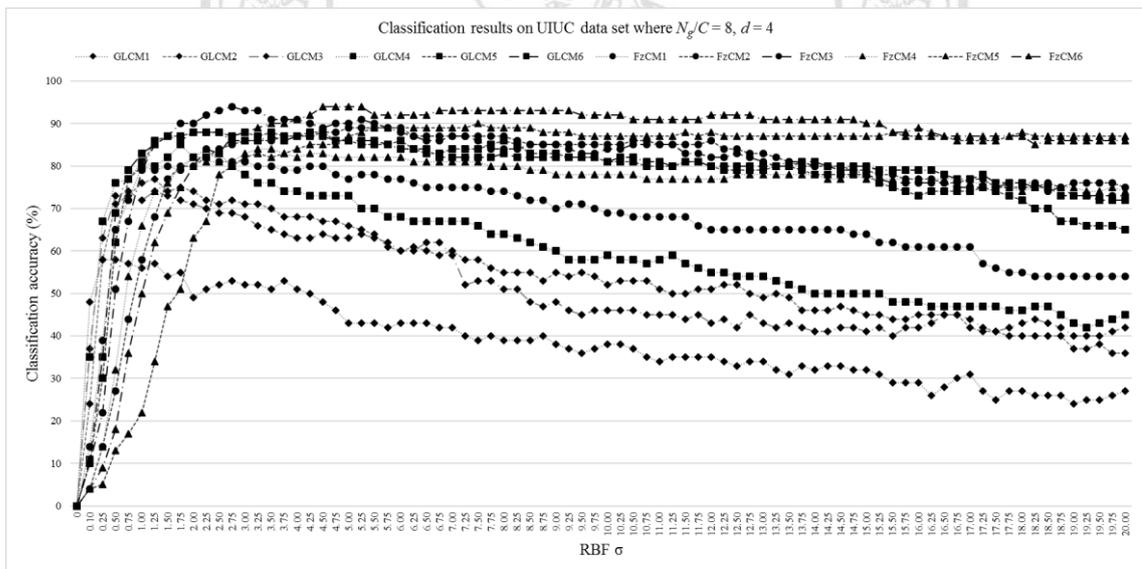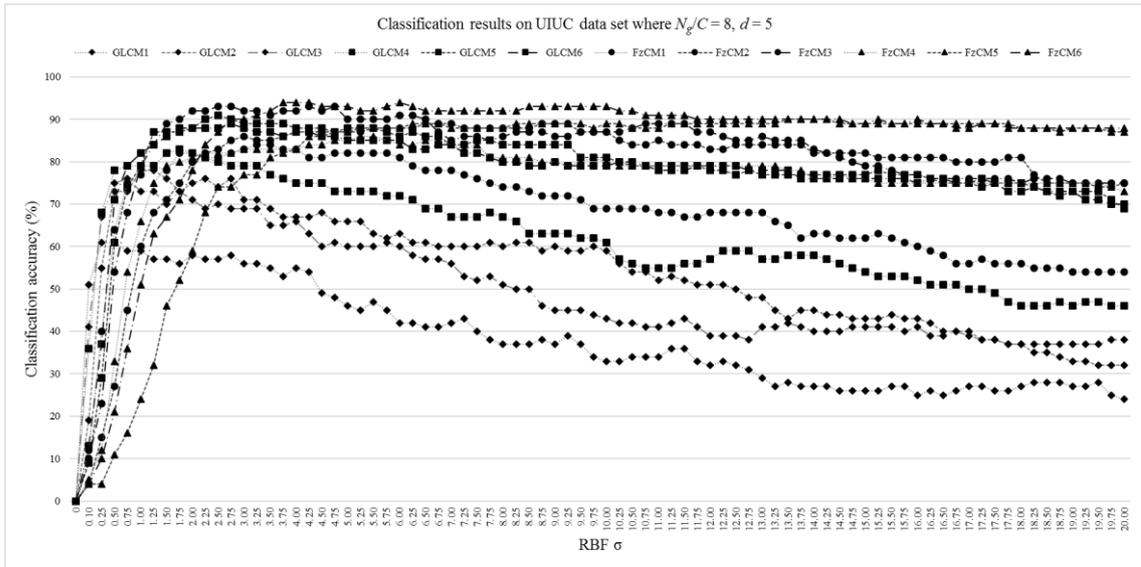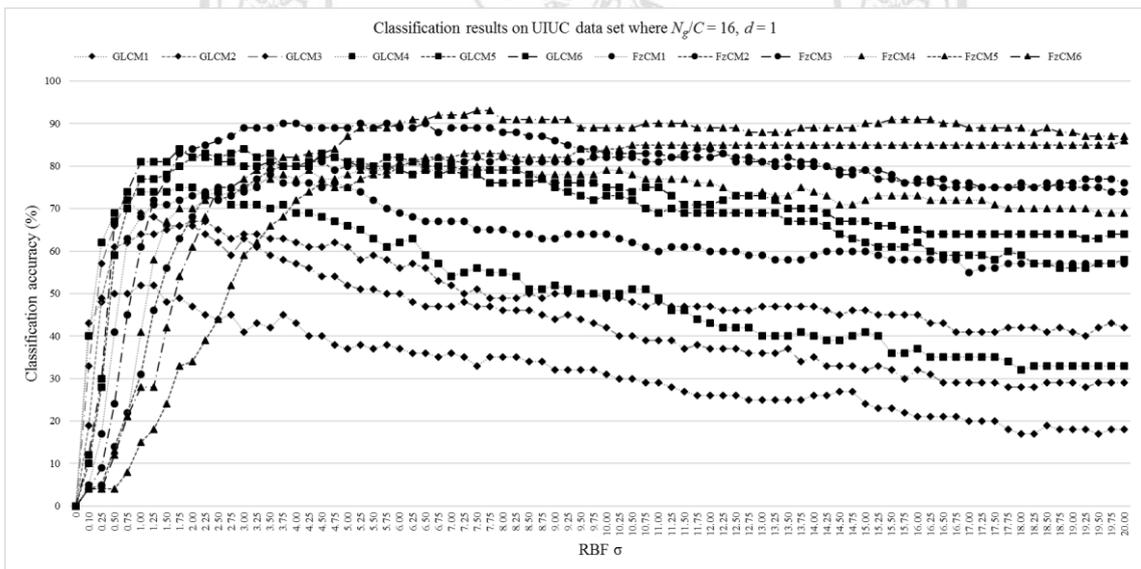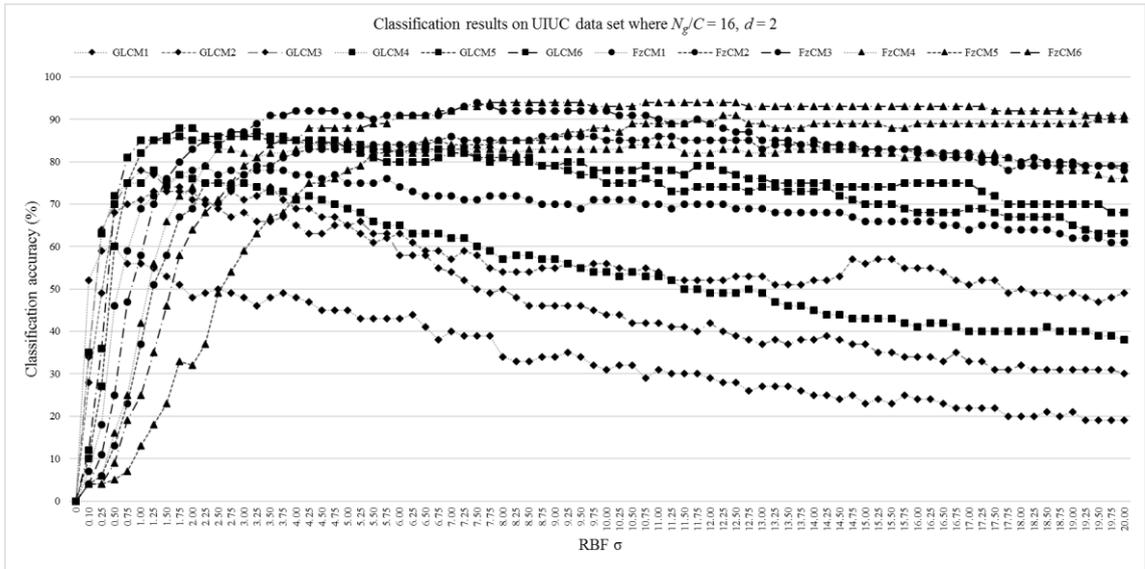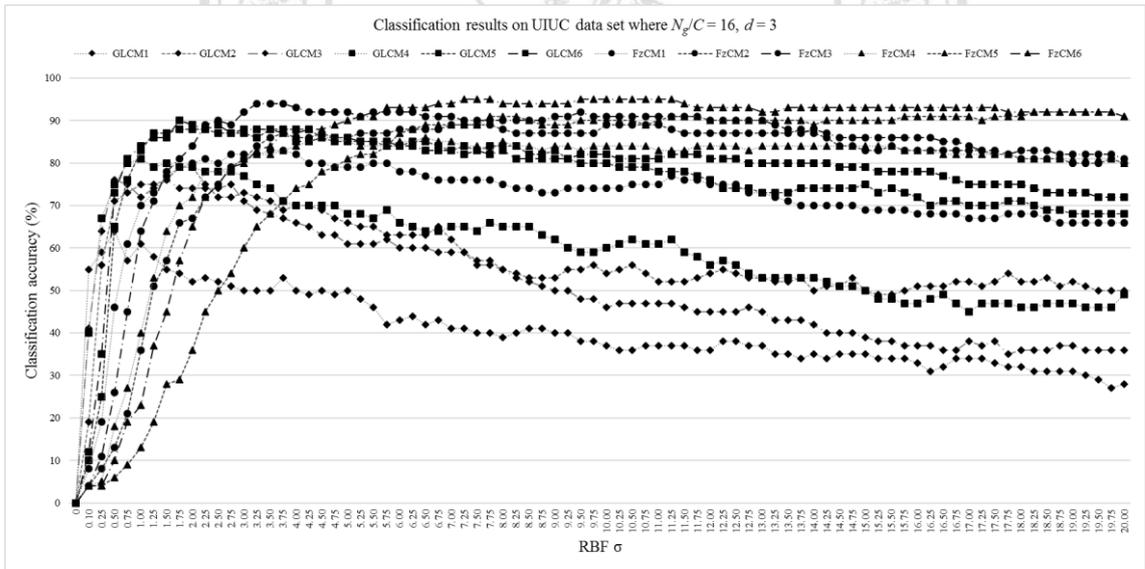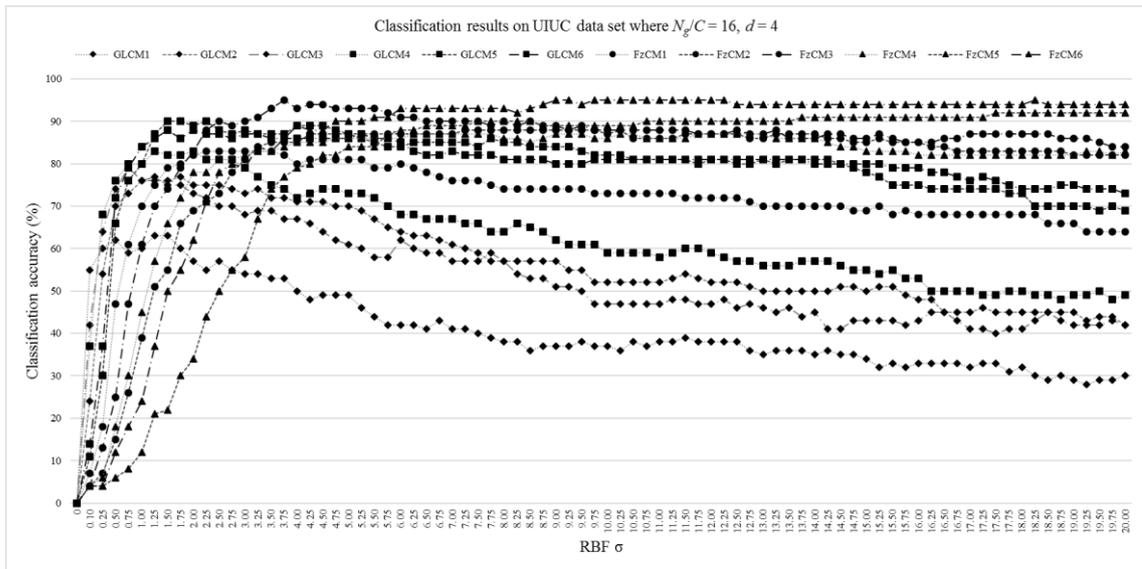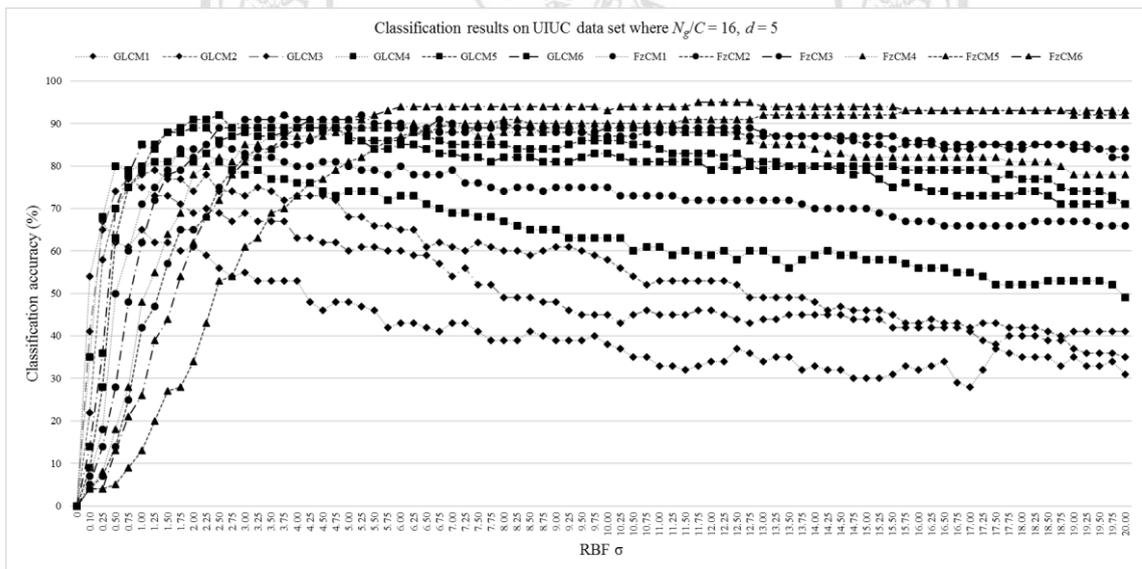*Ng* or *C* = 32 and *d* = 3.
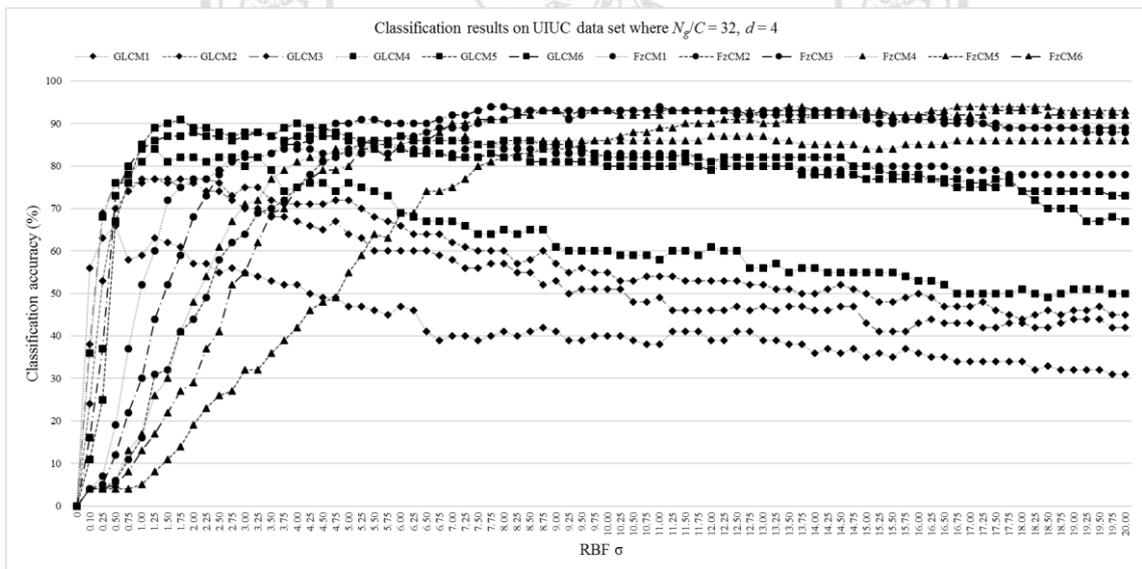
Figure 4.66 The best validation set classification results from the UIUC data set where
Ng or *C* = 32 and *d* = 4.
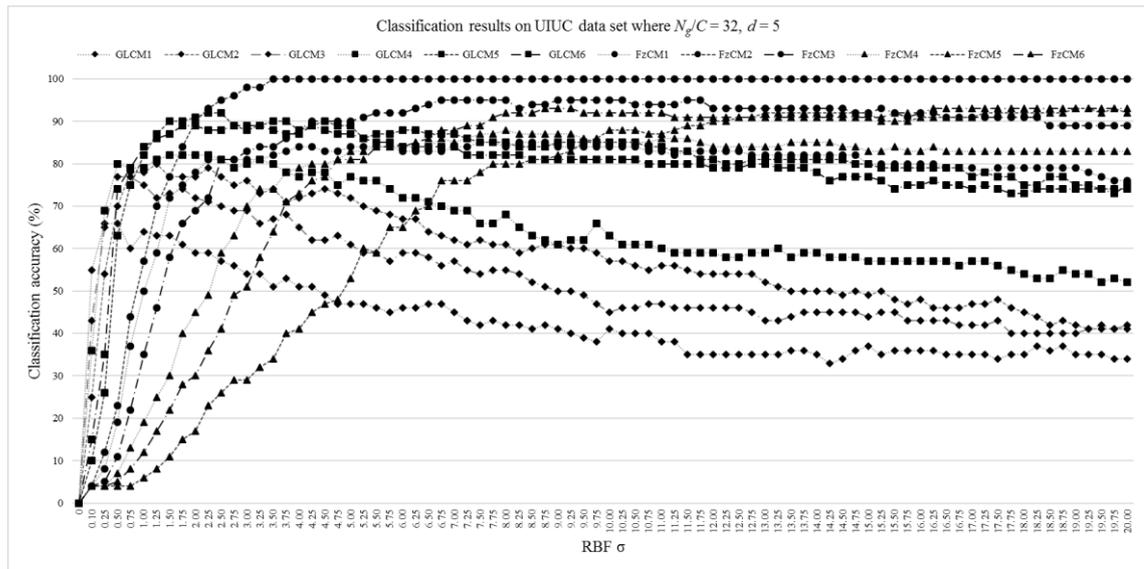
Figure 4.67 The best validation set classification results from the UIUC data set where *Ng* or *C* = 32 and *d* = 5.

Table 4.14 The summarized results for the best correct classification from the UIUC validation set where *d* = 1.

Ng or *C*	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	40.00	64.00	61.00	69.00	79.00	82.00	66.00	81.00	84.00	75.00	83.00	87.00
8	52.00	64.00	67.00	74.00	82.00	84.00	78.00	83.00	92.00	80.00	83.00	91.00
16	52.00	67.00	72.00	75.00	84.00	84.00	78.00	84.00	90.00	81.00	86.00	93.00
32	52.00	67.00	73.00	77.00	84.00	85.00	77.00	87.00	89.00	85.00	89.00	93.00
Minimum	40.00	64.00	61.00	69.00	79.00	82.00	66.00	81.00	84.00	75.00	83.00	87.00
Average	49.00	65.50	68.25	73.75	82.25	83.75	74.75	83.75	88.75	80.25	85.25	91.00
Maximum	52.00	67.00	73.00	77.00	84.00	85.00	78.00	87.00	92.00	85.00	89.00	93.00

Table 4.15 The summarized results for the best correct classification from the UIUC validation set where *d* = 2.

Ng or *C*	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	46.00	67.00	67.00	71.00	84.00	86.00	75.00	81.00	88.00	79.00	83.00	90.00
8	55.00	72.00	75.00	75.00	86.00	87.00	80.00	86.00	92.00	84.00	88.00	92.00
16	60.00	74.00	78.00	78.00	87.00	88.00	79.00	86.00	94.00	85.00	91.00	94.00
32	59.00	73.00	78.00	77.00	87.00	88.00	81.00	89.00	92.00	88.00	91.00	95.00

69

	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
Minimum	46.00	67.00	67.00	71.00	84.00	86.00	75.00	81.00	88.00	79.00	83.00	90.00
Average	55.00	71.50	74.50	75.25	86.00	87.25	78.75	85.50	91.50	84.00	88.25	92.75
Maximum	60.00	74.00	78.00	78.00	87.00	88.00	81.00	89.00	94.00	88.00	91.00	95.00

Table 4.16 The summarized results for the best correct classification from the UIUC validation set where $d = 3$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	50.00	71.00	72.00	73.00	87.00	86.00	76.00	85.00	89.00	78.00	86.00	89.00
8	58.00	76.00	75.00	81.00	88.00	90.00	85.00	87.00	95.00	85.00	90.00	97.00
16	64.00	79.00	76.00	81.00	88.00	90.00	83.00	89.00	94.00	86.00	92.00	95.00
32	61.00	78.00	77.00	81.00	89.00	90.00	86.00	94.00	91.00	88.00	93.00	94.00
Minimum	50.00	71.00	72.00	73.00	87.00	86.00	76.00	85.00	89.00	78.00	86.00	89.00
Average	58.25	76.00	75.00	79.00	88.00	89.00	82.50	88.75	92.25	84.25	90.25	93.75
Maximum	64.00	79.00	77.00	81.00	89.00	90.00	86.00	94.00	95.00	88.00	93.00	97.00

Table 4.17 The summarized results for the best correct classification from the UIUC validation set where $d = 4$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	54.00	72.00	74.00	78.00	84.00	85.00	78.00	86.00	89.00	79.00	85.00	88.00
8	58.00	77.00	74.00	85.00	88.00	88.00	84.00	89.00	94.00	84.00	90.00	94.00
16	63.00	77.00	79.00	83.00	90.00	88.00	83.00	88.00	95.00	87.00	92.00	95.00
32	66.00	77.00	77.00	84.00	91.00	88.00	85.00	93.00	94.00	87.00	94.00	94.00
Minimum	54.00	72.00	74.00	78.00	84.00	85.00	78.00	86.00	89.00	79.00	85.00	88.00
Average	60.25	75.75	76.00	82.50	88.25	87.25	82.50	89.00	93.00	84.25	90.25	92.75
Maximum	66.00	77.00	79.00	85.00	91.00	88.00	85.00	93.00	95.00	87.00	94.00	95.00

Table 4.18 The summarized results for the best correct classification from the UIUC validation set where $d = 5$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	54.00	73.00	74.00	79.00	83.00	84.00	80.00	85.00	87.00	79.00	86.00	90.00
8	61.00	78.00	76.00	83.00	91.00	89.00	84.00	89.00	93.00	86.00	90.00	94.00
16	67.00	79.00	77.00	83.00	92.00	89.00	85.00	89.00	92.00	90.00	93.00	95.00

32	66.00	80.00	77.00	82.00	92.00	89.00	85.00	100.00	95.00	88.00	93.00	93.00
Minimum	54.00	73.00	74.00	79.00	83.00	84.00	80.00	85.00	87.00	79.00	86.00	90.00
Average	62.00	77.50	76.00	81.75	89.50	87.75	83.50	90.75	91.75	85.75	90.50	93.00
Maximum	67.00	80.00	77.00	83.00	92.00	89.00	85.00	100.00	95.00	90.00	93.00	95.00

Table 4.19 The summarized results for the best correct classification from the UIUC validation set.

Method	Distance (d)	Accuracy	Ng or C	RBF σ	Feature set
GLCM	1	85.00	32	2.00	GLCM6
	2	88.00	16	1.75	GLCM6
	3	90.00	8	1.75	GLCM6
	4	91.00	32	1.75	GLCM5
	5	92.00	16	2.50	GLCM5
FCOM	1	93.00	16	7.75	FzCM6
	2	95.00	32	17.25	FzCM6
	3	97.00	8	5.25	FzCM6
	4	95.00	16	3.75	FzCM3
	5	100.00	32	20.00	FzCM2

Again, the classification rates from the feature sets created by FCOM were better than those from GLCM in all distances in this data set. Most of the recognition results were lower than the other data sets since most textures are stochastic or near-stochastic pattern. The images in this data set are very correlated, e.g., T13, T14, and T15. These three classes are very similar due to human perspective. The textures look like a scaled and transformation version of the other classes. Some of them look like a rotation version, e.g., T04 and T05 as shown in figure 4.47. However, the recognition results from FCOM texture features were still higher than the results from GLCM texture features in all cases. Example of incorrect recognition images is shown in figure 4.68. The incorrect classification results occurred when d = 1, 2, 3, and 4 for the same reason as that of Kylberg. The GLCM planes extracted from these images are also similar.

T22_14   T22_16   T07

(a) Example of incorrect classification images   (b) Example images of the predicted class

Figure 4.68 Example of incorrect classification images on UIUC data set.

The UMD texture data set was used in the last experiment. There were 25 texture classes, each with 40 images, 1000 images in total. The size of each image was 1280×900. An example of each texture is shown in figure 4.69. Again, 10-fold cross validation was implemented for this data set. Figure 4.70 to 4.89 show the best classification results for each gray level quantization and distance. Table 4.20 to 4.24 show the summary of the best validation set recognition results for each distance. The summary results of the best validation classification results are shown in table 4.25.

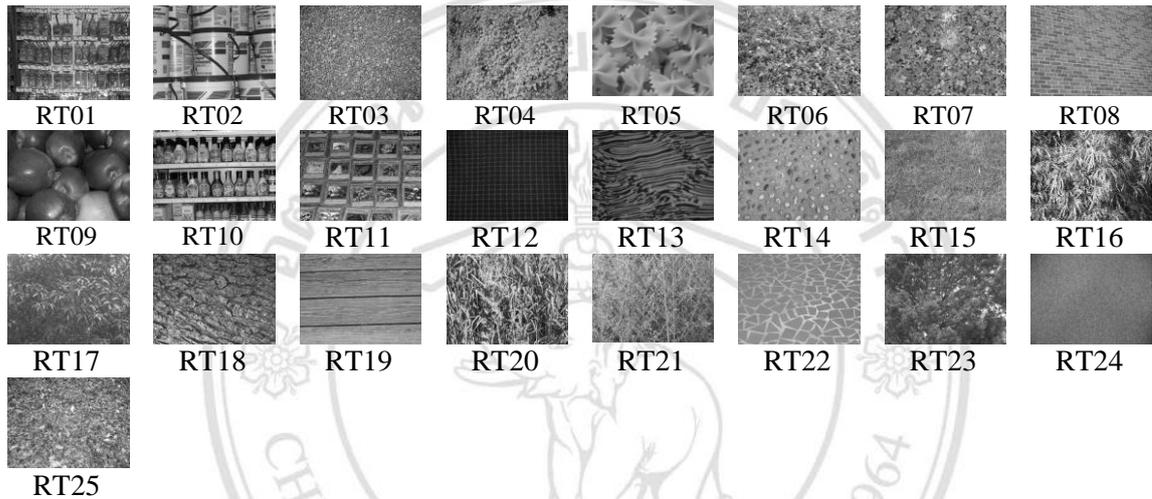| RT01 | RT02 | RT03 | RT04 | RT05 | RT06 | RT07 | RT08 |
RT09	RT10	RT11	RT12	RT13	RT14	RT15	RT16
RT17	RT18	RT19	RT20	RT21	RT22	RT23	RT24
RT25							

Figure 4.69 An example of UMD texture data set.

Figure 4.70 The best validation set classification results from the UMD data set where Ng or $C = 4$ and $d = 1$.

Figure 4.71 The best validation set classification results from the UMD data set where *Ng* or *C* = 4 and *d* = 2.

Figure 4.72 The best validation set classification results from the UMD data set where *Ng* or *C* = 4 and *d* = 3.
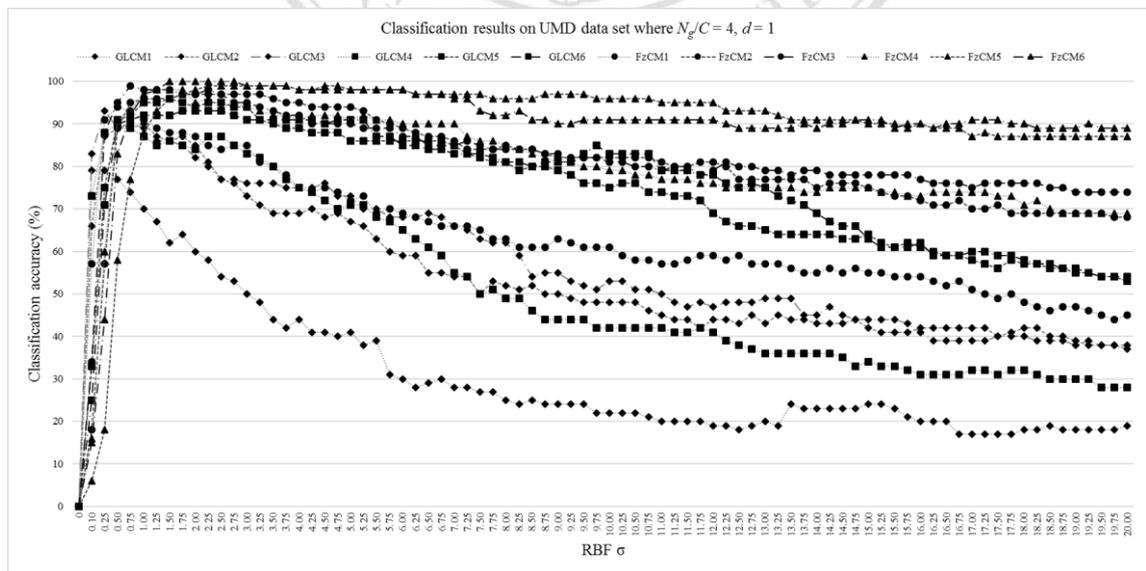
Figure 4.73 The best validation set classification results from the UMD data set where N_g or $C = 4$ and $d = 4$.

Figure 4.74 The best validation set classification results from the UMD data set where N_g or $C = 4$ and $d = 5$.

Figure 4.75 The best validation set classification results from the UMD data set where
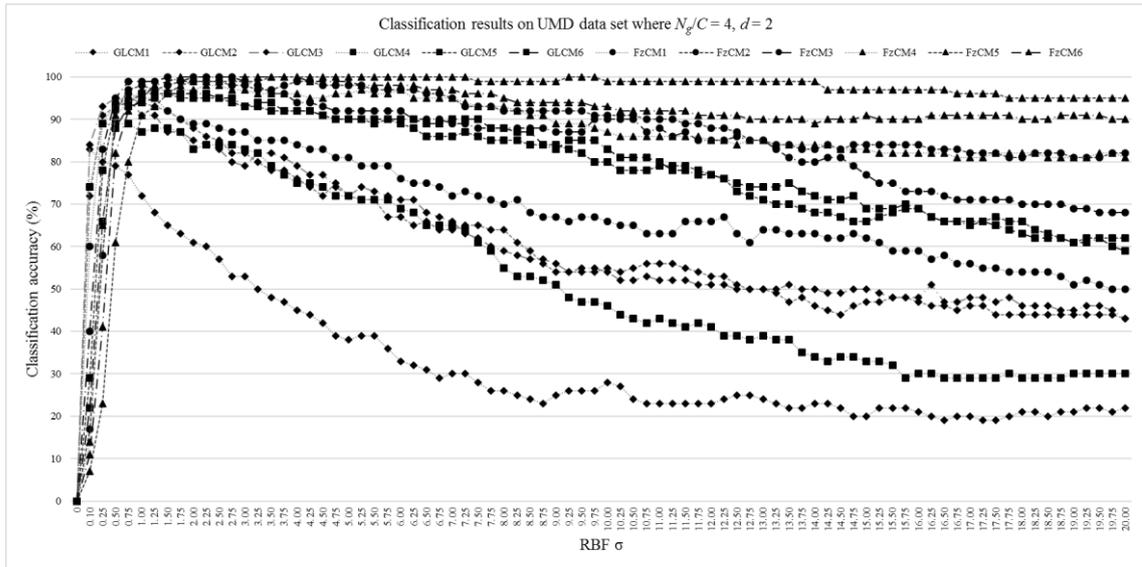N_g or $C = 8$ and $d = 1$.

Figure 4.76 The best validation set classification results from the UMD data set where
N_g or $C = 8$ and $d = 2$.

Figure 4.77 The best validation set classification results from the UMD data set where
N_g or $C = 8$ and $d = 3$.

Figure 4.78 The best validation set classification results from the UMD data set where
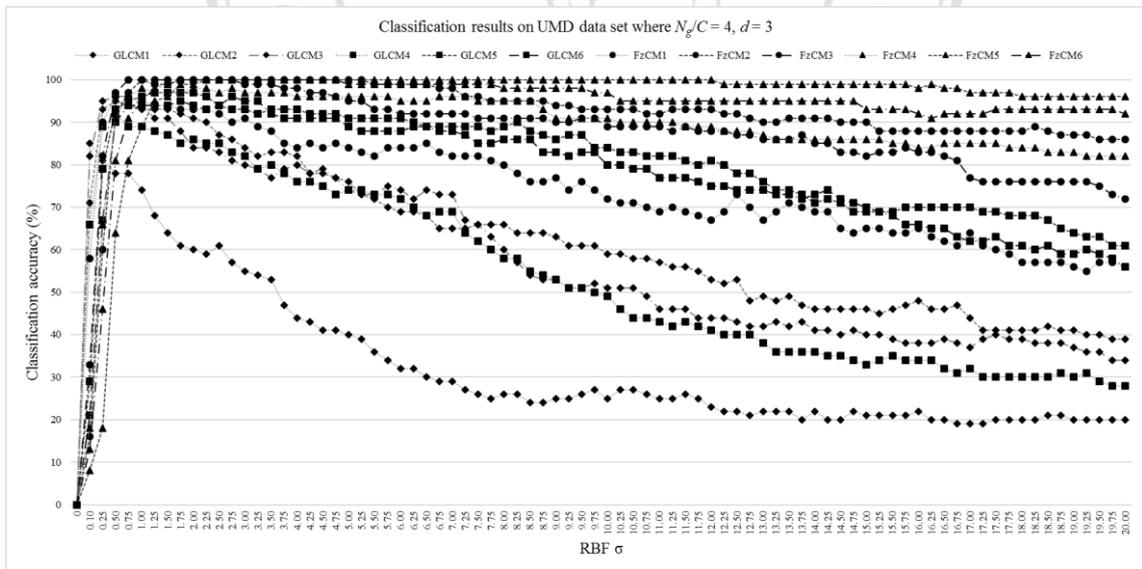N_g or $C = 8$ and $d = 4$.

Figure 4.79 The best validation set classification results from the UMD data set where N_g or $C = 8$ and $d = 5$.
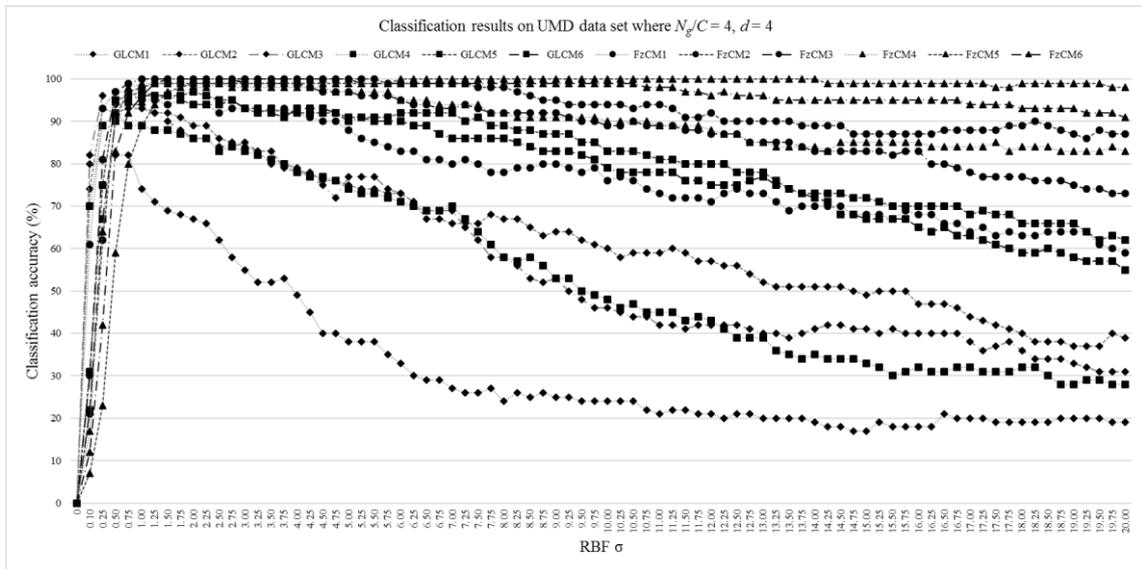

Figure 4.80 The best validation set classification results from the UMD data set where N_g or $C = 16$ and $d = 1$.

Figure 4.81 The best validation set classification results from the UMD data set where
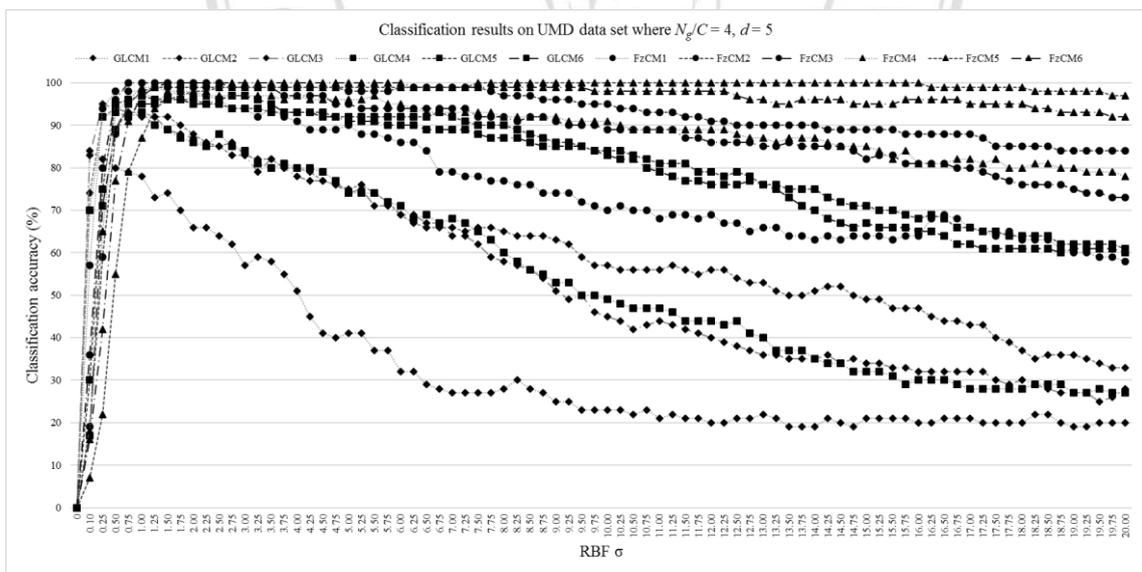Ng or $C = 16$ and $d = 2$.

Figure 4.82 The best validation set classification results from the UMD data set where
Ng or $C = 16$ and $d = 3$.

Figure 4.83 The best validation set classification results from the UMD data set where *Ng* or *C* = 16 and *d* = 4.

Figure 4.84 The best validation set classification results from the UMD data set where *Ng* or *C* = 16 and *d* = 5.
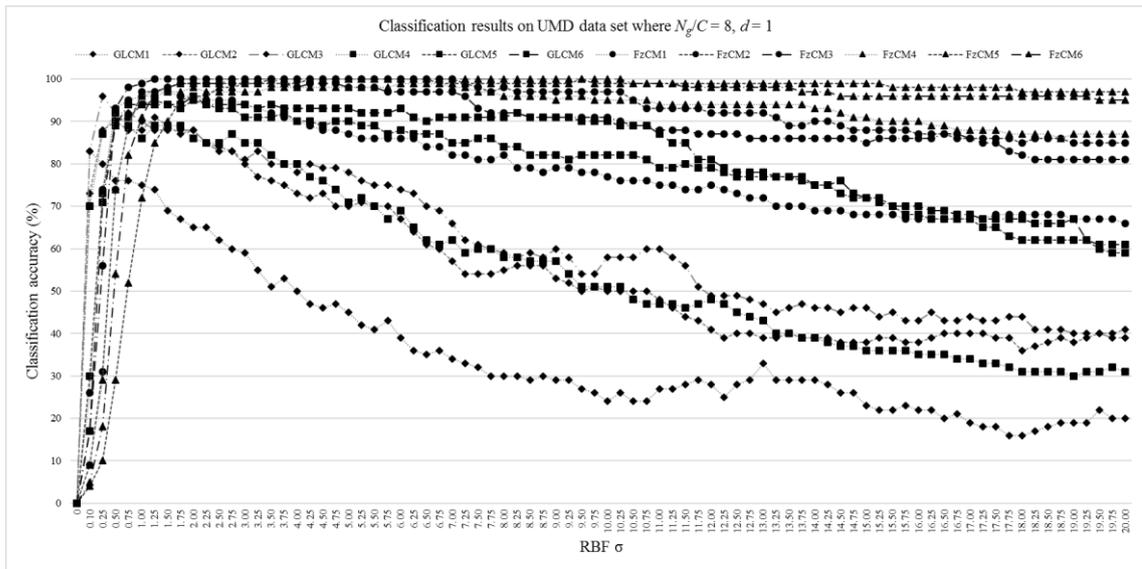
Figure 4.85 The best validation set classification results from the UMD data set where *Ng* or *C* = 32 and *d* = 1.
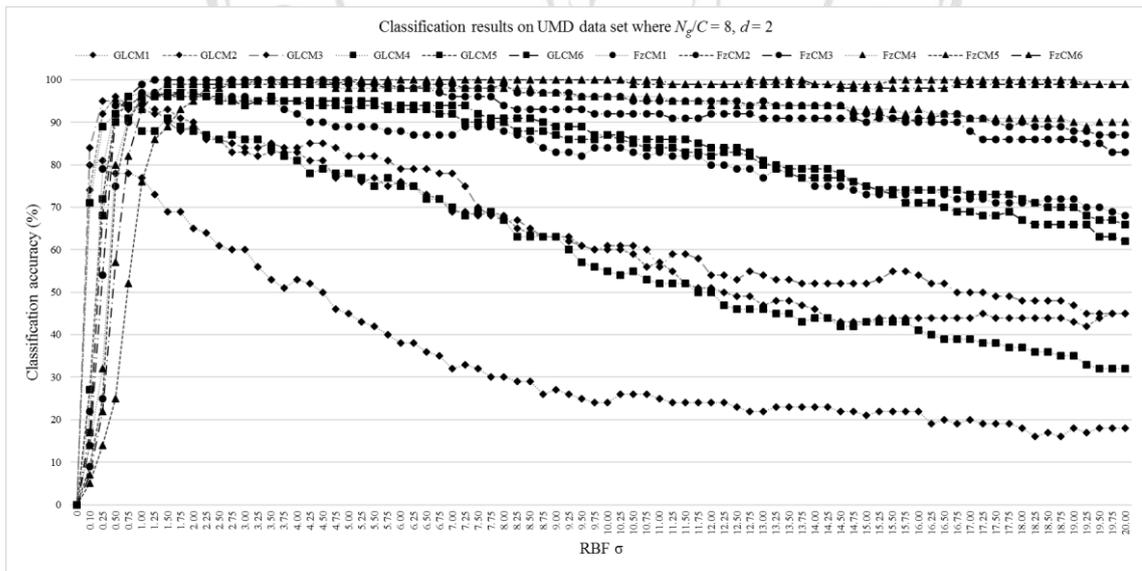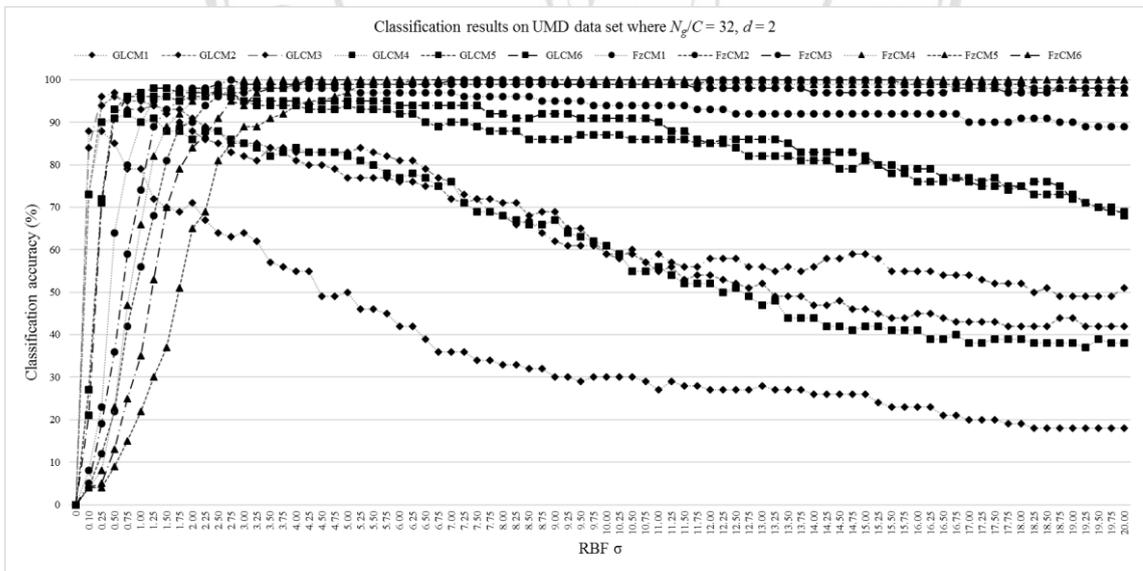

Figure 4.86 The best validation set classification results from the UMD data set where *Ng* or *C* = 32 and *d* = 2.
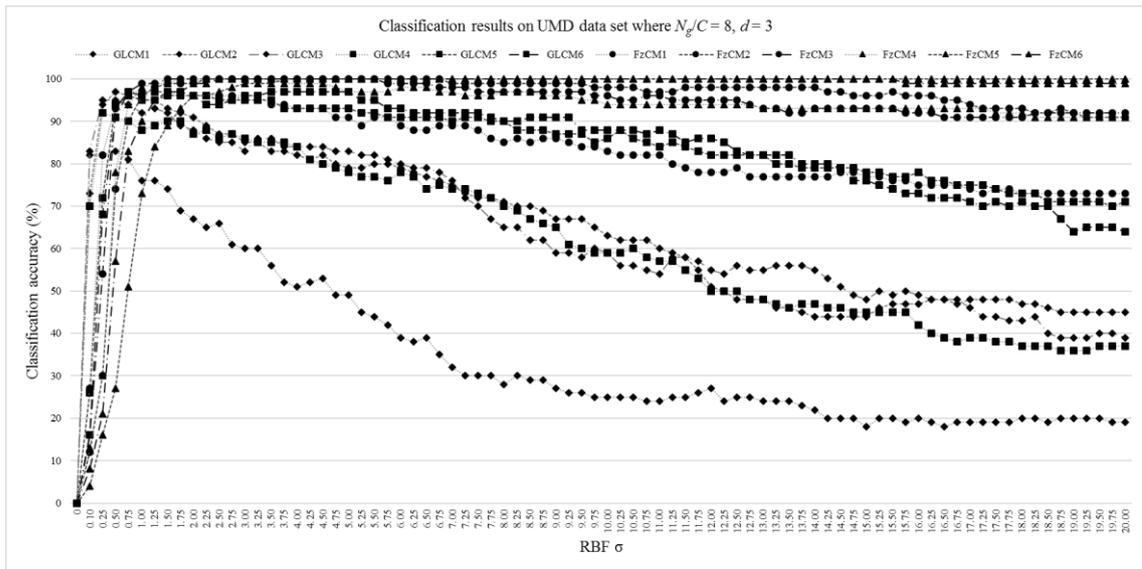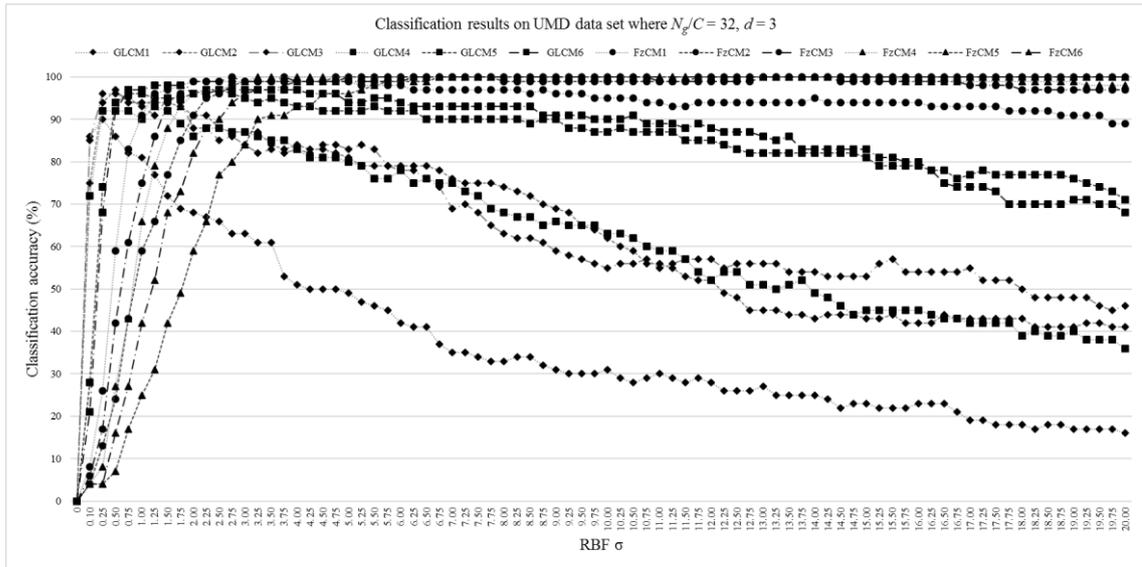
Figure 4.87 The best validation set classification results from the UMD data set where
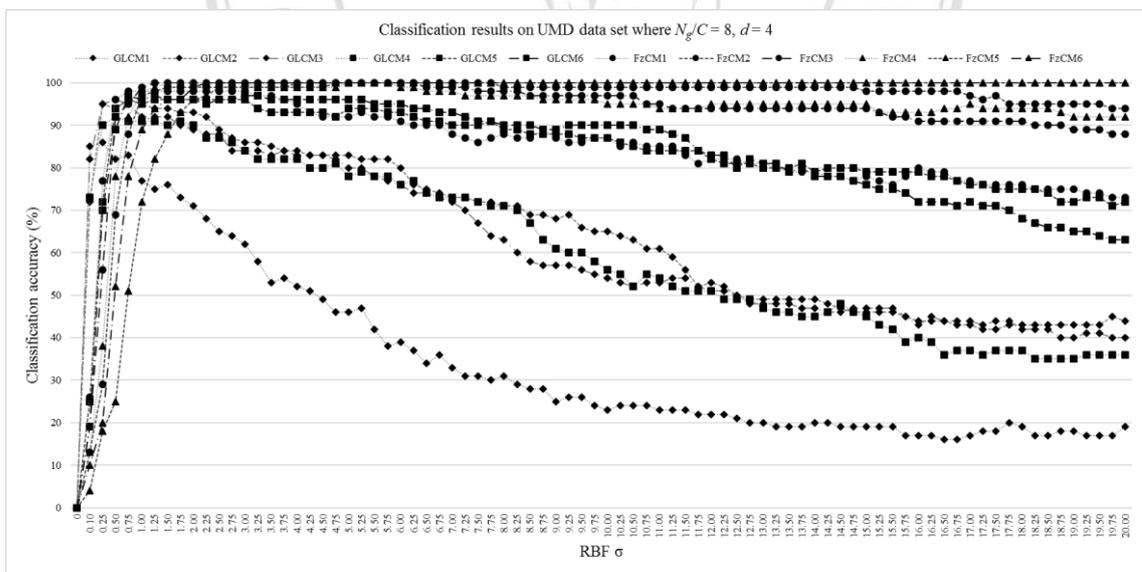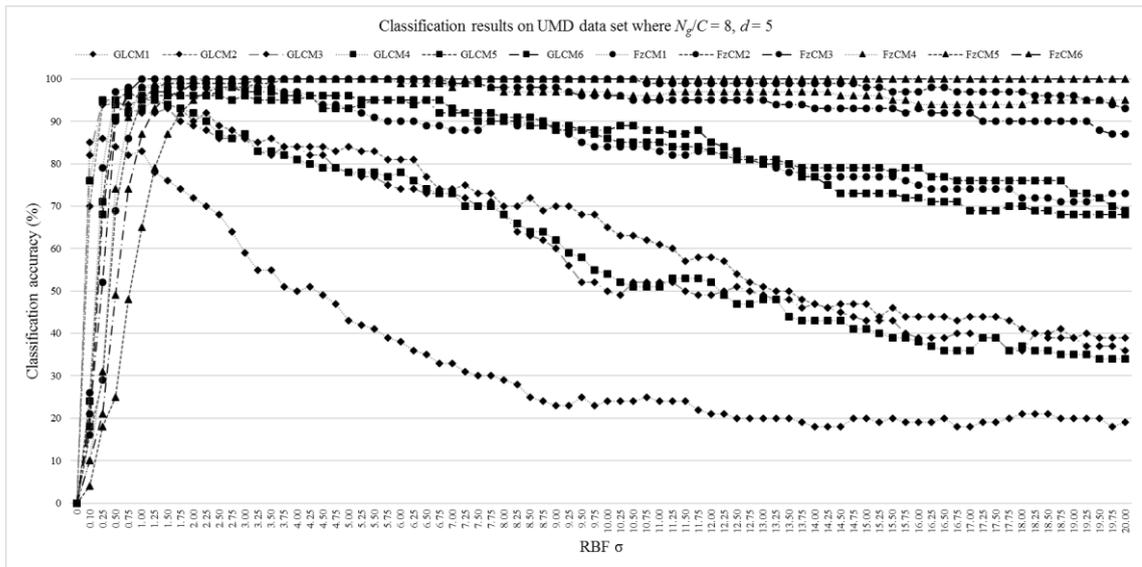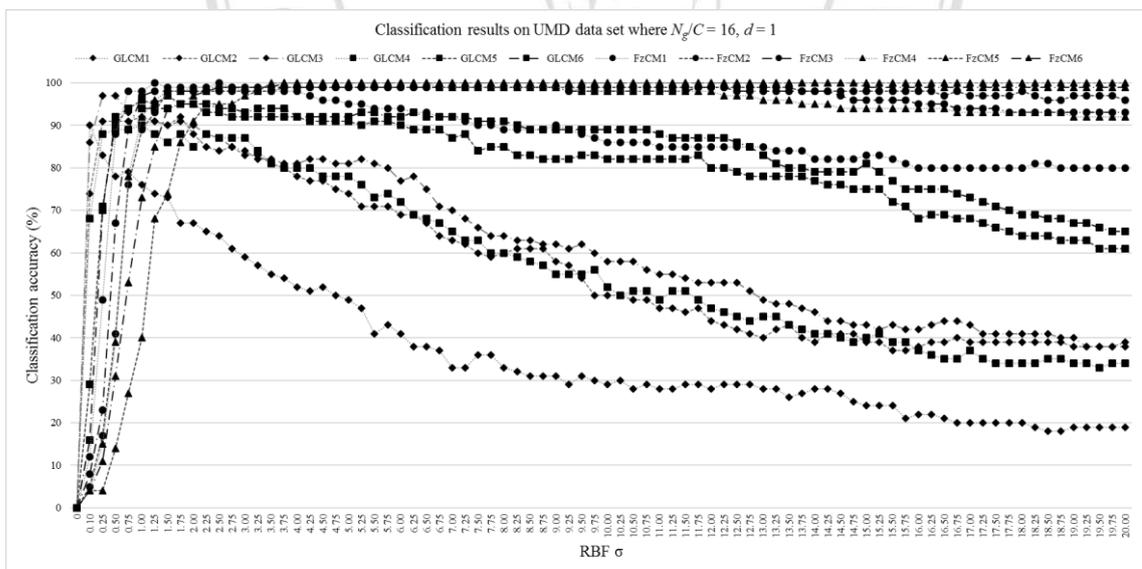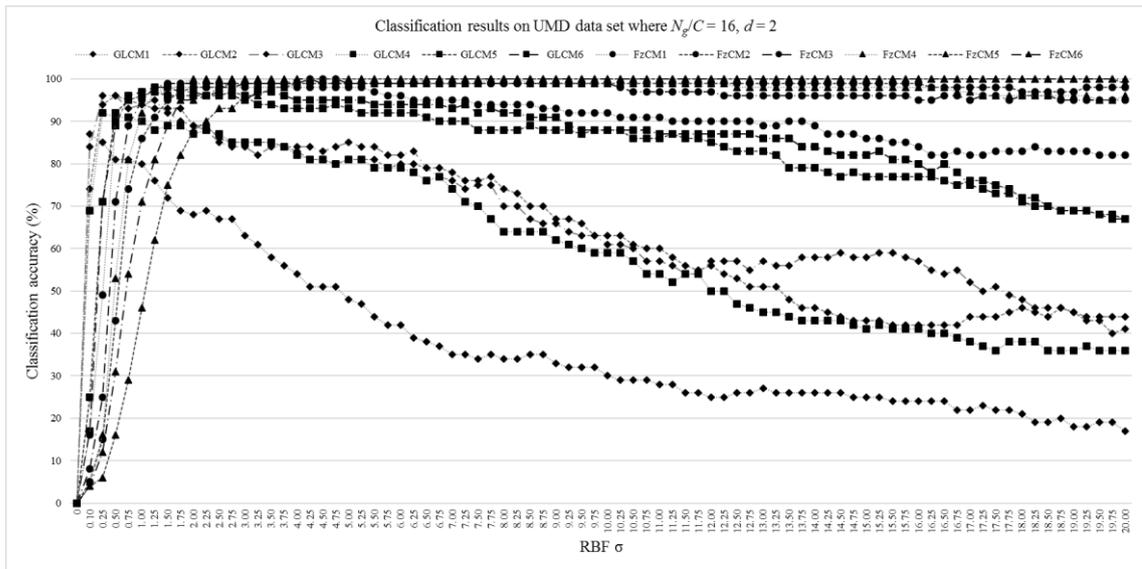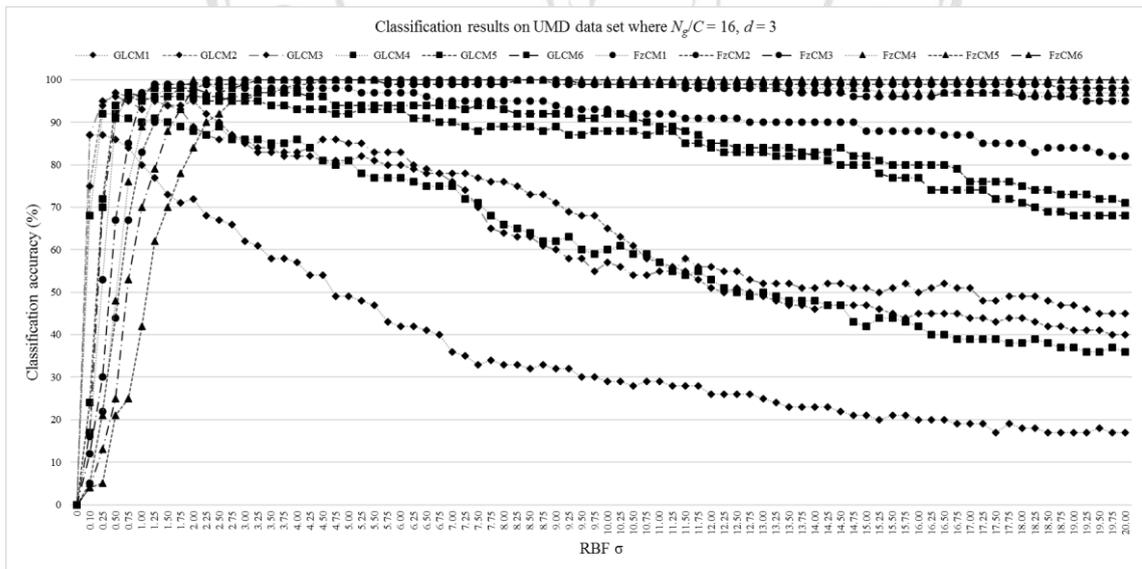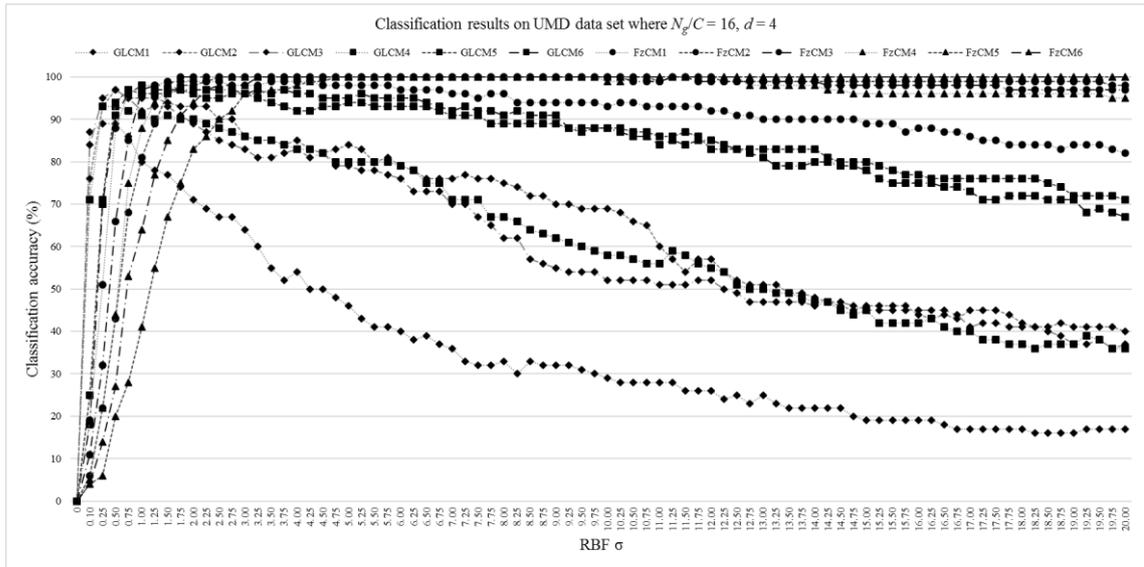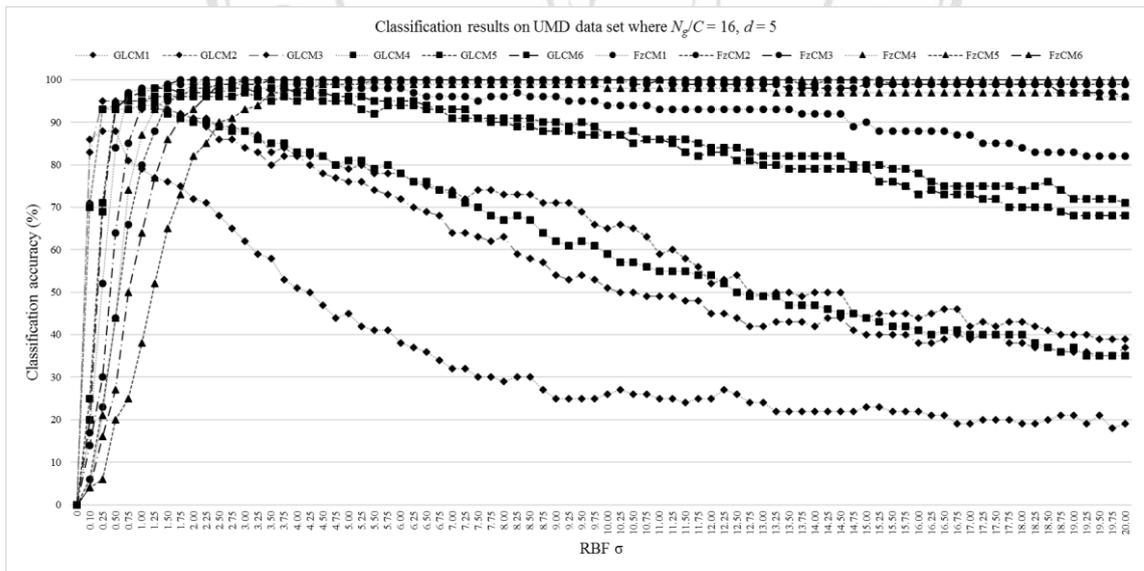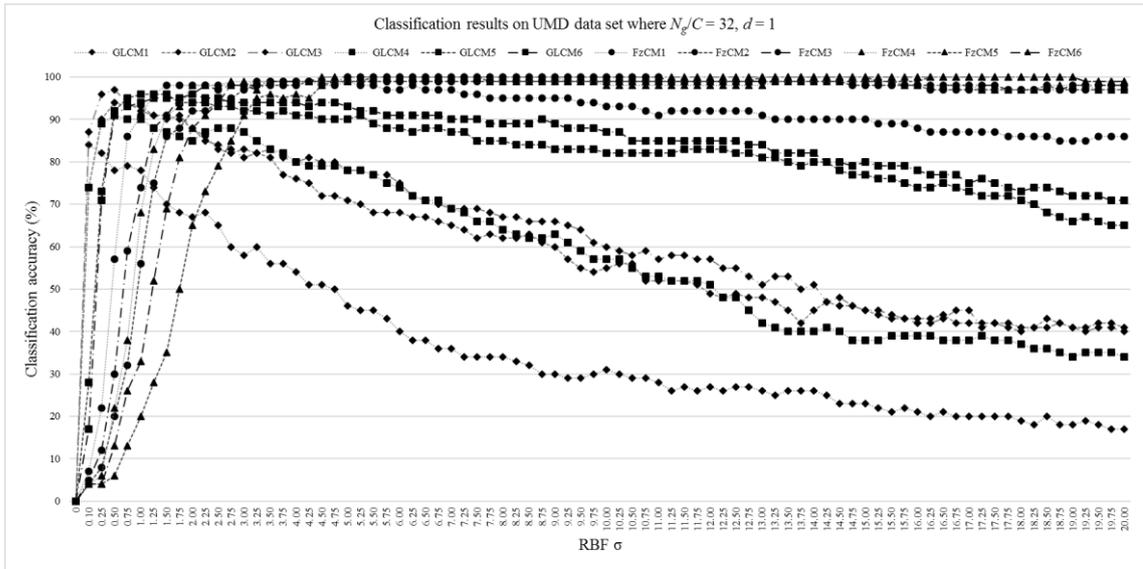*Ng* or *C* = 32 and *d* = 3.
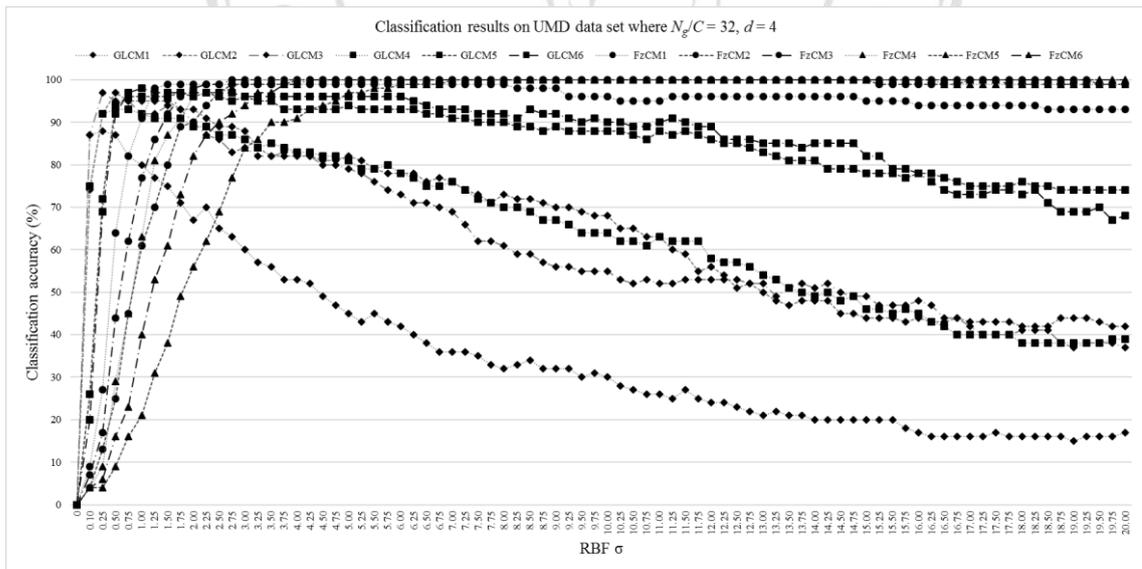
Figure 4.88 The best validation set classification results from the UMD data set where
Ng or *C* = 32 and *d* = 4.

81
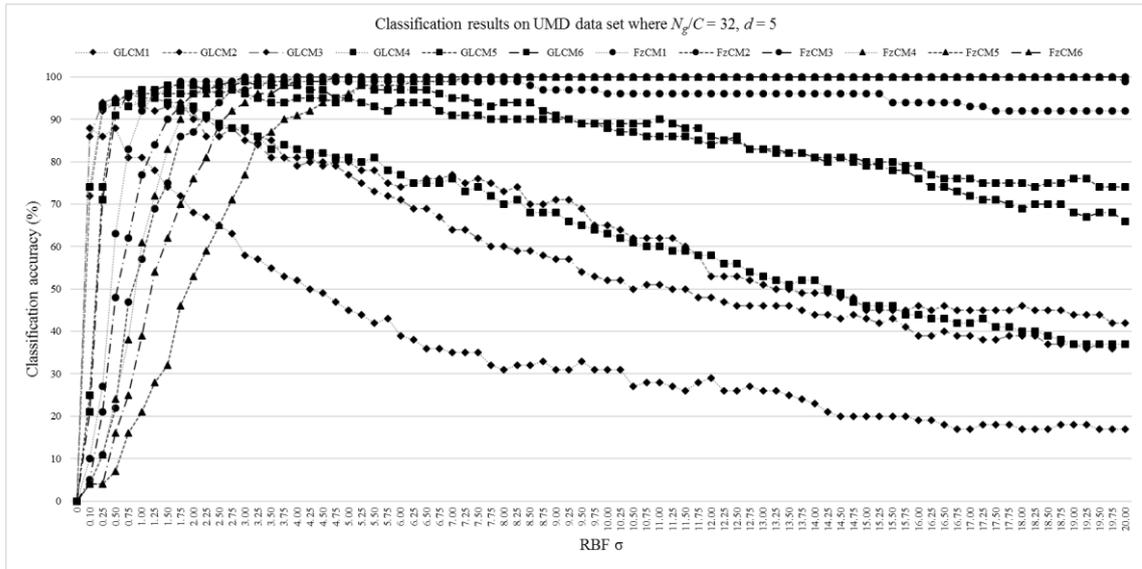
Figure 4.89 The best validation set classification results from the UMD data set where
Ng or *C* = 32 and *d* = 5.

Table 4.20 The summarized results for the best correct classification from the UMD
validation set where *d* = 1.

Ng or *C*	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	79.00	90.00	93.00	90.00	96.00	93.00	94.00	97.00	99.00	98.00	99.00	100.00
8	83.00	91.00	96.00	92.00	95.00	96.00	97.00	100.00	100.00	99.00	100.00	100.00
16	90.00	92.00	97.00	90.00	97.00	95.00	100.00	99.00	99.00	100.00	100.00	100.00
32	84.00	94.00	97.00	91.00	96.00	96.00	99.00	99.00	100.00	100.00	100.00	100.00
Minimum	79.00	90.00	93.00	90.00	95.00	93.00	94.00	97.00	99.00	98.00	99.00	100.00
Average	84.00	91.75	95.75	90.75	96.00	95.00	97.50	98.75	99.50	99.25	99.75	100.00
Maximum	90.00	94.00	97.00	92.00	97.00	96.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4.21 The summarized results for the best correct classification from the UMD
validation set where *d* = 2.

Ng or *C*	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	83.00	95.00	95.00	89.00	96.00	96.00	96.00	99.00	100.00	98.00	100.00	100.00
8	81.00	96.00	95.00	92.00	96.00	97.00	97.00	100.00	100.00	100.00	100.00	100.00
16	87.00	96.00	96.00	92.00	97.00	98.00	98.00	99.00	100.00	100.00	100.00	100.00
32	88.00	96.00	97.00	92.00	97.00	98.00	98.00	100.00	100.00	100.00	100.00	100.00
Minimum	81.00	95.00	95.00	89.00	96.00	96.00	96.00	99.00	100.00	98.00	100.00	100.00
Average	84.75	95.75	95.75	91.25	96.50	97.25	97.25	99.50	100.00	99.50	100.00	100.00
Maximum	88.00	96.00	97.00	92.00	97.00	98.00	98.00	100.00	100.00	100.00	100.00	100.00

82

Table 4.22 The summarized results for the best correct classification from the UMD
validation set where $d = 3$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	85.00	95.00	96.00	92.00	97.00	96.00	96.00	100.00	100.00	98.00	100.00	100.00
8	83.00	97.00	95.00	92.00	96.00	97.00	97.00	100.00	100.00	100.00	100.00	100.00
16	87.00	97.00	96.00	92.00	96.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00
32	90.00	97.00	96.00	93.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00
Minimum	83.00	95.00	95.00	92.00	96.00	96.00	96.00	100.00	100.00	98.00	100.00	100.00
Average	86.25	96.50	95.75	92.25	96.50	97.25	97.75	100.00	100.00	99.50	100.00	100.00
Maximum	90.00	97.00	96.00	93.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00

Table 4.23 The summarized results for the best correct classification from the UMD
validation set where $d = 4$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	82.00	93.00	96.00	92.00	97.00	96.00	97.00	100.00	100.00	99.00	100.00	100.00
8	86.00	96.00	96.00	92.00	96.00	97.00	98.00	100.00	100.00	100.00	100.00	100.00
16	89.00	97.00	97.00	93.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00
32	88.00	97.00	97.00	93.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00
Minimum	82.00	93.00	96.00	92.00	96.00	96.00	97.00	100.00	100.00	99.00	100.00	100.00
Average	86.25	95.75	96.50	92.50	96.75	97.25	98.25	100.00	100.00	99.75	100.00	100.00
Maximum	89.00	97.00	97.00	93.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00

Table 4.24 The summarized results for the best correct classification from the UMD
validation set where $d = 5$.

Ng or C	GLCM						FCOM					
	GLCM1	GLCM2	GLCM3	GLCM4	GLCM5	GLCM6	FzCM1	FzCM2	FzCM3	FzCM4	FzCM5	FzCM6
4	84.00	94.00	95.00	93.00	97.00	97.00	98.00	99.00	100.00	99.00	100.00	100.00
8	86.00	95.00	95.00	95.00	97.00	98.00	98.00	100.00	100.00	100.00	100.00	100.00
16	88.00	95.00	95.00	94.00	97.00	98.00	99.00	100.00	100.00	100.00	100.00	100.00
32	88.00	96.00	95.00	95.00	97.00	99.00	99.00	100.00	100.00	100.00	100.00	100.00
Minimum	84.00	94.00	95.00	93.00	97.00	97.00	98.00	99.00	100.00	99.00	100.00	100.00
Average	86.50	95.00	95.00	94.25	97.00	98.00	98.50	99.75	100.00	99.75	100.00	100.00
Maximum	88.00	96.00	95.00	95.00	97.00	99.00	99.00	100.00	100.00	100.00	100.00	100.00

83

Table 4.25 The summarized results for the best correct classification from the UMD validation set.

Method	Distance (d)	Accuracy	Ng or C	RBF σ	Feature set
GLCM	1	97.00	16	0.25	GLCM3
	2	98.00	16	1.25	GLCM6
	3	98.00	16	1.25	GLCM6
	4	98.00	16	1.00	GLCM6
	5	99.00	32	3.00	GLCM6
FCOM	1	100.00	4	2.75	FzCM6
	2	100.00	4	2.75	FzCM3
	3	100.00	4	5.25	FzCM2
	4	100.00	4	5.50	FzCM2
	5	100.00	4	2.50	FzCM3

This data set is easy to group by humans. The images are very different in the term of contrast. The texture primitives are different in size. The FCOM texture features showed higher classification rates than those from GLCM in all distances. The number of clusters ($C = 4$) from FCOM was lower than the number of gray levels ($N_g = 32$) from GLCM. Example of incorrect recognition images generated by GLCM texture feature sets is shown in figure 4.90.

RT02_7   RT09

RT10_5   RT16

(a) Example of Incorrect classification images   (b) Example images of the predicted class

Figure 4.90 Example of incorrect classification images on UMD data set.

4.3 Summary

In this work, we tested the proposed FCOM texture features with the multiclass support vector machine (one-versus-all strategy) on the four gray scale texture data sets. The six feature sets were extracted from different gray quantization levels (4, 8, 16, and 32) and distance of pixel pair, 1 to 5, in this study. The experimental results were compared to the features extracted from regular GLCM. We found that the feature sets extracted from our FCOM yielded better recognition results than those from the regular GLCM.

The best result summary on the validation set using features computed from the proposed FCOM and GLCM on the Brodatz, Kylberg, UIUC, and UMD, are shown in table 4.26.

The two important parameters, the number of quantization levels and the distance of pixel pair, were studied. In fact, the feature from GLCM yielded the best classification results when the number of quantization levels was equal to the number of gray levels in the original image. In this case, more computational time was used to extract the features. For the pixel pair distance, it depended on the gray level distribution of the original images as shown in table 4.26. In higher contrast data sets, the lower pixel pair distance was selected. On the other hand, the number of cluster used in FCM was the lowest in this study, i.e., four in this case. It was close to the minimum cluster number for fuzzy clustering, two in general. In all data sets, the distance of pixel pair giving the best classification results and used to extract FCOM texture features was close to one.

Table 4.26 The summary of the best gray scale validation set correct classification results.

Texture data set	GLCM			FCOM		
	Accuracy	Ng	d	Accuracy	C	d
Brodatz	100.00	32	1	100	4	2
Kylberg	99.55	8	4	100	4	1
UIUC	92.00	16	5	100	32	5
UMD	99.00	32	5	100	4	1

Furthermore, FCOM is invariance under brightness linear transformation. The prototypes and membership values are similar when the brightness change in linear scale. The classification result is also similar. Examples in this case are shown in figure 4.91 to figure 4.93. Figure 4.91 (a) – (c) in first column shows images with difference brightness. In second column, quantized images from GLCM are also similar to the first column while quantized images from FCOM in the third column are similar to the original image. Figure 4.92 shows corresponding GLCM planes from images in figure

85

4.91. Three GLCMs in this case are very difference while the corresponding FCOMs as shown in figure 4.93 are similar.
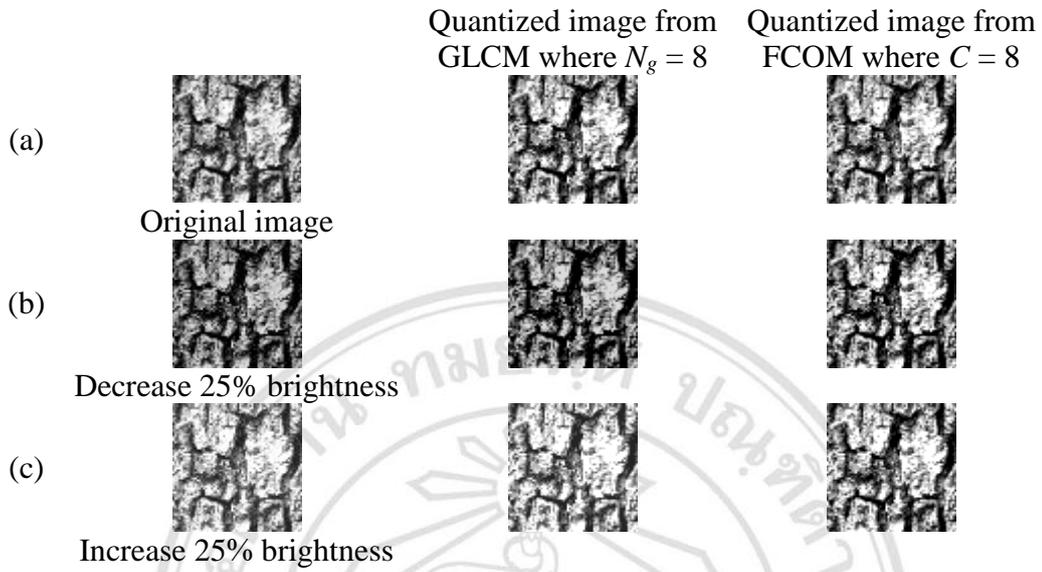
Quantized image from GLCM where $N_g = 8$ Quantized image from FCOM where $C = 8$

(a)

Original image

(b)

Decrease 25% brightness

(c)

Increase 25% brightness

Figure 4.91 Example of difference brightness images and corresponding quantized images from GLCM and FCOM.

(a) Original image   (b) Decrease 25% brightness   (c) Increase 25% brightness
   GLCM plane   GLCM plane   GLCM plane
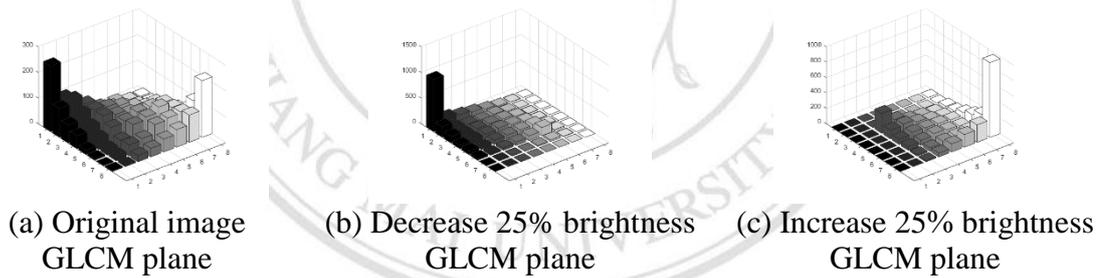
Figure 4.92 Corresponding GLCM where $N_g = 8$ for images in figure 4.91.

(a) Original image FCOM planes

(b) Decrease 25% brightness FCOM planes
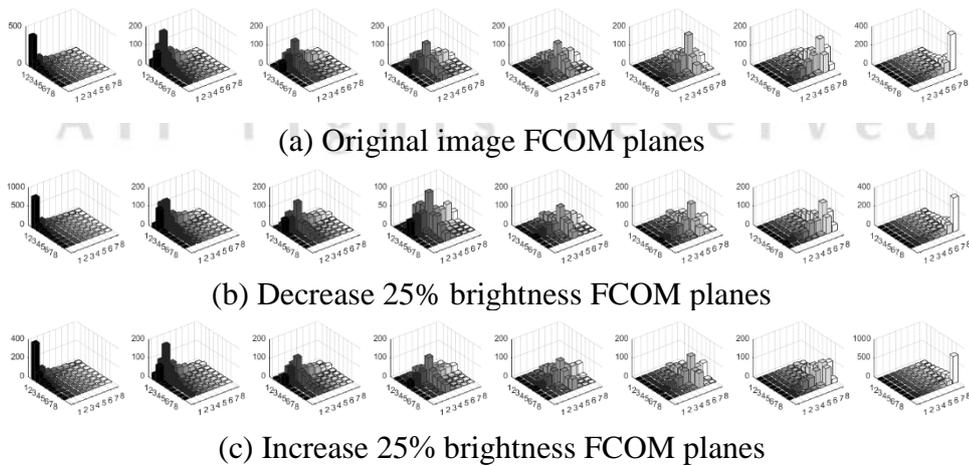
(c) Increase 25% brightness FCOM planes

Figure 4.93 Corresponding FCOM where $C = 8$ for images in figure 4.91.

86

In this studied, we conclude that the feature set extracted from four orientations with four texture properties, i.e., contrast, correlation, energy, and homogeneity is suitable to use for all gray scale texture data sets. It can explain most of texture types, e.g., regular texture and stochastic texture. However, distance of pixel pair will be selected related to human observation, i.e., fine, coarse, grained, and smooth. The fine texture or smooth texture needs a lower distance than the coarse texture or grained texture.