The Effect of Cement Type on Behavior of Reinforced Concrete against Attack Sulfate Salt

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Abstract - *This research work studies The Effect of Cement Type on Behavior of Reinforced Concrete against Attack Sulfate Salt. Two concrete mixes with the same materials content and different cement types were used. Frist mix was used ordinary Portland cement (Type I) and the second mix was used sulfate resistant Portland cement (Type V). For every mix cubes (100*100*100 mm) and cylinders (100*200 mm) were molded. Samples were exposed to magnesium sulfate solutions ($MgSo_4$) with sulfate concentration of 0%, 5%, 7%, and 10% until time periods 28, 60 and 90 days. The concrete strength (compressive and splitting tensile), and rate of steel corrosion were measured. The sulfate resistance Portland cement (Type V) was improved the resistant of concrete against the sulfate salt about 14.2% for compressive strength, 0.8% for splitting tensile strength, and 2.5% for the rate of steel corrosion than ordinary Portland cement (Type I).*

***Key Words*:** sulphate; magnesium; steel corrosion; strength; *resistance*.

1. INTRODUCTION

The major problems affecting concrete durability is the external attack of sulfate salts. Sulfates are highly soluble salts in the form of sodium sulfate (Na_2So_4), calcium sulfate ($CaSo_4$), potassium sulfate (K_2So_4), and magnesium sulfate ($MgSo_4$) which are sometimes found in soil or dissolved in ground water or present in aggregates [1]. The deterioration of reinforced concrete structures due to sulfate attack is the result of sulfate ions in the soil, ground water, and sea water. In hardened cement, C3A reacts with sulfate ions in the presence of calcium hydroxide to form gypsum, leading to degradation of concrete into a non-cohesive granular mass and disruptive expansion [2–5].

Lei and Ditao [6] studied the effect of different types of sulfate solutions on the deterioration of concrete under drying-wetting cycles. Davood, Farzaneh, and Hamed [7] studied the effect of magnesium sulfate concentration on durability of concrete containing micro-silica, slag and limestone powder using durability index. Ittiporn and others [8] studied the durability and testing of mortar with fly ash and limestone cement in sulfate solutions. Kamile [9] studied the effect of C_3A content on sulfate durability of Portland limestone cement mortars. Thidar and Chiaki [10] studied the resistance of plain and blended cement mortars exposed to severe sulfate attacks.

2. MATERUALS AND METHODS

2.1. Materials

Properties of materials used are shown in table 1,2**.**

Table -1: Properties of Coarse Aggregate (Basalt) and Sand

Type of test	value
Maximum Aggregate size	16
Fineness Modulus of Sand	2.21
Specific Gravity of Coarse Aggregate	2.7
Specific Gravity of Fine Aggregate	2.5
Unit Weight of Coarse Aggregate (t\m^3)	1.63
Unit Weight of Coarse Aggregate (t\m^3)	1.7

Table -2: Properties of Cement

Type of test		Type I	Type V
Surface Area of Particles (cm^2/gm)		2850	2750
Volume change (mm)		3	2
Setting Time	Initial (min)	75	83
	Final (hour)	3.8	4.2
Compressive Strength (Kg\cm^2)	3days	190	185
	7 days	285	277
	28 days	379	370

2.2. Concrete Mix Proportions, Samples, and Experimental Program

Two mixes of concrete were produced to cast a series of test specimens divided from mix M1 to mix M8. M1, M2, M3, and M4 were contained ordinary Portland cement (Type I) and exposed to magnesium sulfate solutions ($MgSo_4$) with sulfate concentration of 0%, 5.0%, 7.0%, and 10.0% until time periods 28, 60 and 90 days respectively. M5, M6, M7, and M8 were contained sulfate resistant Portland cement (Type V) and exposed to magnesium sulfate solutions ($MgSo_4$) with sulfate concentration of 0%, 5%, 7%, and 10% until time periods 28, 60 and 90 days respectively as shown in Table 3. For each mix 12 cubes (100*100*100 mm), 12 cylinders (100*200 mm), and 12 cylinders (100*200 mm) inside it Ø16 steel reinforcement as shown in in figure 1 were molded. The Concrete was cast in steel cubes and cylinders, a vibration table was used to compact them. They were demolded after approximately 24 h, were initially cured in water for 7 days, and were transferred to tanks containing magnesium sulfate solutions ($MgSo_4$) with sulfate concentration of 0%, 5%, 7%, and 10% until their testing ages 28, 60 and 90 days.

Table -3: Concrete Mixes

Cement Type	Mix	Water	Cement	Fine Agg.	Coarse Agg.	Curing Condition
		(kg/m³)				
Ordinary Portland Cement (Type I)	M1	175	350	747	1121	Water+0% $MgSo_4$
	M2	175	350	747	1121	Water+5% $MgSo_4$
	M3	175	350	747	1121	Water+7% $MgSo_4$
	M4	175	350	747	1121	Water+10% $MgSo_4$
Sulfate Resistant Portland Cement (Type V)	M5	175	350	747	1121	Water+0% $MgSo_4$
	M6	175	350	747	1121	Water+5% $MgSo_4$
	M7	175	350	747	1121	Water+7% $MgSo_4$
	M8	175	350	747	1121	Water+10% $MgSo_4$

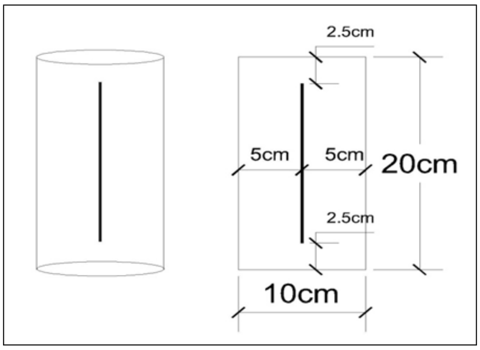

Fig. (1): The Corrosion Specimen

2.3. Experimental Tests

Compression tests were carried out on 100 mm cubic and splitting tensile test carried out on 100*200 mm cylinder using a 2000 KN compression machine. The loading rates for the machine applied in the compression and splitting tensile tests were 0.6 and 0.03 N/mm²/sec respectively. Compressive strength and splitting tensile strength were measured at the ages of 28, 60, and 90 days.

The high impedance voltmeter was used to measure the corrosion potentials and noting the potentials against a saturated calomel electrode (SCE). Half-cell potentials more positive than-270 mV represents a passive state of corrosion while potentials more negative than -270 mV represent an active state of corrosion (figure 2). The qualitative indication of the corrosion of reinforcing bars was measured by using this technique. The rate of steel corrosion was measured at the ages of 28, 60, and 90 days.

Fig. (2): The Half-Cell Potential Test

3. RESULTS AND DISCUSSION

Results of compressive strength, splitting tensile strength, and rate of corrosion for all mixes of concrete was shown in the table 3 to 5.

3.1 Compressive Strength

The compressive strength of specimens was determined after exposure time periods of 28, 60 and 90 days of magnesium sulfate salt solution 5, 7, and 10% $MgSo_4$. The values of average compressive strength for each mix was shown in Table 3, Figure 3, and Figure 4. The relation between the period of sulfate exposure and percentage of average decrease in compressive strength for cement Type I and Type V were shown in Figure 5. It was observed that the compressive strength of concrete decreased with the increasing of percentage MgSo4. After 90 days of exposure to 5, 7, and 10% magnesium sulfate solution MgSo4 the percentage of decreasing in compressive strength of specimens with Type I cement was 20.5, 31.4, and 34.1% and the percentage of decreasing in compressive strength of specimens with Type V cement was 5.1, 9.7, and 13%. The sulfate resistance Portland cement (Type V) was improved the compressive strength of concrete against the sulfate salt solution 5, 7, and 10% $MgSo_4$ by averaging about 2.0, 6.6, and 14.2%.

Table -3: Compressive Strength for Average 3 Cubes at 28, 60, 90 Days

Cement Type	Mix	Compressive Strength (Kg/cm²) 28 days	60 days	90 days	Curing Condition
Ordinary Portland Cement (Type I)	M1	369	386	440	Water+0% $MgSo_4$
	M2	347	358	350	Water+5% $MgSo_4$
	M3	334	320	302	Water+7% $MgSo_4$
	M4	320	305	290	Water+10% $MgSo_4$
Sulfate Resistant Portland Cement (Type V)	M5	360	381	432	Water+0% $MgSo_4$
	M6	350	370	410	Water+5% $MgSo_4$
	M7	338	354	390	Water+7% $MgSo_4$
	M8	322	338	376	Water+10% $MgSo_4$

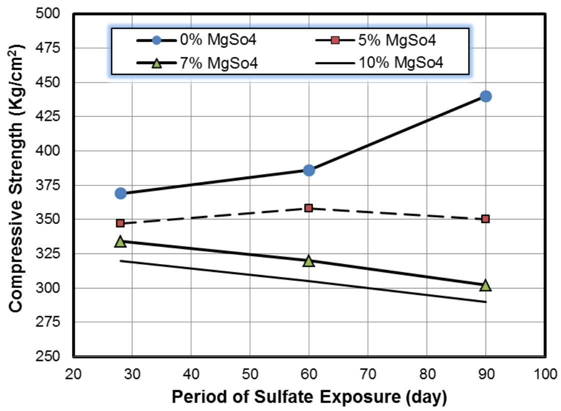

Fig.(3): Relation between Period of Sulfate Exposure and Compressive Strength for Cement Type I

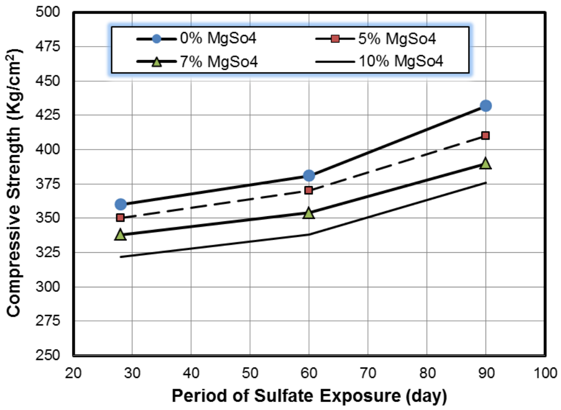

Fig.(4): Relation between Period of Sulfate Exposure and Compressive Strength for Cement Type V

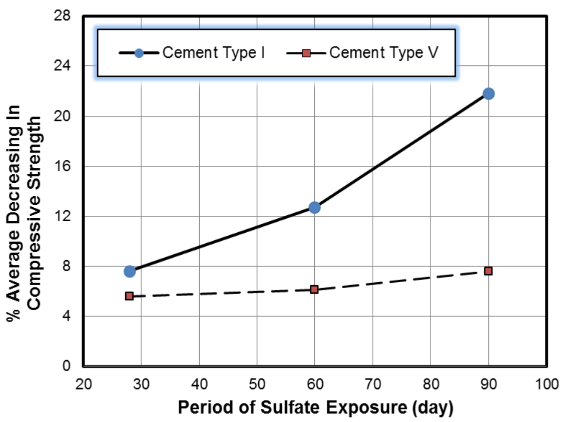

Fig.(5): Relation between Period of Sulfate Exposure and Percentage of Average Decreasing in Compressive Strength for Cement Type I and TypeV

3.2 Splitting Tensile Strength

The splitting tensile strength of specimens was determined after exposure time periods of 28, 60 and 90 days of magnesium sulfate salt solution 5, 7, and 10% $MgSo_4$. The average splitting tensile strength values for each mix was shown in Table 4, Figure 6, and Figure 7. The relation between the period of sulfate exposure and percentage of average decrease in splitting tensile strength for cement Type I and Type V were shown in Figure 8. It was observed that the splitting tensile strength of concrete decreased with the increasing of percentage $MgSo_4$. After 90 days of exposure to 5, 7, and 10% magnesium sulfate solution MgSo4 the percentage of decreasing in splitting tensile strength of specimens with Type I cement was 27.1, 28.1, and 32.3% and the percentage of decreasing in splitting tensile strength of specimens with Type V cement was 25.1, 27.3, and 30.6%, The sulfate resistance Portland cement (Type V) was improved the splitting tensile strength of concrete against the sulfate salt solution 5, 7, and 10% $MgSo_4$ by averaging about 0.3, 3.7, and 0.8%.

Table -4: Splitting Tensile Strength for Average 3 Cylinders at 28, 60, 90 Days

Cement Type	Mix	Splitting Tensile Strength (Kg/cm²)			Curing Condition
		28 days	60 days	90 days	
Ordinary Portland Cement (Type I)	M1	26.8	29.0	30.6	Water+0% $MgSo_4$
	M2	26.1	24.3	22.3	Water+5% $MgSo_4$
	M3	25.2	23.9	22.0	Water+7% $MgSo_4$
	M4	23.8	22.3	20.7	Water+10% $MgSo_4$
Sulfate Resistant Portland Cement (Type V)	M5	27.1	30.3	36.6	Water+0% $MgSo_4$
	M6	26.5	28.6	27.4	Water+5% $MgSo_4$
	M7	25.6	26.7	26.6	Water+7% $MgSo_4$
	M8	24.3	24.9	25.4	Water+10% $MgSo_4$

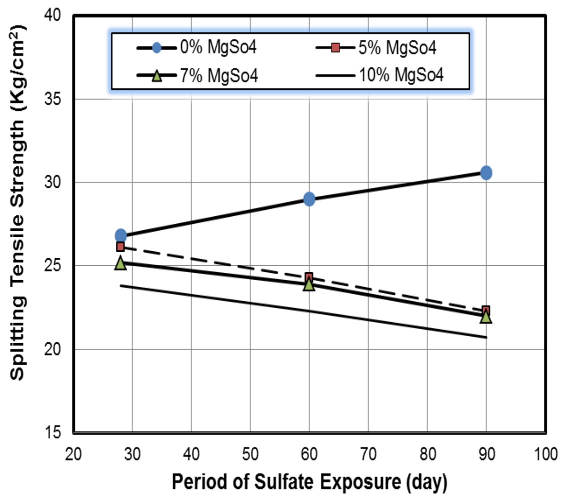

Fig.(6): Relation between Period of Sulfate Exposure and Splitting Tensile Strength for Cement Type I

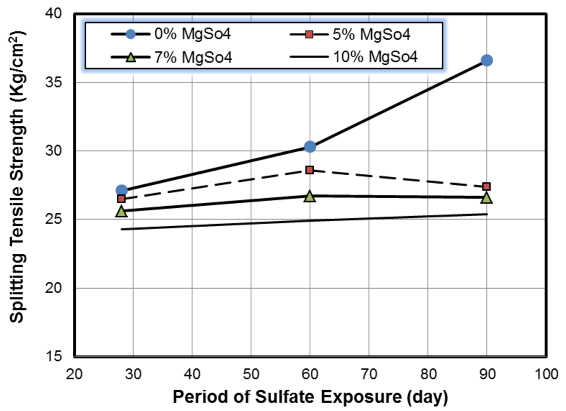

Fig.(7): Relation between Period of Sulfate Exposure and Splitting Tensile Strength for Cement Type V

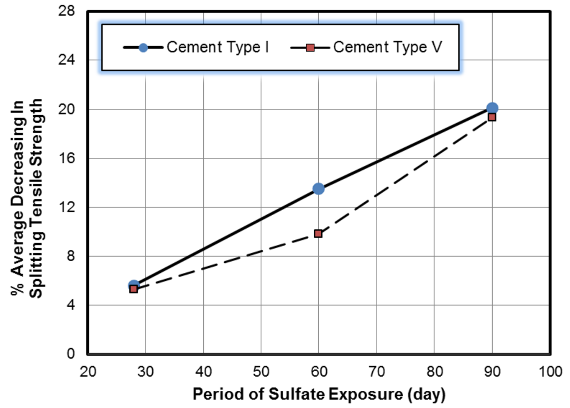

Fig.(8): Relation between Period of Sulfate Exposure and Percentage of Average Decreasing in Splitting Tensile Strength for Cement Type I and Type V

3.3 Rate of Steel Corrosion

The rate of steel corrosion for specimens was determined after exposure time periods of 28, 60 and 90 days of magnesium sulfate salt solution 5, 7, and 10% $MgSo_4$. The average rate of steel corrosion values for each mix was shown in Table 5, Figure 9, and Figure 10. The relation between the period of sulfate exposure and percentage of average increase in the rate of steel corrosion for cement Type I and Type V were shown in Figure 11. It was observed that the rate of steel corrosion increased with the increasing of percentage $MgSo_4$. After 90 days of exposure to 5, 7, and 10% magnesium sulfate solution $MgSo_4$ the percentage of increase in rate of steel corrosion of specimens with Type I cement was 30.2, 46.4, and 67.6% and the percentage of increase in rate of steel corrosion of specimens with Type V cement was 29.0, 43.5, and 63.0%,

The sulfate resistance Portland cement (Type V) was improved the rate of steel corrosion against the sulfate salt solution 5, 7, and 10% $MgSo_4$ by averaging about 0.3, 1.3, and 2.5%.

Table -5: Rate of Steel Corrosion for Average 3 bars at 28, 60, 90 Days

Cement Type	Mix	Rate of Steel Corrosion (um/year)			Curing Condition
		28 days	60 days	90 days	
Ordinary Portland Cement (Type I)	M1	138.0	153.0	173.0	Water+0% $MgSo_4$
	M2	149.3	185.2	225.3	Water+5% $MgSo_4$
	M3	157.5	199.2	253.2	Water+7% $MgSo_4$
	M4	190.7	220.3	290.0	Water+10% $MgSo_4$
Sulfate Resistant Portland Cement (Type V)	M5	82.9	128.3	138.0	Water+0% $MgSo_4$
	M6	89.6	151.3	178.0	Water+5% $MgSo_4$
	M7	94.2	163.5	198.0	Water+7% $MgSo_4$
	M8	114.2	183.0	225.0	Water+10% $MgSo_4$

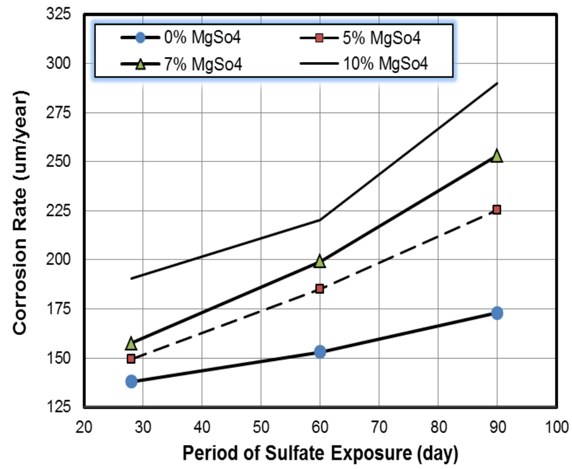

Fig.(9): Relation between Period of Sulfate Exposure and Corrosion Rate for Cement Type I

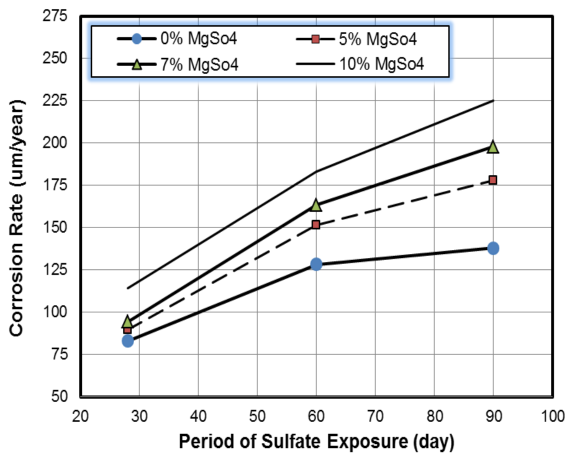

Fig.(10): Relation between Period of Sulfate Exposure and Corrosion Rate for Cement TypeV

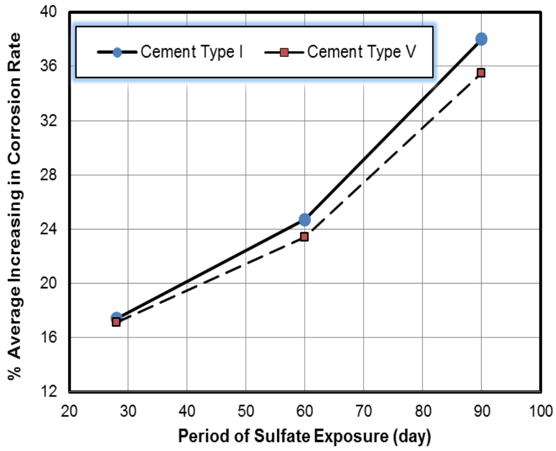

Fig.(11): Relation between Period of Sulfate Exposure and Percentage of Average Increasing in Corrosion Rate for Cement Type I and Type V

3.4 Surface Disintegration

Concrete specimen exposed to magnesium sulfate solution ($MgSo_4$) exhibits slight attack with only a surface layer of mortar scaled. While the specimen in water suffers the loss of surface material from the corner and edges, the surface becomes uneven. It is observed that the surface deterioration is different in the three concentrations of solutions. Visual in section revealed that the specimen exposed to 10% magnesium sulfate solution is more severely damaged than that exposed to other solutions. Type V cement specimens have a smaller disintegration and breakup than Type I cement specimens. The shape of cubes specimens after exposed to time period 90 days of sulfate solution were shown in the Table 6.

Table -6: Shape of Cubes Specimens after Exposed to time Period 90 days of Sulfate Solution

Cement Type (I)	Cement Type (V)
 0% $MgSo_4$	 0% $MgSo_4$
 5% $MgSo_4$	 5% $MgSo_4$
 7% $MgSo_4$	 7% $MgSo_4$
 10% $MgSo_4$	 10% $MgSo_4$

4. CONCLUSION

Based on the experimental results presented in this paper, the main conclusions are as the follows:

1- Sulfate attack process decreases the mechanical properties of the concrete due to change the chemical and physical properties of the cement.

2- A decrease in strength, with a period of exposure, was noted in all types of specimens in $MgSo_4$ solutions.

3- A higher reduction in strength was noted in specimens immersed in 10% $MgSo_4$ solution, followed by 7% and 5% $MgSo_4$ solution after 90 days of exposure.

4- The sulfate resistance Portland cement (Type V) was improved the compressive strength of concrete against the sulfate salt solution 5, 7, and 10% $MgSo_4$ by averaging about 2.0, 6.6, and 14.2%.

5- The sulfate resistance Portland cement (Type V) was improved the splitting tensile strength of concrete against the sulfate salt solution 5, 7, and 10% $MgSo_4$ by averaging about 0.3, 3.7, and 0.8%.

6- The sulfate resistance Portland cement (Type V) was improved the rate of steel corrosion against the sulfate salt solution 5, 7, and 10% MgSo4 by averaging about 0.3, 1.3, and 2.5%.

5. REFERENCES

[1] Lei Jiang and Ditao Niu, "Study of deterioration of concrete exposed to different types of sulfate solutions under drying-wetting cycles," Construction and Building Materials, 117 (2016) 88–98.

[2] Rasheeduzzafar, Al-Amoudi OSB, Abduljawad SN, Maslehuddin M., "Magnesium–Sodium Sulfate Attack in Plain and Blended Cements," J Mater Civil Eng 1994;6(2):201–22.

[3] Al-Amoudi OSB, Maslehuddin M, Saadi MM., "Effect of Magnesium Sulfate Sodium on the Durability Performance of Plain and Blended Cements," ACI Mater J 1955;92(1):15–24.

[4] Al-Amoudi OSB. , "Performance of 15 Reinforced Concrete Mixtures in Magnesium and Sodium Sulfate Environments," Construct Build Mater J 1995;9(3): 149–58.

[5] Al-Amoudi OSB., "Sulfate Attack and Reinforcement Corrosion in Plain and Blended Cements Exposed to Sulfate Environments," Build Environ 1998;33(1): 53–61.

[6] Lei Jiang and DitaoNiu,"Study of deterioration of concrete exposed to different types of sulfate solutions under drying-wetting cycles,"Construction and Building Materials 117 (2016) 88–98.

[7] Davood M., Farzaneh N. and Hamed N.,"Influence of magnesium sulphate concentration on durability of concrete containing micro-silica, slag and limestone powder using durability index," Construction and Building Materials 117 (2016) 107–120.

[8] Ittiporn S., Warangkana S., Lalita B., Pitisan K., and Somnuk T.," Durability and testing of mortar with inter ground fly ash and lime stone cements in sulfate solutions," Construction and Building Research, Vol. 64,PP. 39-46, 2014.

[9] Kamile T. F.," The effect of C_3A content on sulfate durability of Portland limestone cement mortars ," Construction and Building Materials 36 (2012) 437–447.

[10] Thidar A., and Chiaki T., "Resistance of plain and blended cement mortars exposed to severe sulfate attacks," Construction and Building Materials ,25 (2011), 2988–2996.